Oxbow System Assessment and Protocol Development-Phase III
FINAL REPORT

FY 12 104(b)(3)

Wetland Program Development Project

CA # CD-00F42801 Project 2

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Cover Page Photo: Secchi Disk depth measurement by Jody Cason in Oxbow 654 June 6, 2011.

Executive Summary

This project is the last in a three-phase collaboration by the Oklahoma Water Resource Board (OWRB), Oklahoma Conservation Commission (OCC), and Oklahoma State University (OSU) to assess, develop and implement a comprehensive wetland monitoring program. The previously funded Phase I (CA#CD-966785-01) and Phase II (CA#CD-00F074-01) projects that preceded were completed in 2010 and 2012, respectively. This last (Phase III) project examined a wide variety of environmental measures and assessment methods to assist with the development of methodologies most applicable toward evaluating condition of oxbows and other wetland systems.

Data collected during the Phase II project were evaluated using the Oklahoma Water Quality Standards Use Support Assessment Protocols (USAP). Comparison of the use support conclusions against Level 1 (desktop assessment) and Level 2 (rapid field assessment) assessment measures demonstrated the need for alternate means of assessing beneficial use attainment and questions the utility of the current beneficial uses assigned to wetland systems. These analyses demonstrated that oxbows with low degrees of local and landscape disturbances, while apparently functioning normally, consistently failed to meet the criteria established for fish and wildlife use and threats from nutrient enrichment. In other words, the application of the current surface water standards conclude that every sampled oxbow wetland as impaired. An impairment determination would require state resources to complete total maximum daily load (TMDL) allocations. In an ongoing effort to develop water quality standards for wetlands, the state of Oklahoma, through the Oklahoma Wetlands Technical Workgroup (OWTW), has developed beneficial uses for wetland waterbodies that recognize and incorporate the natural functions of wetlands. Wetland Habitat and Biota, Flood Protection and Erosion Control, and Water Quality Enhancement have been proposed as "new" beneficial uses for wetland waterbodies.

The Level 1 assessment method developed and used in the Phase I project has been revised during this project. The updated method yields scoring more indicative of the potential for environmental impact from surrounding land-use than the original method. Statistical analysis indicated the revised land-use coefficients and variables measuring road density, population density, and the presence/absence of 303(d) impairment (within 2 km upstream to the oxbow) improved relationships with field based measures of oxbow condition (i.e. water chemistry and plant community). Statistical analysis did not note a strong predictive difference between uses of a 1 km circular or the delineated immediate watershed buffer. However, anecdotal evidence from two adjacent oxbows highlights a cogent rationale for using delineated watersheds as opposed to generic buffers. These two oxbows included a large active oilfield site within the circular buffer, but this activity was excluded from the watershed of one of the oxbows. The watershed approach may help to explain the large difference in chloride concentration between the two oxbows, which would be unaccounted for with a circular buffer. Small sample size reduced the power of statistical analysis. Because there was a relative small distribution of land-use differences between sites the ability to distinguish between sites was further reduced. Future examination of the revised Level 1 assessment method should include a broader distribution of sites that include the developed (specifically open space) land-use feature as well as a comparison between the delineated watershed and the circular buffer surrounding the watershed. It is important to establish a cost-

benefit between the two buffer methods as a delineated buffer requires more individual decision-making and resources than application of a standardized buffer.

As part of this project, Oklahoma Rapid Assessment Method (OKRAM), a draft Level 2 assessment, was created. OKRAM has been successfully deployed across 40 interdunal depressional wetlands of the Pleistocene Sand Dunes ecoregion adjacent to the Cimarron River. NWI maps for this region were also updated to provide a more up-to-date and accurate resource for future monitoring in this wetland rich area. OKRAM appears to provide a measure of wetland condition that is verifiable with plant community and soil data. OKRAM's first field evaluation appears to meet all the requirements of a Level 2 rapid assessment: (1) it aggregates nine metrics into a single condition score that reflects the physical, chemical and biological attributes present, (2) requires metrics to be collected or verified on-site, (3) is rapid, requiring less than one day to complete, and (4) can be verified with additional plant community and soil chemistry data. Plant community metrics in this study correlated well with OKRAM scores. Improvements in metrics can further be achieved through adding additional stress indicators and evaluating if indicators are organized into the appropriate stress severity category. Furthermore, metrics that are currently measured solely on the areal extent of stress indicators present (i.e., Water Source and Vegetation Condition) may be improved through the application of stress severity scores as in other metrics in OKRAM (i.e., Hydroperiod and Sediment). Overall metric aggregation may further be refined to place emphasis on the metrics most important in defining wetland condition. Moving forward, it may also be necessary to score individual metrics using discrete categories (e.g., A, B, C, D) rather than continuous scaling (e.g., 0-100). Scoring options will continue to be evaluated to determine how to most accurately and consistently assess condition of Oklahoma wetlands.

Development of guidance material is considered a priority moving forward as the OKRAM methodology is refined. Guidance will include background material on why metrics are included with justification from the primary literature and clear instructions on how to score each metric. More detailed descriptions of each stress indicator along with pictures will aid in the accurate identification of stressors. Currently, project staff are evaluating the repeatability of OKRAM on riverine and lacustrine wetlands across Oklahoma. At each site, multiple users are applying OKRAM independently to determine if indicators can be identified and metrics scored consistently. Following these field evaluations and calibrations of OKRAM, further refinement and modification may be necessary to provide an effective and consistent rapid assessment method applicable to the wide variety of wetlands found in Oklahoma.

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Project Background

Wetlands are distinguishable from other ecosystems by three main characteristics: hydrology, physiochemical environment, and biota (Mitsch and Gosselink, 2007). The unique wet-dry cycles of wetlands drive a variety of hydrologic, biogeochemical and habitat processes and functions. These hydrologic cycles also create challenges to ecosystem monitoring using the existing framework for other surface waters in Oklahoma. As such, an evaluation of the use of water quality monitoring and assessment programs traditionally used for more permanent water bodies (e.g., lakes, rivers, and streams) may not be appropriate for wetlands. However, the development of assessment/monitoring schemes to evaluate water quality of all of Oklahoma's surface water resources is critical to the State. Currently, the Beneficial Uses Monitoring Program (BUMP) conducted by the Oklahoma Water Resources Board, monitors over 130 reservoirs in the state. This monitoring program is based on Use Support Assessment Protocols (USAP) that are designed to determine attainment of beneficial uses designated for Fish and Wildlife Propagation, Agriculture, Industrial and Municipal Process and Cooling Water, Primary Body Contact Recreation, Secondary Body Contact Recreation, and Aesthetics. According to OAC 785:45, separate protocols exist in Oklahoma to assess attainment of assigned beneficial uses based on the type of waterbody. There is one set for streams, another for lakes, and at this time none specifically for wetlands. The consequence of an impairment based on the existing USAP is: listing a wetland as a 303d (impaired waterbody) listing and scheduling for a total maximum daily load (TMDL) allocation to restore the impairment.

One goal of this project was to assess the applicability of current lakes and stream protocols on wetlands. Oxbow wetlands seemed the logical choice for the first application of USAP on wetlands because they often exhibit characteristics of streams and lakes as well as wetlands because of their formation and position on the landscape. Oxbows form when a U-shaped meander is cut off from the main portion of river by erosion and deposition processes (**Figure 1 and Figure 2**). Oxbows may be river-like when they still receive stream flow throughout the year, may be lake-like when they are large and separated from river processes, or may be more wetland-like when they are smaller or older and have been subjected to natural sedimentation processes. Since oxbows have characteristics that are also consistent with wetland habitats, the application of USAP decision criteria relevant for lakes may indicate poor water quality when in fact the water quality characteristics of the system may actually represent a "normal" condition profile for oxbow wetlands.

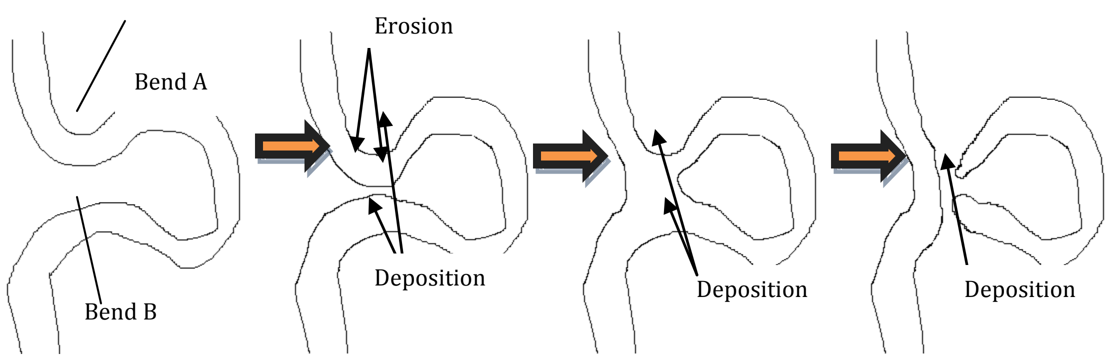


Figure 1. Oxbow Formation Showing Erosion and Deposition Processes in a River Meander Over Time.

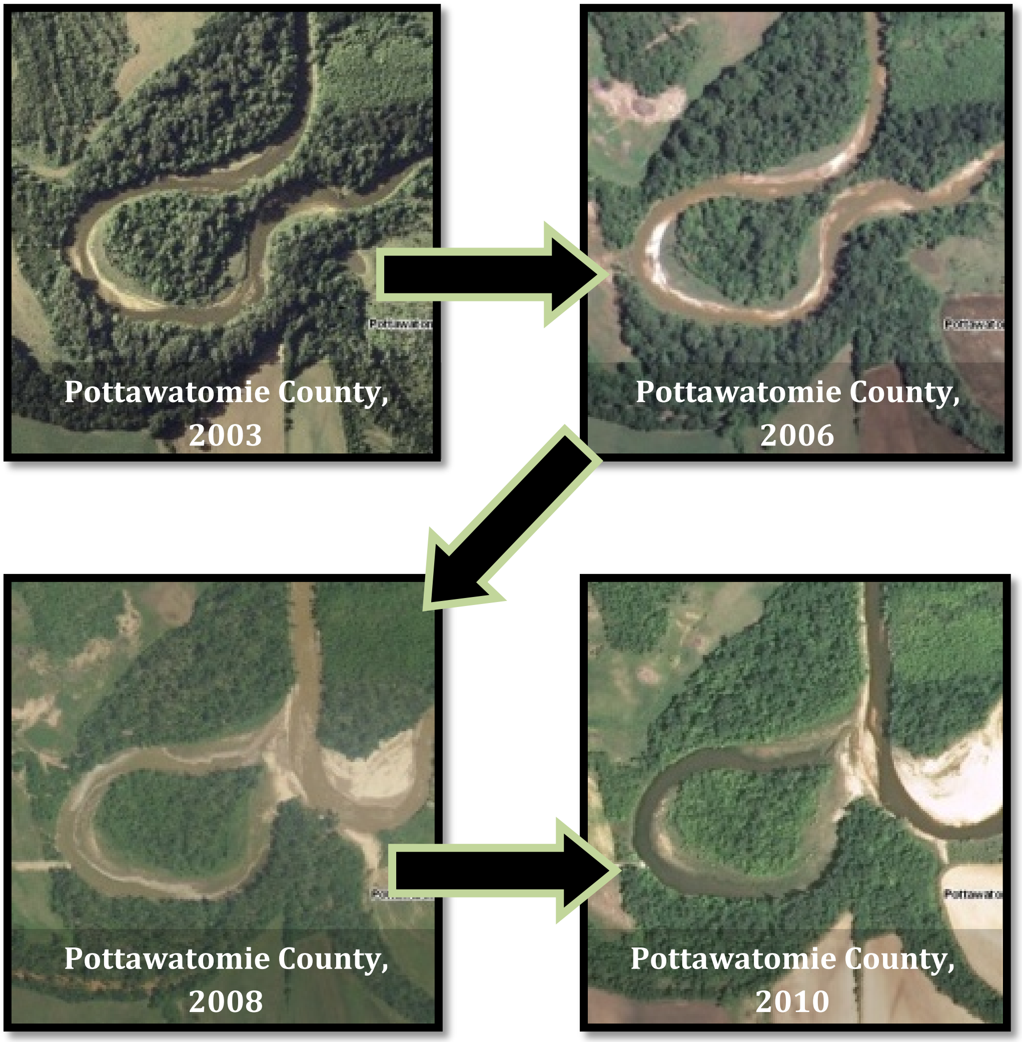


Figure 2. Oxbow Formation in Pottawatomie County from 2003 to 2010 at Site 1167.

The Oklahoma Water Resource Board (OWRB), Oklahoma Conservation Commission (OCC), and Oklahoma State University (OSU) collaborated to assess oxbow systems through a three-phase project. <u>Phase I</u> used a Level 1 assessment to identify the oxbow systems within the state, create a GIS map of oxbow wetland locations, identify key oxbow systems to be assessed, conduct an initial site visit to verify those sites, collaborate with OWTW, and deliver a categorized list and GIS-based map of oxbow systems in Oklahoma (OWRB 2010a).

<u>Phase II</u> conducted the environmental data collection (OWRB 2012). Using the oxbow wetland list generated by Phase I, GIS analysis, and ground-truthing, 25 oxbows were selected for assessment. Oxbows were selected to encompass a range of conditions within the Cross Timbers ecoregion (**Figure 3**). Data collection spanned over a two year period and was designed to allow for the application of a variety of assessment methods and metrics and followed the design and protocols in the approved QAPP (OWRB 2010a).

Phase III consisted of five tasks of which the first three (QAPP, Preliminary RAM Development, Calibration of Level 1 assessment) have previously been submitted, reviewed and approved by EPA. Deliverables yet due are Task 4, Application of the OKRAM to Additional Wetland Systems, and Task 5, the Final Report. This report is designed to serve as a summation of all three phases of the Oxbow Wetland projects and fulfill Phase III project output requirements for Tasks 4 and 5. While fulfilling workplan requirements, this report addresses the following two questions posed throughout the 3-phased effort:

- What are the key functions of oxbow systems and what is their relationship to designated beneficial uses under the USAP approach?
- What assessment protocols (USAP, HGM, CRAM, and IBI) are most appropriate for assessing conditions of oxbow and other wetland systems?

Throughout this report these questions are addressed in the context of Oklahoma's developing wetland assessment methodology. The first chapter presents the current State of Oklahoma assessment methodologies and how the data develops a perspective of the applicability for these methodologies to wetland systems. The following two chapters present refinements of Level 1 and 2 assessment methodologies. The Level 1 method is designed for oxbows while the Level 2 assessment was developed using oxbows but further tested in additional wetland types. The final chapter presents the portion of the wetland rich interdunal Cimarron Pleistocene Sand Dune (CPSD) ecoregion in Oklahoma NWI that was updated as a part of workplan completion.

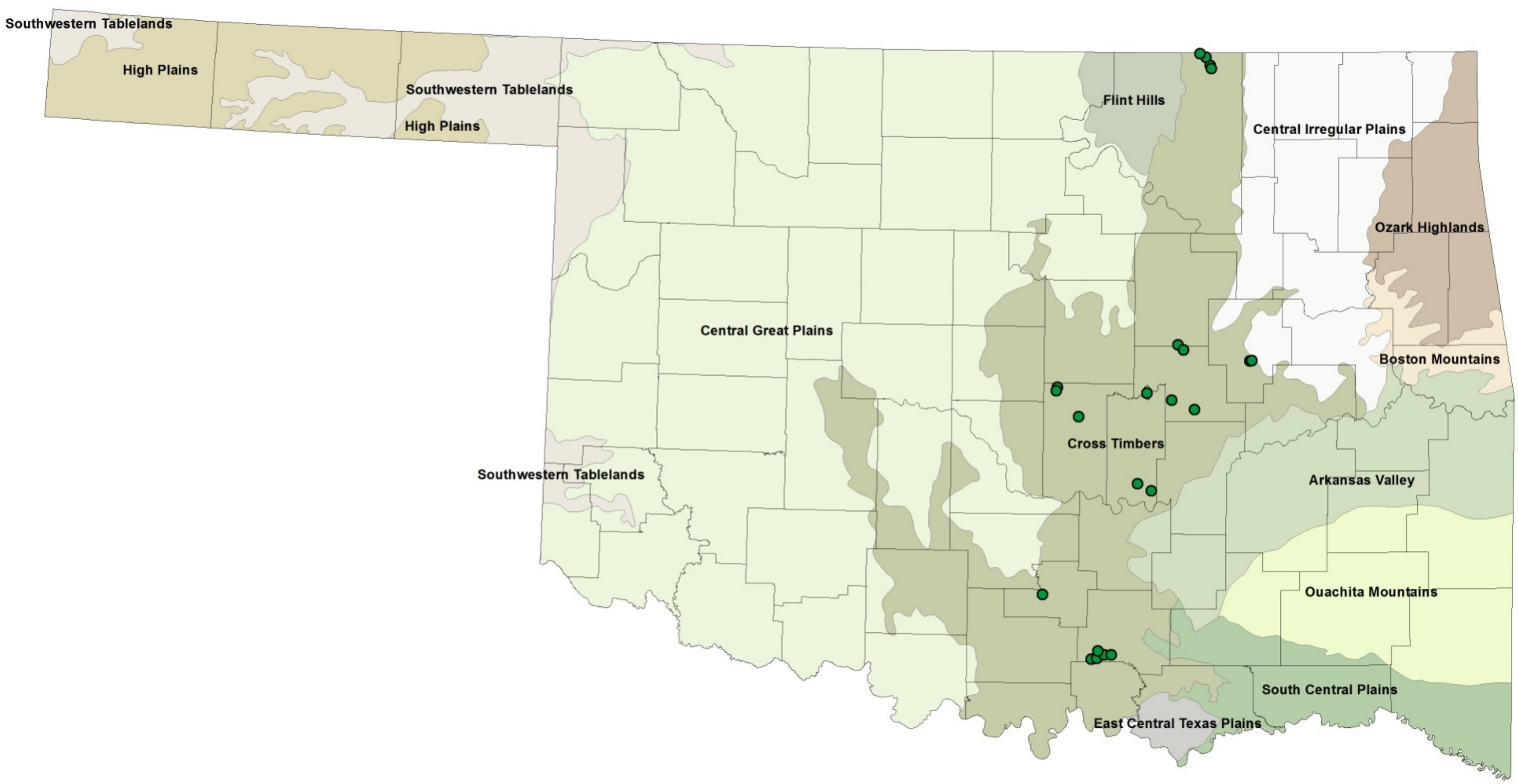


Figure 3. Distribution of Sampled Oxbows within the Cross Timbers Ecoregion.

Application of Oklahoma Water Quality Standards to Oxbows

Introduction

Designated Beneficial Uses

All Oklahoma surface waters have designated beneficial uses assigned in Appendix A of the Oklahoma Water Quality Standards (OWQS). Beneficial use specifies appropriate water uses to be achieved and protected. For surface waters not listed in Appendix A, the following beneficial uses are designated by default: Irrigation Agriculture (AG), Nutrients, Warm Water Aquatic Community (WWAC) and Primary Body Contact Recreation (PBCR). All wetlands carry the default beneficial uses, accompanying water quality standards and impairment determination methods as detailed in the OWRB rules and regulations of Oklahoma's Water Quality Standards (Chapter 45) and Implementation of Oklahoma's Water Quality Standards (Chapter 46). To determine whether a waterbody is attaining its designated beneficial use it is assessed according to the criteria given in the OWQS. The criteria, given in Chapter 45, specify what water quality parameters affect the use while the method prescribed to assess whether a specific beneficial use is being supported is given in Chapter 46. Data collected during the Phase II Oxbow project were processed through these implementation rules.

Water Quality Criteria

General narrative criteria are applied to the following parameters: minerals, solids and nutrients. Fish and Wildlife Propagation are addressed with the criteria of dissolved oxygen (DO), temperature, pH, oil and grease, biological (bacteria), toxic substances, turbidity, and sediments. Select parameters from these categories are used as the benchmark or indicators as to whether the designated use is achieved. In short, if the water quality parameter meets the criteria then standards are met. The process of using measured parameters to determine beneficial use achievement or impairment is defined in the Use Support Assessment Protocols (USAP). Consequences of an impairment conclusion include listing of the waterbody on the 303d (impaired waters) list and scheduling of that waterbody for a TMDL allocation. TMDLs determine the amount of a pollutant is acceptable to achieving a given beneficial use. In short, USAP assumes environmental harm with an impairment conclusion. The general criteria for protection of irrigation agriculture beneficial use examine chlorides, sulfates and total dissolved solids. Primary Body Contact Recreation (PBCR) beneficial use is evaluated with *Escherichia coli* (*E coli*) and *Enterococci*. Aesthetics beneficial use impairment is determined by examination of nutrients. Fish consumption beneficial use requires the examination of a host of chemicals measured in both the water column and fish tissue. Specifics of each USAP assessment methodology are presented in the methods section organized by beneficial use and parameter.

Methods

Water quality sample collection, turbidity measurement, multiparameter recordings and chlorophyll-a collection methods are posted on the OWRB's website listed under the lakes standard operating procedures (SOP) heading (OWRB 2014). All collections were executed as described within the QAPP (OWRB 2010b).

Reported environmental data collected were analyzed for default beneficial use impairments in accordance with the USAP (OAC 785:46-15) of the Oklahoma Water Quality Standards (OWQS). As oxbow systems have characteristics of both streams and lakes, both lake and stream assessment methods were applied. For the parameters of DO, turbidity and nutrients, a different set of assessment metrics were employed depending on whether it is a running water (stream) system or a still water (lake) system. Due to cost and logistic constraints, not every default beneficial use was examined by the project. For example, laboratory costs for fish consumption beneficial use would have severely limited the number of sites and uses evaluated so fish consumption was not examined. In general, the parameters routinely monitored by BUMP were collected and processed. Specific parameters collected and the accompanying beneficial uses assessed using USAP consisted of:

- AG – sulfates, chlorides and (estimated) total dissolved solids
- Nutrients – chlorophyll-*a* (lake) and total phosphorus and nitrate (stream)
- WWAC – DO, pH and turbidity
- PBCR – *E coli* and *Enterococci*

The Use Support Assessment Protocols (USAP) of the OWQS has temporal and spatial requirements for data used to determine beneficial use attainment. In general, each of the 12 oxbows sampled met the minimum 10 sample requirement for streams and lakes under 250 acres in size. Seven sample runs were planned and executed for each oxbow with 2 sample sites per oxbow. Aggregating the sites by oxbow usually resulted in meeting the minimum sample size for beneficial use assessment. As several oxbows were dry during some of the sample runs, they did not meet the minimum sample requirement. Eight of the 12 selected oxbows were sampled each time while oxbow 249 was dry during 4 of the sample runs, oxbow 669 was dry 2 of those runs and oxbows 413 and 658 were dry during 1 of the sample runs. This resulted in oxbows 249 and 669 not having the requisite number of samples. Oxbow 669 fell short because only site 669-A had enough water to sample on March 21, 2011, thus only 9 aggregate samples were available. In the same fashion, oxbow 1157 had no water to sample 4 of the 7 runs and there was no water at site 1157-A to sample. This resulted in exactly 10 aggregated samples, but a lab accident reduced the chlorophyll-*a* sample count to 9. In the case of having less than the requisite number of samples, these oxbows were evaluated using the USAP protocols to represent the likely beneficial use scenario but the conclusions do not carry the same weight as an assessment using 10 or more samples.

WWAC - DO, pH and Turbidity Criteria

There are multiple assessment methods for DO summarized in **Table 1**, excerpted from Appendix G of the OWQS. Streams assessment is fairly straight forward; if more than 10% of the samples are below the criterion, the stream is deemed impaired or if more than two concentrations of DO in a stream are below 2 mg/L in a given year, then the use is deemed impaired. In lakes, percent water column anoxia and surface DO levels are the measures used for beneficial use determination. If more than 10% of the samples from the epilimnion during periods of thermal stratification, or the entire water column when no stratification is present, are less than 5.0 mg/L from April 1 through June 15 or less than 4.0 mg/L from June 16 through October 15, or less than 5.0 mg/L from October 16 through March 31, the waterbody is considered impaired for DO. Fully supported is concluded if 10% or less of the samples from the epilimnion during periods of thermal stratification, or the entire water column when no stratification is present, are less than 6.0 mg/L from April 1 through June 15 and less than 5.0 mg/L during the remainder of the year. For the water column determination, a lake shall be deemed to be not supported with respect to the DO criterion if 50% or more of the water volume (if volumetric data is available) or more than 70% of the water column (if no volumetric data is available) at any given sample site is less than 2.0 mg/L. A lake shall be deemed to be fully supported during periods of thermal stratification with respect to the DO criterion if less than 50% of the volume (if volumetric data is available) or 50% or less of the water column (if no volumetric data is available) of all sample sites in the lake are less than 2.0 mg/L.

Table 1. Dissolved Oxygen Criteria to Protect Fish and Wildlife Propagation and All Subcategories Thereof. [1]

SUBCATEGORY OF FISH AND WILDLIFE PROPAGATION (FISHERY CLASS)	DATES APPLICABLE	D.O. CRITERIA (MINIMUM) (mg/L)	SEASONAL TEMPERATURE (^{o}C)
Habitat Limited Aquatic Community			
Early Life Stages	4/1 - 6/15	4.0	25[3]
Other Life Stages			
Summer Conditions	6/16 - 10/15	3.0	32
Winter Conditions	10/16 - 3/31	3.0	18
Warm Water Aquatic Community			
Early Life Stages	4/1 - 6/15	6.0[2]	25[3]
Other Life Stages			
Summer Conditions	6/16 - 10/15	5.0[2]	32
Winter Conditions	10/16 - 3/31	5.0	18
Cool Water Aquatic Community & Trout			
Early Life Stages	3/1 - 5/31	7.0[2]	22
Other Life Stages			
Summer Conditions	6/1 - 10/15	6.0[2]	29
Winter Conditions	10/16 - 2/28	6.0	18

[1] For use in calculation of the allowable load.

[2] Because of natural diurnal dissolved oxygen fluctuation, a 1.0 mg/l dissolved oxygen concentration deficit shall be allowed for not more than 8 hours during any 24 hour period.

[3] Discharge limits necessary to meet summer conditions will apply from June 1 of each year. However, where discharge limits based on Early Life Stage (spring) conditions are more restrictive, those limits may be extended to July 1.

When more than 10% of the pH samples fall outside of the range 6.5 to 9.0 Standard Units, then the waterbody is deemed impaired. If no more than 10% of the samples exceed the acceptable pH range then the waterbody is deemed fully supported. The turbidity screening value for streams is 50 Nephelometric Turbidity Unit (NTU) while the value for lakes is 25 NTU. Whether a lake or stream, when more than 10% of the samples exceed the screening value, the waterbody is deemed impaired and when no more than 10% of the samples exceed the screening value then the waterbody is deemed fully supported.

PBCR – *E. coli* Criteria

Primary Body Contact Recreation beneficial use determination is based on whether the average of samples taken during the recreation period exceeds the criterion value. The minimum sample size is five samples within a 30 day period. For *E. coli* the criteria is a geometric mean of 126 colonies per 100ml and/or should any one sample exceed 235 colonies/100ml for lakes then the waterbody is deemed impaired, while should any one sample exceed 406 colonies/100ml for streams then the system is deemed impaired. Not all oxbow sites met the minimum sample requirement. In addition, the sample period to aggregate samples extended from June 6, 2011 through September 28, greater than the 30 day period. Because some oxbow sites had less than the requisite samples, all sites were termed an evaluation as opposed to an assessment determination. No samples were collected for oxbow 249.

AG – Sulfates, Chlorides and Total Dissolved Solids Criteria

Agriculture (AG) beneficial use utilizes Appendix E, a compendium of averaged values for sulfate, chloride and total dissolved solids (TDS) aggregated by waterbody segment as the comparator for the mean sample concentration. Provided the chloride and sulfate sample concentrations are less than 250 mg/L and TDS is less than 700 mg/L, AG beneficial use is deemed fully supported. When these variables are greater than the threshold value, AG beneficial use is deemed not supported.

Nutrients Criteria

Generally, a dichotomous process using geographic, physical and chemical attributes determine whether nutrients threaten a stream's beneficial uses. For lakes, an annual average of chlorophyll-*a* is the most general means to recommend a waterbody for listing as a nutrient-limited watershed (NLW). A NLW means a watershed of a waterbody where a designated beneficial use is adversely affected by excess nutrients, as determined by Carlson's Trophic State Index (using chlorophyll-*a*) of 62 or greater, or is otherwise listed as "NLW" in Appendix A of the Oklahoma OWQS. A NLW designation is interpreted as a threatened beneficial use. The conclusion of threatened status does not in and of itself determine whether a waterbody is impaired for a beneficial use but does require additional, detailed information gathering (impairment study) to determine whether nutrients have impaired a beneficial use.

All data collected during the Phase II Oxbow wetlands project were compared against the water quality criteria to yield a beneficial use impairment decision, beneficial use indication (not enough samples for a decision), or beneficial use threatened conclusion (**Table 2).** USAP results should be interpreted as yielding acceptable (achieving beneficial use) health or bad (impaired beneficial use) health. USAP conclusions or indications are compared against the revised Level 1 assessment method and macroinvertebrate collections (from Level 2 assessments). These comparisons are meant to serve as either supporting or refuting the USAP evaluation. The small sample size precluded statistical application while the lack of reference or least impacted condition for oxbow systems precludes anything more than a categorical comparison.

Table 2. Tabular Summary of Beneficial Use Assessment as Applied to the Phase II Oxbow Data Set Collected 9/21/2010 through 5/23/2012

Oxbow		Nutrients		Fish & Wildlife Propagation					Agriculture			Primary Body Contact *E coli*	
				Turbidity			Dissolved Oxygen						
Site	WBID	Lake	Stream	Stream	Lake	pH	Stream	Lake	Sulfates	Chlorides	TDS	Stream	Lake
235	520700	NLW	FS	NS	NS	NS	NS	NS	FS	FS	FS	FS*	FS*
249	121400	NLW*	FS*	NS	NS	FS	NS	NS	NS*	FS*	FS	No data	No data
273	520510	NLW	FS	NS	NS	FS	FS	FS	FS	FS	FS	FS*	FS*
341	520700	NLW	FS	NS	NS	FS	NS	NS	FS	FS	NS*	FS*	FS*
342	520700	NLW	FS	NS	NS	FS	NS	NS	FS	FS	FS	FS*	FS*
413	121400	NLW	FS	NS	NS	NS	FS	UD	FS	FS	FS	FS*	FS*
654	310800	NLW	FS	NS	FS	NS	NS	NS	FS	FS	FS	NS*	NS*
658	310800	NLW	FS	NS	NS	FS	FS	FS	FS	FS	FS	FS*	FS*
665	310800	FS	T	FS	FS	FS	NS	NS	FS	FS	FS	FS*	FS*
669	310800	FS*	FS*	NS	NS	FS	FS	FS	FS*	FS*	FS	NS*	NS*
1157	520700	NLW *	FS	NS	NS	NS	NS	NS	FS	FS	FS	FS*	FS*
1167	520510	NLW	FS	NS	FS	FS	FS	UD	NS	FS	FS	NS*	NS*

* Evaluative indication: not a determination

NS -Not Supporting UD - Undetermined FS - Fully Supporting

NLW - Nutrient Limited Watershed T – Threatened

Nutrients - Additional investigation required for use determination with Threatened or NLW conclusion

Notes relevant to the application of the collected data to the water quality criteria include using the value of 1000 NTU turbidity when >1000 NTU values were reported, entering ½ detection limit when Below Detection Limit (BDL) values were reported, and finally, using zero values when not enough samples were collected to allow for an impairment conclusion. Dissolved oxygen assessment using the lakes criteria assumed the profile was stratified when the percent of water column was less than 2 mg/L. To do this, the rate of DO decrease per unit depth was calculated between the oxic and anoxic values and slope applied to estimate where 2 mg/L might have been. The estimated depth of anoxia was compared to the total depth measured, to yield a beneficial use indication. While no laboratory analysis for total dissolved solids (TDS) was performed, the multiprobe units used for field measurements did offer a readout of TDS (an indirect measure serving as a useful TDS indicator).

Examination of macroinvertebrate data are used to shed additional light on the importance of fish and wildlife impairment assessments and evaluations. Macroinvertebrate collections were taken at 18 oxbows including 10 of the 12 sites sampled for USAP application. Lack of water precluded sampling of the final 2 oxbows. Macroinvertebrate identification of all captured individuals was to the genus level when possible. Analyses of site biological condition based on macroinvertebrate collections are preliminary because the necessary reference condition has not been developed for comparison. However, several simple indexes were used: percent dominant 2 taxa, commonly used by the OCC and OWRB Water Quality Division (OCC, 2008), the 3 dominant percent taxa suggested by EPA (2002), and finally simply plotting the total number of taxa and individuals in each sample (EPA, 1998). Methods used for collection and analysis are given in the QAPP (OWRB 2010b).

Lastly, landscape scoring from the revised Level 1 assessment, was used in addition to the aforementioned metrics as comparators to the USAP evaluations. Collectively, the comparisons of water quality data with land-use and macroinvertebrate community may help form a picture of the value of applying current USAP to oxbow wetlands. Sites with undisturbed land-use and high biotic integrity that fail to attain standards provide evidence that current standards may be inappropriate for oxbow wetlands. The Level 1 assessment method used to generate the landscape scoring is presented in Appendix A while the chapter "Level 1 Assessment" presents the rationale for the method itself.

Results and Discussion

The predominant factor affecting a USAP assessment was whether there was water to sample. Hydrology was a factor not only when it was dry, but also when it was too shallow to collect all environmental measures (**Figure 4**). Sampling during a period when the majority of the state was experiencing exceptional drought assuredly had an influence on hydrology, but does highlight a salient issue: lack of surface water to sample does not necessarily detract from a waterbody's ability to support flora and fauna endemic to wetlands. This also highlights the temporal aspect of sampling; meaning that sampling following an inundation event would have much lower constituent concentration than sampling as the water levels recede and constituents are concentrated by evaporation and seepage. Additionally, inundation events may also include the addition of refractory organic material, stimulating biogeochemical reactions which contribute to chlorophyll-*a,* nutrients, dissolved solids, pH and dissolved oxygen impairments. A final aspect of oxbow hydrology, highlighting segregation from both lakes and streams, is that a two year sample interval is more likely to result in an adequate sample number for beneficial use assessment with lakes and streams than for oxbows which generally became dry.

Figure 4. Oxbow 413 Following an Inundation Event on August 15, 2011.

In general, the sampled oxbows were turbid with excessive algae growth and low dissolved oxygen (**Figure 5**). All but 2 oxbows were assessed as being threatened by nutrients using the lakes USAP while only 1 oxbow was assessed as threatened via streams USAP. Combined 11 of the 12 oxbows assessed would be concluded as in poor health due to excessive nutrients. Of the 3 parameters used to assess Fish and Wildlife Propagation beneficial use, 3 oxbows failed the pH assessment while 11 of 12 failed turbidity and 7 of 12 failed dissolved oxygen. No oxbow passed every fish and wildlife USAP parameter. For the 3 parameters used to assess Agriculture beneficial use, 2 oxbows failed for sulfate and another for total dissolved solids. Finally, 3 oxbows had exceedance for bacteria measures (lake and stream one time exceedance criterion). According to USAP every oxbow is in bad health (impaired) requiring a TMDL and mitigation for beneficial uses to be achieved. The question is whether these USAP assessments are appropriate measures for oxbow wetland systems.

The conclusion of impaired water quality for oxbows 1167 and 341 may be appropriate. Site 1167 (failed for nutrients, turbidity, pH, sulfate and dissolved oxygen) received discharge from a small municipal wastewater treatment plant and 341 (failed for nutrients, turbidity, dissolved oxygen and total dissolved solids) is adjacent an active oilfield site and cement plant. Of all the oxbows sampled, oxbow 669 seemed to be the "cleanest" by water quality measures. While it was assessed as impaired for turbidity and bacteria, this system had relatively high oxygen when sampled, showed periods of low turbidity and algae with relative stable water quality parameters throughout the sample period; indicative of a waterbody capable of supporting a variety of flora and fauna.

Figure 5. Water Quality Typical of Oxbows Sampled during the Phase II Project; Oxbow 342 on August 4, 2010.

Through comparison of water quality data with macroinvertebrate metrics, we can further evaluate the applicability of current USAP protocols to oxbows. Examination of the total abundance number of individuals is not a good metric for analyzing biological integrity but does show a large gradient across sites with a range greater than 2 orders of magnitude (**Figure 6**). This implies that though the sample size is small (12) the potential for capturing a range of biological conditions within the small sample size is good. Number of taxa, a measure of richness, measures the overall variety of the macroinvertebrate assemblage. Richness measures reflect the diversity of the aquatic assemblage (Resh et al. 1995). Increasing diversity generally correlates with increasing health of the system and suggests that niche space, habitat, and food source are adequate to support survival and propagation of many species. Taxa number ranged from a low of 14 to a high of 55 presenting a fair range and suggesting greater diversity and health at the sites with a higher taxa number (**Figure 7**). A generalized interpretation of this plot would be the sites at the left hand side are less impacted than those to the right. This interpretation is preliminary as it does not address whether the taxa identified are particularly sensitive or insensitive (tolerant) to perturbation. For example, the oxbow with the most taxa may all be tolerant while the oxbow with the least counted taxa contains the most sensitive.

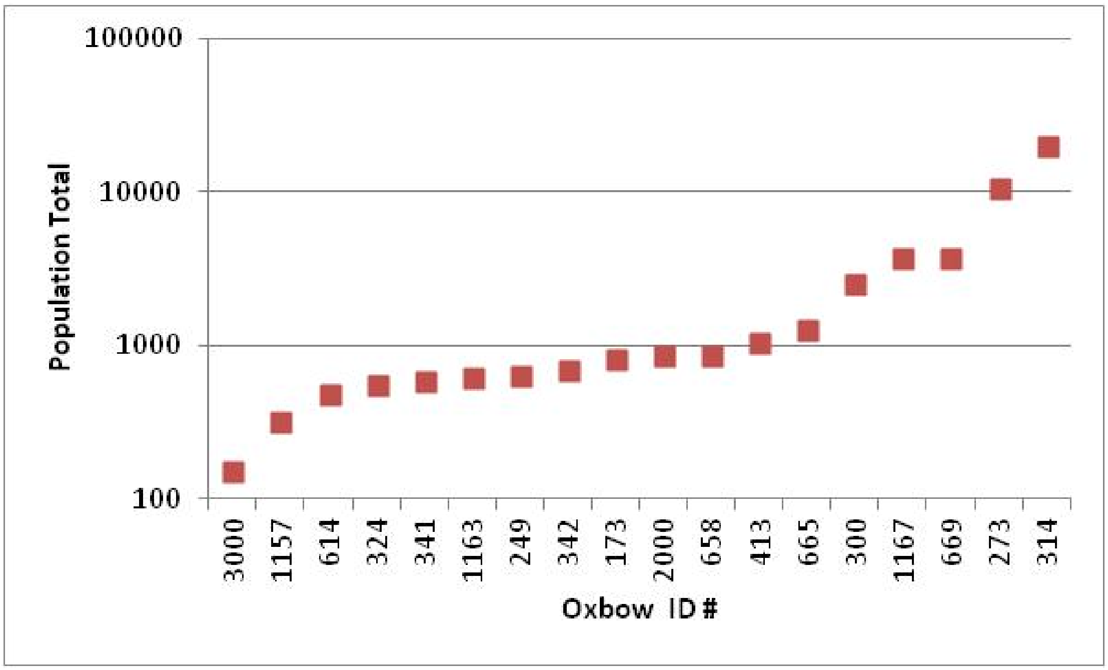


Figure 6. Total Macroinvertebrate Abundance of Phase II Oxbow Wetlands.

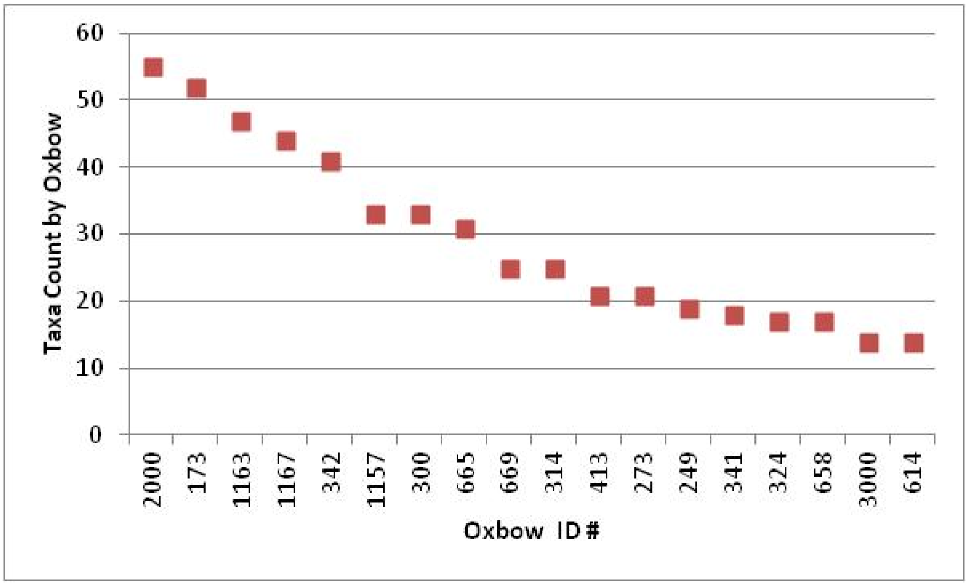


Figure 7. Macroinvertebrate Taxa Richness of Oxbow Phase II Wetlands

Tolerance/Intolerance measures are intended to be representative of relative sensitivity to perturbation and may include numbers of pollution tolerant and intolerant taxa or percent composition (Barbour et al. 1995). Unfortunately, a lookup list of tolerant/intolerant genera for oxbow wetlands is not available. However, simple metrics indicating tolerance and intolerance can be calculated. The premise is that though individual abundances may vary in magnitude a healthy and stable assemblage will be relatively consistent in its proportional representation. Percentage of the dominant taxon is a simple measure of redundancy (Plafkin et al. 1989). A high level of redundancy is equated with the dominance of a pollution tolerant organism and a lowered diversity. One tolerance metric available and commonly used for Oklahoma stream systems is the 2^{nd} dominance percentage. Here the percent of the second most dominant taxa is calculated. Although the range of percentages is not large, 2 to 27, values below 20% are thought of as high scoring for Oklahoma streams (**Figure 8**). A preliminary interpretation would be that the oxbows to the right of 324 would be the best or healthiest. Consequently oxbow 324 and those to the left in **Figure 8** would be considered less healthy. The 3 dominants metric presents the percentage of the three most dominant taxa for each site breaking the score range into three categories: greater than 70% as the worst or most tolerant taxa and 34 to 55% as the best or least tolerant taxa (EPA 2002). This system seems to suggest that oxbows 342 and 173 are in the best condition, those left of oxbow 2000 are in the worst condition, and all others are in fair condition (**Figure 9).** The interpretive schemes for the two tolerant/intolerant measures do not agree. While it is not possible to say conclusively, one possibility for the conflict between the metrics is the influence of the most abundant taxa. At oxbows with an extremely high percentage of the sample represented by the most dominant taxa, the 2^{nd} dominance percentage would be relatively low while the 3 dominants metric would be high. This appears to be the case for the four oxbows with the lowest values for 2^{nd} dominance percentage (314, 300, 3000, and 665), but had 3 dominants metric scores above 79%.

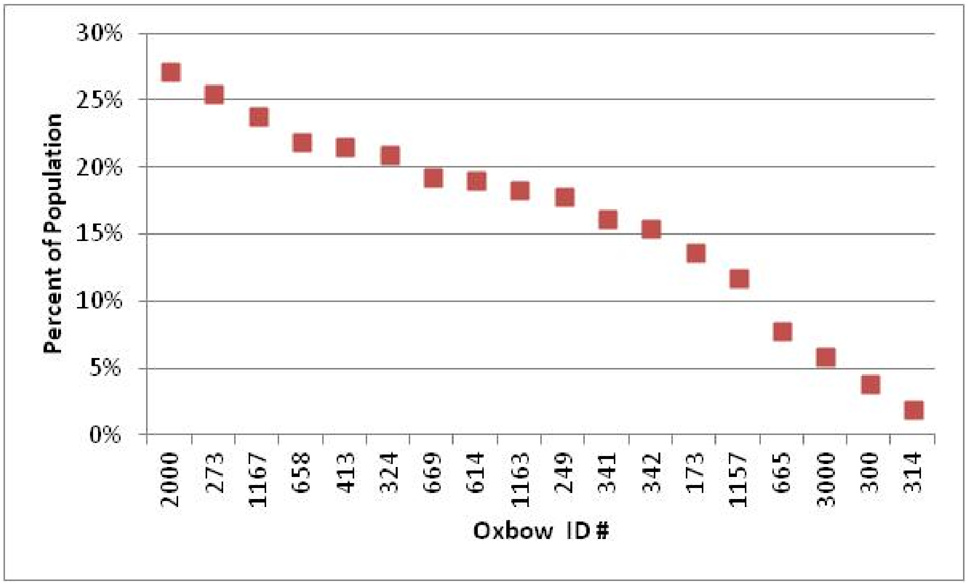


Figure 8. Percentage of Second Most Dominant Taxa as Percentage for Each Oxbow Phase II Wetland.

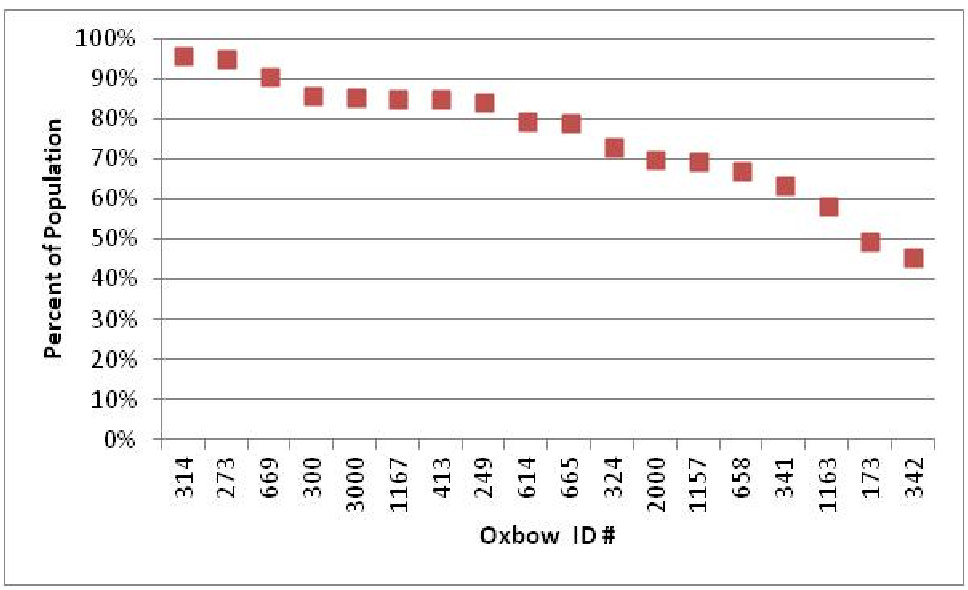


Figure 9. Percentage of Three Most Dominant Taxa for Each Oxbow Phase II Wetland.

These metrics were also placed in context of the USAP assessments and Level 1 landscape scores for potential relationships. **Table 3** presents the compiled matrix. Again, due to the low sample size no statistics were utilized to identify potential relationships. Three USAP parameters (DO, PBCR and pH) showed a general relationship to the macroinvertebrate measures presented. The dissolved oxygen (DO) beneficial use impairment (for Fish and Wildlife Propagation beneficial use) conclusion did appear to correlate to the Dominant 2 metric (**Figure 8**). Here, values below 19% were assessed or interpreted as impaired for Fish and Wildlife Propagation beneficial use while values at or above 19% were assessed as undetermined or meeting Fish and Wildlife Propagation beneficial use. This apparent trend is inverse to the Dominant 2 rule where values of 20% or less represent higher quality systems and higher percentages represent lower quality systems (assuming low dissolved oxygen impairment equals a low quality system). Various scenarios can explain this inverse relationship. For example, the oxbows scoring as best in the Dominant 2 metric showed an extreme (order of magnitude) dominance of the most abundant taxa over the rest. As a result, this metric would not be a clear indicator of relative health. An alternative explanation can be that the taxa most suited to a healthy oxbow wetland is tolerant to low dissolved oxygen.

Table 3. Summary of USAP, Landscape and Macroinvertebrate Metrics as Applied to the Oxbow Phase II Wetland Sample Sites. A "y" indicates the beneficial use is being met and a red shaded "n" indicates impairment.

Site #	Land-use Score	Richness Metrics		Tolerant/ Intolerant Metric		Nutrient USAP Metric	Fish and Wildlife Propagation Beneficial Use USAP Metrics				Agriculture Beneficial Use USAP	Primary Body Contact Beneficial Use USAP
		Taxa Total	Ind. total	Dom 2	3 Dom %		Turb lake	Turb Strm	pH	DO		
665	99	31	1272	0.08	0.79	n	y	y	y	n	y	y
1157	92	33	322	0.12	0.70	n	n	n	n	n	y	y
342	68	41	697	0.15	0.46	n	n	n	y	n	y	y
341	66	18	587	0.16	0.64	n	n	n	y	n	n	y
249	74	19	642	0.18	0.84	n	n	n	y	n	n	
669	90	25	3726	0.19	0.91	y	n	n	y	y	y	n
413	58	21	1038	0.22	0.85	n	n	n	n	y	y	y
658	86	17	872	0.22	0.67	n	n	n	y	y	y	y
1167	57	44	3722	0.24	0.85	n	n	y	y	y	n	n
273	65	21	10593	0.26	0.95	n	n	n	y	y	y	y
235	91					n	n	n	n	n	y	y
654	91					n	n	y	n	n	y	n

Fish and wildlife impairments due to pH appeared to also be inversely related to both dominance measures. All of the pH impairments were due to measures below 6.5, an indicator of low oxidation-reduction (REDOX) potential and commonly low dissolved oxygen. Again, similar explanations can be given for the apparent inverse relationship between USAP pH and macroinvertebrate metrics. Conversely to the two apparent inverse relationships two PBCR impairments are associated with higher percentages of both tolerance metrics; following the expectation of a higher dominance percentages (or lower biota quality) increasing the probability of a PBCR impairment.

Oxbows with known pollutant impacts include 1167 with a point source discharge and 341 with adjacent non-point sources. Treated sewage from a small municipality discharged into 1167 until just after the data collection period and 341 has an oil and gas well installment within 100 meters and a cement plant within 375 meters of the oxbow. Oxbow 1167 USAP evaluation indicates a fail for every beneficial use while 341 performed similarly but for a PBCR pass. The lower landscape scores for these two oxbows reflect a high potential for impact from their surroundings. Macroinvertebrate metrics indicate poor condition for 1167 but fair to healthy condition for 341. If generalities are possible from these two oxbows it appears that all metrics examined spotted the point source pollutant oxbow but macroinvertebrate metrics did not perform well for the non-point source impacted oxbow.

Level 1 assessment of each oxbow predicted 1 of the 12 sites to be in excellent condition, 7 to be in good condition and the remaining 4 in fair condition. This is in sharp contrast to USAP results where every site was impaired. Landscape scores appeared to generally follow the Dominant 2 metric lower landscape scores associated with the higher Dominant 2 percentages. USAP assessments painted a picture of severely impacted waterbodies: none of the 12 supporting fish and wildlife propagation, all but one threatened by excessive nutrients and 25% impaired for agriculture and primary body contact uses. Only 2 of the 12 oxbows presented clear explanatory pollutant sources; point source discharge into 1167 and non-point sources proximate to 341. This leaves 10 oxbows in want of explanatory sources of impact. It also implies the inapplicability of current default USAP for oxbows; seemingly healthy, oxbows would be listed as impaired because the natural range of conditions under which they are found falls outside the expectations for healthy lakes and streams.

Conclusion

Preliminary macroinvertebrate metrics produced conflicting results. Whether it was due to the preliminary nature of the metric or reflects a true conflict between oxbow condition and USAP assessment; it is not clear. Without a clear delineation of least impacted or reference condition oxbows characterized by their physical, chemical and biological a null hypothesis to clearly dispute USAP impairment conclusions is not possible. The overwhelming conclusion of impairment for Fish and Wildlife Propagation and threat of nutrient impairment by USAP does not clearly agree with the biological and landscape features examined. Oxbows were deemed impaired according to USAP regardless of their surrounding landscape and biotic communities. Furthermore when accounting for known pollutant sources the landscape features directly conflicts with the PBCR conclusion. These results lend credence to the current effort to define beneficial uses for wetlands in a context other than how they have been used in the past. It is clear that oxbows in Oklahoma do not fit the norms as defined by USAP assessment; in particular the Fish and Wildlife Propagation beneficial use and defining threats from nutrient enrichment. Seemingly healthy oxbows should be listed as impaired and a total maximum daily load (TMDL) scheduled using the current USAP.

In an ongoing effort to develop water quality standards for wetlands, the state of Oklahoma, through the Oklahoma Wetlands Technical Workgroup (OWTW) has developed beneficial uses for wetland waterbodies that recognize and incorporate the natural functions of these unique waterbodies. In general, the approach identifies the primary functions of wetland ecosystems and truncates them down into three categories; 1) habitat, 2) hydrology, and 3) water quality. These truncated categories were then used to develop designated uses (referred to as beneficial uses in Oklahoma's water quality standards). Proposed "new" beneficial uses to address these categories for wetland waterbodies are: Wetland Habitat & Biota, Flood Protection and Erosion Control, and Water Quality Enhancement. In addition to these beneficial uses derived from wetland functions, the state also proposes to apply certain existing beneficial uses such as Recreation and Aesthetics to wetland waterbodies. This approach relied upon current science related to wetland functions to inform the creation of these designated/beneficial uses in a manner that is consistent with the Clean Water Act and Oklahoma statutes. It is thought that this approach will address the apparent deficiencies of USAP to assess fish and wildlife and nutrient threats as wetland policy moves forward and avoid implementation of TMDLs on what are otherwise healthy wetland ecosystems.

Level 1 Assessment

Introduction

A Level 1 or Landscape Assessment is a diagnostic tool which allows the overall condition of a wetland to be assessed by examining land-use surrounding the target wetland. This is a desktop type of analysis, so it is a relatively quick and inexpensive method of determining condition. Use of a desktop tool allows for resources to be focused more efficiently toward the area most likely to meet data quality objectives. For this reason a Level 1 assessment method was developed during Phase I of this project. This method relied solely on data derived from land cover data within a circular 1km buffer around the center of the oxbow. A summation of the coverage of all land covers, weighted for impact, was used to score surrounding land-use. Oxbows with higher scores, from fair to excellent condition, were selected for follow up monitoring during Phase II. Using information collected during this phase, the Level 1 assessment was revised to present a more representative desktop tool for oxbows.

Although the previous buffer approach serves as an indicator of how adjacent land may influence an oxbow, generic (1 km circular buffers) possess potential to misrepresent the system. Several revisions were competed with the Level 1 assessment method with perhaps the most significant replacing the circular buffer with a watershed based buffer. In this case catchment areas were delineated using DEM elevation layers and ArcHydro tools in GIS. **Figure 10** highlights the benefits of delineating the immediate watershed as the buffer for landscape assessments over relying on simpler buffer methods. For the case of neighboring oxbow sites, 341 and 342, median chloride and sulfate values were significantly higher for site 341 than for 342. The delineated watershed of 341 includes a portion of a state highway, an oil and gas well site, and a cement operation. None of these appear in the delineated watershed of site 342, but the buffer method captures all of these features as part of the areas influencing both sites. The Phase II report noted the difference in the chemical results from these adjacent oxbows, however, could not account for the cause. The elevated chlorides and sulfates in oxbow 341 are likely to have been related to the industrial influences in its watershed, while site 342 was less impacted or un-impacted by these features.

Modifications beyond a watershed based assessment were also developed and evaluated for predictability of water quality condition. In addition to delineating watersheds for each oxbow, landscape level changes were made. First, land-use coefficients of developed and pasture/hay areas were lowered to reflect greater impact to local water quality. All land-use coefficients were summed to give one land-use feature value. Second, three landscape features were created; road density, population density, and upstream 303d (water quality impairment) listings. Each was assigned a coefficient weighted and summed with the land-use value to present a final landscape rating between 1 and 100. Additional landscape features were added to better represent;

- the direct impact of people living near the wetland (population density),
- increase the weight of roadway impacts (road density) and
- account for the potential of negative impact due to inundation by impaired waters from high bank flood events (303d listing).

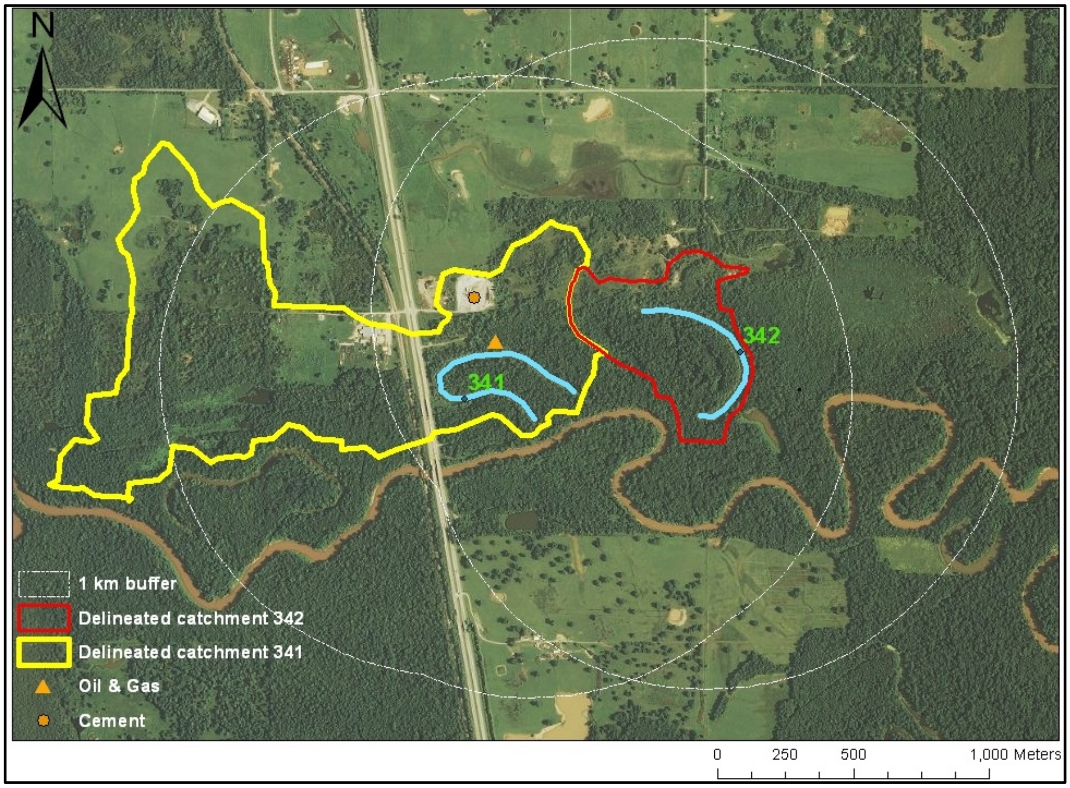


Figure 10. Visual Comparison Illustrating The Differences Between Buffer Landscape Assessments Performed In Phase IA And Delineated Catchment Landscape Assessment

Methods

The revised Level 1 assessment equation is

$$LDWT = 0.5*(a) + 0.2*(b) + 0.2*(c) + 0.1*(d)$$

Where

a = Land-use Score = ∑ Land-use Coefficient *Area per Land-use

b = Road Density Score

c = Population Density Score

d = 303(d)

A complete description of the revised Level 1 assessment and its application is summarized in **Appendix A**.

The ability of five variations of the Level 1 assessment to reflect oxbow condition was evaluated through comparisons with measurements of water quality and the plant community. Statistical tests allowed a thorough evaluation of the revised Level 1 assessment method. The original land-use assessment (OLUA) method land-use used a 1 km buffer zone around each oxbow following the original method and land-use scoring. The delineation original land-use scoring method (DOLU) applied the same land-use scoring to the delineated catchment instead of the buffer area. The revised land-use assessment (RLUA) method used the revised land-use coefficients applied to the delineated watersheds only for a land-use score (excluded population density, road density and 303(d) locations). The landscape original land-use assessment (LOLU) method applies the newly established landscape scoring method (including population density, road density and 303(d) locations), using original land-use coefficients, to the 1 km buffer. Finally, the landscape delineation revised land-use (LDWT) method applies the landscape scoring method with the revised land-use coefficients to the delineated watershed following every step of the revised method. **Table 4** presents the matrix design used to examine the differences in Level 1 assessments as applied to Phase II oxbows. Regressions were run between the assessment output and water quality parameters and plant metrics. Multiple regression analysis used the individual water quality parameters and plant metrics as explanatory variables and Level 1 score as the response. Plant metrics used included evenness, percent wetland obligate species and the square root of the percent invasive species. Water quality parameters included ln (Chl-*a*), salinity, total phosphorus, ammonia and specific conductance. When the assumptions of regression were not met, non-parametric Spearman correlations were conducted between Level 1 score and explanatory variable. Only when a significant statistical relationship was noted was a result reported.

Table 4. Level I Assessment Method Comparison Matrix

Method Name	Scoring Description	Area Assessed		Metrics Assessed		LU Coefficients	
		1 km buffer	Delineated Catchment	Land-use only	Landscape (Land-use + additional)	Original	Revised
OLUA	Original Land-use (LU) Assessment	x		x		x	
DOLU	Delineation, Original LU Scoring		x	x		x	
RLUA	Revised LU Assessment		x	x			x
LOLU	Landscape, Original LU Assessment	x			x	x	
LDWT	Landscape, Delineation, Revised LU		x		x		x

Results

Scoring of the revised method shifted the predicted quality of four oxbows out of one category and into another (**Figure 11**). One oxbow fell into the excellent category (site 665), six (235, 249, 654, 658, 669 & 1157) in the good category and five (273, 341, 342, 413 & 1167) in the fair category). Site 413 and 1167 scored the lowest of all 12 for land-use.

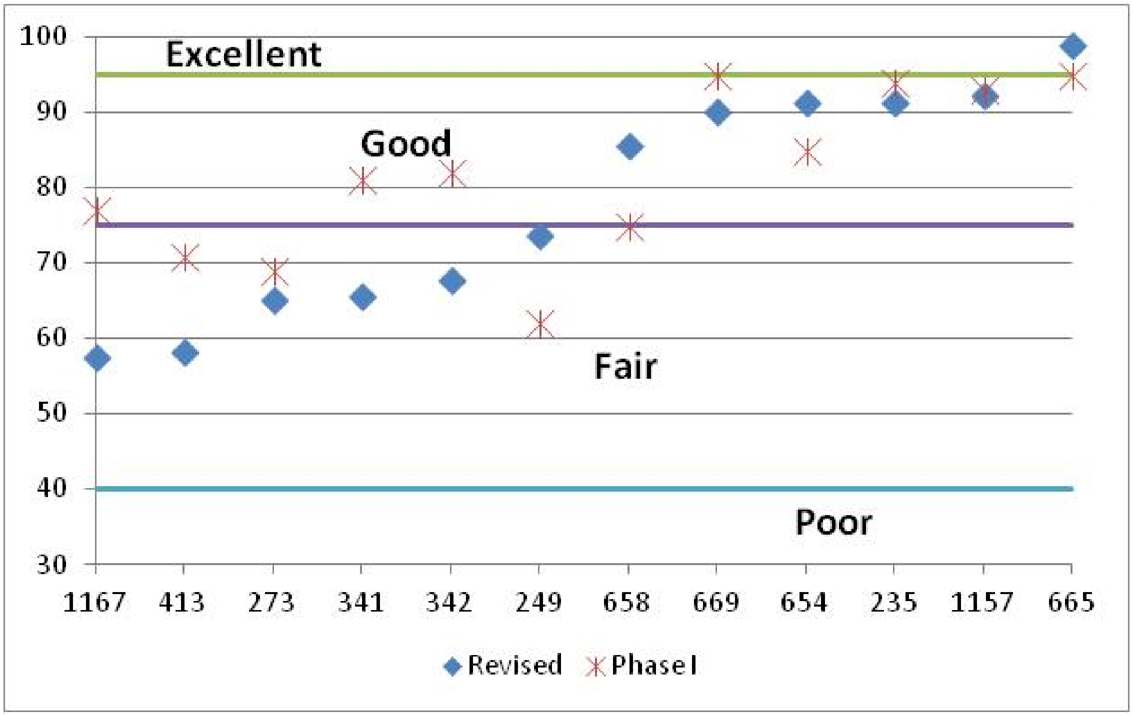


Figure 11. Summary Comparison of Revised and Phase I (Original) Level 1 Assessment Landscape Scores by Oxbow

For many water quality parameters (pH, oxidation reduction potential, turbidity, chloride, hardness, Secchi depth, total suspended solids, etc), no significant correlations were found with any of the assessment methods. General linear regression results show that RLUA (R-sq = 49.6%, p=0.011), OLUA (R-sq=53.2%, p=0.009), and DOLU (R-sq=47.7%, p=0.013) were significant indicators of variability in average oxbow chlorophyll-*a* levels when transformed by natural log. Because test assumptions were not met for general linear regression, a non-parametric Spearman correlation test was used to determine strong, significant correlations with average chlorophyll -*a* levels for LDWT (Spearman rho=-0.734, p=0.007) and LOLU (Spearman rho=-0.748, p=0.005). See **Table 5** below. The high R-Sq's and Spearman rhos reported show that all five assessment methods were able to predict chlorophyll-*a* well.

Table 5. Assessment Score Relationships to Chlorophyll-*a*, n=12

Water Quality Parameter, Average	Assessment Method				
	RLUA	OLUA	DOLU	LDWT	LOLU
ln (Chl- *a*) ug/L	R-Sq = 49.6% R-Sq(adj) = 44.5% p= 0.011	R-Sq = 53.2% R-Sq(adj) = 48.5% p=0.009	R-Sq = 47.7% R-Sq(adj) = 42.5% p=0.013	Spearman rho = 0.734 p = 0.007	Spearman rho = -0.748 p = 0.005

Though all methods showed statistical significance the LDWT and LOLU (landscape based) assessment scores were significantly correlated with more water quality parameters than the land-use-only methods (RLUA, OLUA, and DOLU). Specifically, LDWT predicted 35.5% of variability in salinity (p=0.041), 40.3% of variability in total phosphorus (p=0.026), and 34.2% of variability in specific conductance (p=0.046) (**Table 6**). LDWT was also strongly correlated to ammonia (Spearman rho=-0.615, p=0.033). LOLU predicted 35.7% of variability in total phosphorus, was strongly correlated to salinity (Spearman rho=-0.636, p=0.026) and specific conductance (Spearman rho=-0.664, p=0.018), and moderately correlated to ammonia (Spearman rho=-0.587, p=0.045). In general LDWT showed a greater predictive significance for total phosphorus and ammonia water quality parameters than LOLU. This shows that the revised land-use scoring successfully predicts selected water quality variables well.

Table 6. Landscape Score Relationships to Salinity, Total Phosphorus, Ammonia, and Specific Conductance, n=12

Water Quality Parameter, Averaged for Each Site	LDWT	LOLU
Salinity (ppt)	R-Sq = 35.5% R-Sq(adj) = 29.0% p=0.041	Spearman rho = -0.636 p =0.026
Total Phosphorus (mg/L)	R-Sq = 40.3% R-Sq(adj) = 34.4% p=0.026	R-Sq = 35.7% R-Sq(adj) = 29.2% p=0.040
Ammonia (mg/L)	Spearman rho = -0.615 p=0.033	Spearman rho = -0.587 p=0.045
Specific Conductance (u/cm)	R-Sq = 34.2% R-Sq(adj) = 27.6% p=0.046	Spearman rho = -0.664 p=0.018

LDWT and LOLU scores also exhibited significant correlations with plant metrics. LDWT predicted 27.7% of variability in evenness (p=0.010), 19.4% of variability in percent of wetland obligate plants (p=0.035), and 35.8% of variability in the percent of invasion (transformed by square root) (p=0.003). LOLU predicted 20.6% of variability in evenness (p=0.029), 22.0% of variability in percent of wetland obligate plants (p=0.024), and 44.0% of variability in percent of invasion, as transformed by square root (p=0.001). These indicate that LDWT predicts evenness better than LOLU but the opposite is true for percent obligate species and square root of percent invasive species (**Table 7**). The lower explanatory capability of plant variables compared to water quality variables is likely due to a lower influence of watershed features on plant species composition. For example, seed dispersal may be more heavily influenced by airborne factors than land-use and topographic features.

Table 7. Landscape Score Relationships to Plant Metrics, n=23

Plant Metric	LDWT	LOLU
Evenness	R-Sq = 27.7% R-Sq(adj) = 24.2% p0.010	R-Sq = 20.6% R-Sq(adj) = 16.9% p0.029
% Obligate	R-Sq = 19.4% R-Sq(adj) = 15.6% p0.035	R-Sq = 22.0% R-Sq(adj) = 18.3% p0.024
SqRt % Invasion	R-Sq = 35.8% R-Sq(adj) = 32.8% p0.003	R-Sq = 44.0% R-Sq(adj) = 41.4% p0.001

Discussion

All Level 1 Assessment methods exhibited significant correlation to average chlorophyll-*a* levels. The RLUA and DOLU, which differed only in land-use scoring showed similar results with the statistical significance varying. Scoring coefficients for certain land classes were changed, particularly for developed land classes (See **Appendix A**). For these sites, low, medium, and highly developed land-uses were not well represented. Developed open space, for which the coefficient differed most between scoring frameworks (.3 in RLUA and .6 in DOLU), was more represented than the other developed land-uses, but did not dominate the assessment area of any sites. Pasture/Hay, scored 0.4 in RLUA and 0.5 in DOLU, made up the most area of altered coefficient land-uses, but again, did not dominate the assessment area of any sites. Results were similar not so much that the criteria were similar but land-use between sites was similar. A better test of landscape methodology would be to choose sites based on widely variable land-use characteristics. The current site selection made during Phase I was based on identifying oxbows with relatively small land-use impacts.

The landscape assessment methods, LDWT and LOLU, which included population density, road density, and presence/absence of upstream 303(d) impairments in addition to land-use for scoring, correlated significantly to plant metrics of evenness, % obligate, and % invasive in addition to more water quality parameters than the land-use only methods, including salinity, total phosphorus, ammonia, and specific conductance. The sites tested were non-randomly drawn from a subset of oxbows that were randomly selected from the statewide population of oxbows. Consequently, no inferences may be made from this study about the larger population. However, for this small population of oxbows, landscape methods (LDWT and LOLU) performed better at predicting Level 3 conditions than land-use only methods. Again, because of little variability noted in some of the added factors and modified coefficients, similar significance between the RLUA and DOLU assessment methods would be expected.

LDWT and LOLU scores performed similarly to one another. Although the LOLU method involved a circular buffer for the scoring of land-use, road density was still scored using the delineated watersheds for each site. This may have scored the methods more similarly than had this not been done. To fully test buffer against delineation methods, implementation of another assessment with road density calculated from the circular buffer would be necessary. Further work to compare these buffers using larger populations of wetlands and different types of wetlands could yield a more definitive answer. The value of understanding the difference in outcome is that the delineation requires more skill, data, and time to determine as opposed to a 1 km circular buffer. The rationale for keeping the delineated buffer is the directly measured water quality differences noted between oxbows 341 and 342 as they relate to delineated watershed features (high potential for impact by adjacent NPS pollutant sources). While this revised method is helpful for oxbows, wetlands influenced primarily by surface inundation events, the usefulness of the method for wetlands influenced by subsurface recharge, is likely significantly less. This idea could be incorporated when investigations are conducted for differences between buffer types.

Conclusion

Statistical analysis indicated that the revised land-use coefficients and variables of road density, population density, and the presence/absence of 303(d) impairment (within 2 km upstream to the oxbow) were predictive for assessing oxbow condition. However, statistical analysis did not note a strong predictive difference between use of a 1 km circular or the delineated immediate watershed buffer of an oxbow. Small sample size reduced the power of statistical analysis while a relative small range distribution of land-use between sites and methods reduced the ability to distinguish differences. However adjacent oxbows 341 and 342 displayed a cogent rational for using delineated watersheds as opposed to generic buffers. The small sample size and promising relationships suggest more evaluations are worthwhile. Future examination of the revised Level 1 assessment method should include sites with a broader range of surrounding land-uses, particularly the developed (specifically open space) land-use feature. Additional comparison between the watershed delineated and circular buffer is also warranted as a delineated buffer requires more individual decision-making and time than application of a standardized buffer.

Level 2 Assessment

Introduction

The development of appropriate wetland assessment methods is a cornerstone of a state wetland program. Wetland assessment provides a unified and consistent means of evaluating ecosystems for a number of programmatic needs including identifying high priority wetlands for protection, tracking trends in wetland condition, designing and monitoring wetland mitigation projects, and supporting water quality standards. The United States Environmental Protection Agency (USEPA) suggests a three level approach to wetland assessment. Level 1 or landscape assessments are almost entirely conducted remotely, Level 2 are rapid field based assessments of wetland condition and Level 3 assessments are intensive field based assessments (USEPA 2006). Oklahoma has been in the process of developing a Level 2 Rapid Assessment Method (RAM) since 2010. Oklahoma's current Wetland Program Plan highlighted the development of a RAM as a fundamental action towards meeting the state's monitoring and assessment objective:

"*Develop a sensible monitoring and assessment strategy to serve as the foundation for tracking local and statewide trends in wetland health and extent, prioritizing and tracking restoration activities, and guiding compensatory mitigation projects*" (OCC 2013).

The first draft of the Oklahoma Rapid Assessment Method (OKRAM) was created in 2012 following an extensive literature review of existing RAMs in Delaware (Jacobs 2010, Sifneos et al. 2010), California (Collins et al. 2008, Stein et al. 2009), Ohio (Mack 2001, Peterson and Niemi 2007), Florida (Miller and Gunsalus 1997, Reiss and Brown 2007), Colorado (Johnson et al. 2011), North Carolina (NCWFAT 2010) and Rhode Island (Kutcher 2010, Kutcher 2011). A review of the primary literature on the relationship between anthropogenic stressors and wetland condition was also conducted. The following is a limited selection of the reviewed literature on buffer effects (Castelle et al. 1994, Rickerl et al. 2000), landscape alteration (Gray 2004, Brazner et al. 2007), alteration to habitat connectivity (Lehtinen et al. 1999, Fairbarin and Dinsmore 2001), effects of sedimentation (Luo et al. 1997, Gleason 2003), and hydrologic alteration (Euliss and Mushet 1996, Voldseth et al. 2007) that provided a framework for development of OKRAM.

Wetland experts from the Oklahoma Water Resources Board (OWRB), Oklahoma Conservation Commission (OCC) and Oklahoma State University (OSU) engaged in a series of discussions to determine what components and formats from existing RAMs would best serve to assess the condition of wetlands in Oklahoma. Primarily, the goal was to create a rapid wetland assessment method that could be used in ambient monitoring of wetland condition to track broad trends in wetland health as well as identify wetlands in need of restoration and protection. Project staff viewed OKRAM as a starting point in the long-term development of an array of related assessment methods that could eventually be used for additional applications including support of Clean Water Act § 404 and water quality standards.

Through the preliminary planning meetings, project staff at OWRB, OCC and OSU determined that to the extent practicable, a statewide RAM was desirable to provide consistency and ease of application. Project staff acknowledged that geographic differences and differences among wetland classes could potentially limit our ability to develop a uniform assessment. As such, it was determined the best path forward was to consider regional and class variation while developing a broadly applicable draft OKRAM. Once a draft was established it could be applied with focus on specific ecoregions and wetland types. Through subsequent application within additional ecoregions and among additional wetland classes, RAM developers could begin to evaluate where methods succeed and fail in assessing condition across the broad spectrum of wetlands across Oklahoma.

To meet the goal of applicability across broad geographic area and wetland types, project staff at OWRB, OCC and OSU determined that a stressor based approach would be desirable (Jacobs 2010). A stressor based approach eliminates the need to scale variables related to the structure and complexity of biotic and abiotic ecosystem components across the broad range of reference states that may exist among the diverse ecoregions and wetland types of Oklahoma. A secondary benefit of a stressor-based approach is that the sources of wetland degradation can be identified during RAM application, providing insight into restoration and protection strategies (Jacobs 2010). The theoretical underpinning of OKRAM is similar to that of the Functional Assessment of Colorado Wetlands (FACWet) and the Delaware Rapid Assessment Protocol (DERAP) in which the presence of stressors causes ecosystem condition to deviate from condition at undisturbed sites (Jacobs 2010, Johnson et al. 2013). Furthermore, when stressors are not identified, the wetland is assumed to maintain the best possible ecological condition (Johnson et al. 2013). The foundational concept that stress can be used as a measure of ecological condition requires calibration with Level 3 assessment methods, which are being developed concurrently with OKRAM. As a result, moving forward with the development of OKRAM will require continued refinement through comparisons with additional, intensive measures of wetland condition.

Additionally, through the development process, we sought to create a RAM that met the characteristics outlined by Fennessey et al. (2004) in their review of rapid assessment methods of wetland condition. Rapid assessments (1) provide a single score that reflects the condition of a wetland relative to comparable systems, (2) require no more than one day of field and office time for two staff members, (3) consist of an on-site assessment and (4) can be verified with Level 3 site data. The purpose of this project was to assess if OKRAM succeeded in meeting the above characteristics at depressional wetlands in central Oklahoma.

Oklahoma Rapid Assessment Method (OKRAM)

The draft OKRAM deployed for this project consists of nine metrics, aggregated into three component attribute scores and finally combined to give one overall condition score. The metrics included in OKRAM were based on metrics from the California Rapid Assessment Method (CRAM) and FACWet, but adjusted based on regionally important stressors according to the primary literature and best professional judgment of project staff. Metrics are divided into three attributes (hydrologic condition, water quality condition, and biotic condition) with each attribute representing fundamental physical, chemical and biological components of wetland condition. Metrics are scaled from 0 to 1, with 1 representing ideal or least disturbed conditions and 0 representing complete degradation of the metric resulting from anthropogenic activities. The component attributes along with the metrics that comprise those attributes are described below. For information about OKRAM beyond what is outlined in this section, a draft version of OKRAM is presented in **Appendix B**.

Hydrologic Condition

Hydrology is the primary driver of the physicochemical and biological processes of wetland ecosystems. The frequency and duration of inundation of wetlands drives the system to shift between aerobic and anaerobic conditions. The availability of oxygen has profound impacts on nutrient cycling and availability which in turn affects the biota that utilize wetlands (Mitsch and Gosselink 2007). The hydrologic condition attribute in OKRAM is comprised of three metrics, hydroperiod, water source and hydrologic connectivity. Each metric represents a unique feature of the hydrology of wetlands and is scored to reflect the relative degree of anthropogenic disturbance that causes the hydrologic regime to deviate from a least disturbed condition.

Hydroperiod refers to the duration and frequency of inundation. Deviation from natural conditions can obviously impact the hydrologic functions that wetlands provide such as flood abatement, water storage and groundwater recharge. However, deviation can also alter biogeochemical processes and biological communities (Mitsch and Gosselink 2007). The hydroperiod metric is scored by assessing the severity and coverage of hydrologic stress that will cause the duration and frequency of inundation to shift away from reference conditions. Some common hydroperiod stressors include water pumping into or out of a wetland, sedimentation resulting in basin volume loss, and drainage ditches.

The water source metric assesses the degree of landscape alteration in the watershed of a wetland. Land-use change from native vegetation to impervious surface and agricultural land can alter the movement of water from the uplands into a wetland ecosystem. Impervious surface prevents the infiltration of water into the soil and can create "flashier" drainage patterns, increasing the frequency of inundation in aquatic systems and wetlands (Scheuler 1992, Allan 2004). Agricultural land, when irrigated can increase the surface water present in a watershed and also increase the movement of water from uplands into wetlands. Furthermore, rain events during post-harvest when agricultural lands are barren can alter the ability of uplands to retain precipitation through decreased plant interception and uptake (Euliss and Mushet 1996). The water source metric is scored by quantifying the amount of anthropogenic alteration to the land-use in the watershed of the wetland.

Hydrologic connectivity refers to the ability of water to move between the wetland and adjacent ecosystems. The inability of water to leave a wetland can alter the depth of inundation which can stress the biotic communities present as well as alter the movement of materials such as sediment, nutrients, and detritus. Common barriers to hydrologic connectivity include road grades and levees. The metric is scored by quantifying the percentage of the wetland boundary that has been altered.

Water Quality

The water quality condition attribute assesses the biogeochemistry of wetlands and focuses on alteration to the natural input of materials and chemicals. Inputs of nutrients, contaminants and sediment can affect the biotic communities present through processes such as the covering of seed banks or eggs (Gleason et al. 2003) or through alteration to the biogeochemical cycles that take place in wetlands. This attribute is comprised of four component metrics including nutrients/eutrophication, sediment, chemical contaminants and buffer filter.

The nutrient/eutrophication metric assesses the intensity and coverage of unnatural inputs of nutrients to a wetland. Many wetlands, due to their low topographic position on the landscape are natural sinks for materials and nutrients from the surrounding uplands (Zedler and Kercher 2004). Wetlands naturally transform these nutrients through normal hydrologic processes that shift conditions from aerobic to anaerobic (Mitsch and Gosselink 2007). However, unnatural inputs of nutrients can overwhelm the capacity of wetlands to perform natural nutrient cycling processes and ultimately alter the chemistry of the system. Common indicators of altered nutrient inputs are unnatural discharges, excessive algal growth and livestock/animal waste.

The sediment metric assesses the intensity and coverage of unnatural inputs of sediment to a study area. Sediment can reduce water clarity or cover seeds or eggs altering biotic communities (Gleason et al. 2003). Sedimentation can also reduce basin volume and alter the hydrology of wetland ecosystems (Luo et al. 1997). Common indicators of altered sediment inputs include upland erosion such as rills or gullies, excessive turbidity in the water column, and silt covered vegetation.

The chemical contaminant metric is a measure of the unnatural inputs of materials other than nutrients and sediment into a wetland. These contaminants include salt, petroleum products, or any other chemical that can alter wetland processes. Common indicators include point source discharges from a factory, oil sheen and salt crust.

The final metric in the water quality condition attribute is buffer filter, which is a measure of the capacity of the uplands surrounding a wetland to prevent nutrients, sediment and contaminants from reaching the wetland. Natural land-uses have the capacity to filter nutrients and capture sediment from adjacent agricultural or urban land (Castelle et al. 1994). This metric is scored based on the length of intact buffer adjacent to a wetland. The length of the buffer required to perform filtration functions is based on the severity of the alteration of the adjacent land-use.

Biotic Condition

The biotic condition attribute is a measure of the degree of anthropogenic impact to the habitat present in a wetland and the surrounding area and is comprised of two component metrics: vegetation condition and habitat connectivity. The vegetation condition metric is a measure of the degree of anthropogenic alteration to the vegetation present within a wetland. The metric is scored as a percentage of area within a wetland that has been degraded through the colonization of invasive species, the planting of crops or pasture grasses, excessive grazing, herbicide application and mechanical disturbance. The habitat connectivity metric is a measure of the degree of human alteration to the landscape around a wetland that could impact wildlife movement. It is assessed by quantifying the area of connected intact habitat surrounding a wetland. Acceptable habitat includes native uplands, aquatic systems, other wetlands, and several man-made features with little impact to wildlife movement such as dirt roads. The metric is measured within a 2500 meter buffer around the wetland.

Methods

Study Area and Study Sites

The study region for application of OKRAM validation was the Pleistocene Sand Dunes ecoregion (CPSD) adjacent to the Cimarron River. This area includes more than 273,000 ha and encompasses portions of five counties (Woods, Major, Kingfisher, Garfield and Logan) in north central Oklahoma (**Figure 12**). The CPSD has a high density of depressional wetlands of the same origin that have formed in the valleys of dune fields on old Cimarron River alluvial terraces (**Figure 13**). Because these wetlands are in close proximity and of similar origin, they are ideal study systems for the trial application of OKRAM. Natural variability between systems assessed within a narrow time frame can be limited, and deviation of metrics can be more easily attributed to anthropogenic factors. Forty interdunal depressional wetlands that exhibit both least disturbed and disturbed conditions were selected for this study. **Figure 14** shows the location of all study sites. Initially, 20 reference or least disturbed and 20 disturbed sites were selected for inclusion. Disturbance was initially based on the land-use surrounding each wetland and was verified in the field. Of the 20 reference sites, five were removed from the reference pool due to modifications to the land-use (predominantly, improved pasture of invasive/non-native grasses) undetected from remotely sensed materials and initial windshield reconnaissance. Of the 20 disturbed sites, 16 were selected as the most disturbed due to a high intensity of human activities (predominantly, agriculture) within the wetland itself, rather than only the surrounding landscape. As a result, 15 wetlands were placed into an *a priori* least disturbed category, 16 wetlands were placed into an *a priori* high disturbance category and 9 wetlands were considered in an intermediate disturbance class. **Figure 15** displays photographs from reference and highly degraded wetlands. **Figure 16** contains photographs of stressors that commonly impacted wetlands in the study area.

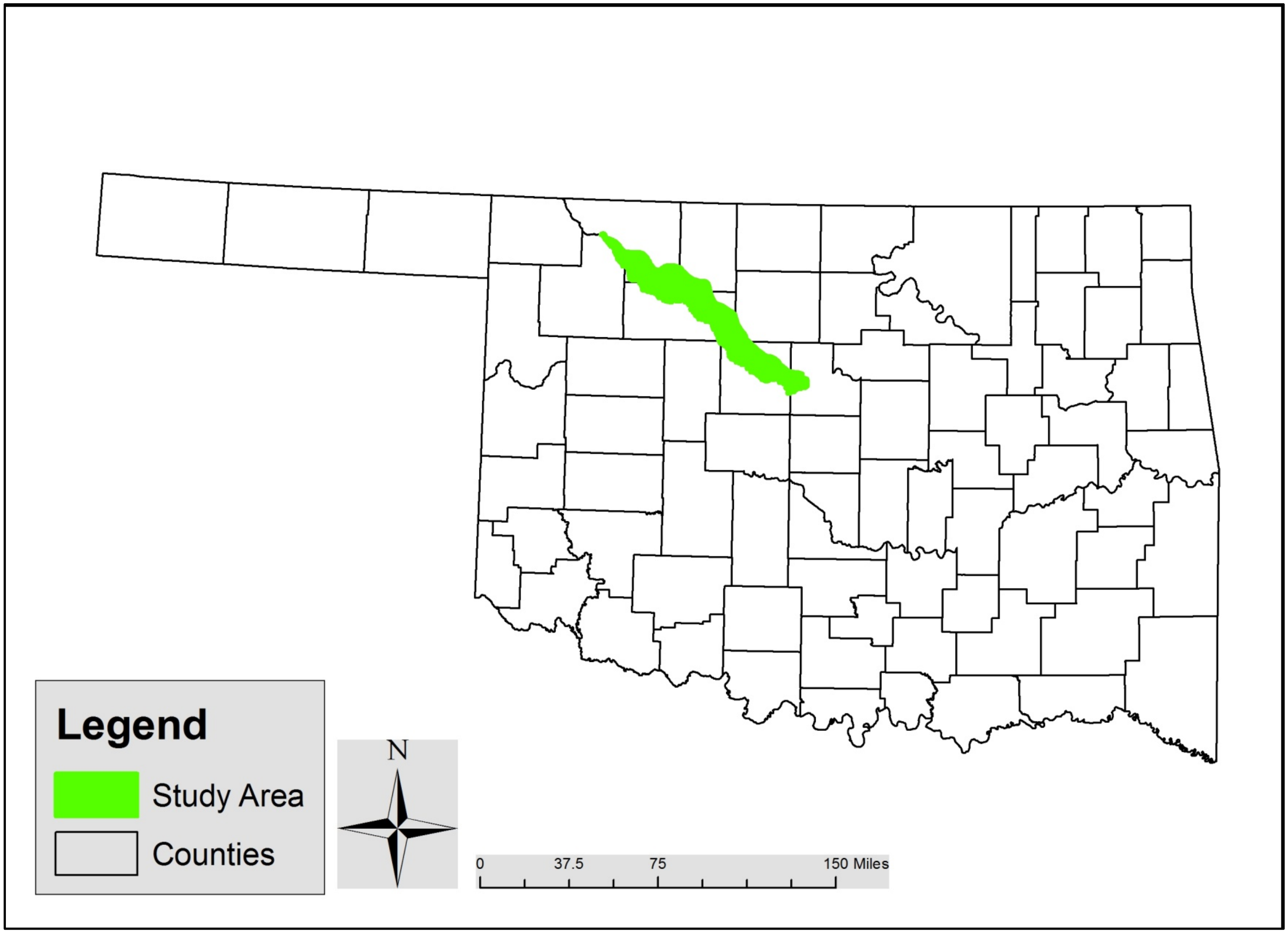


Figure 12. Study Area for Wetland Mapping

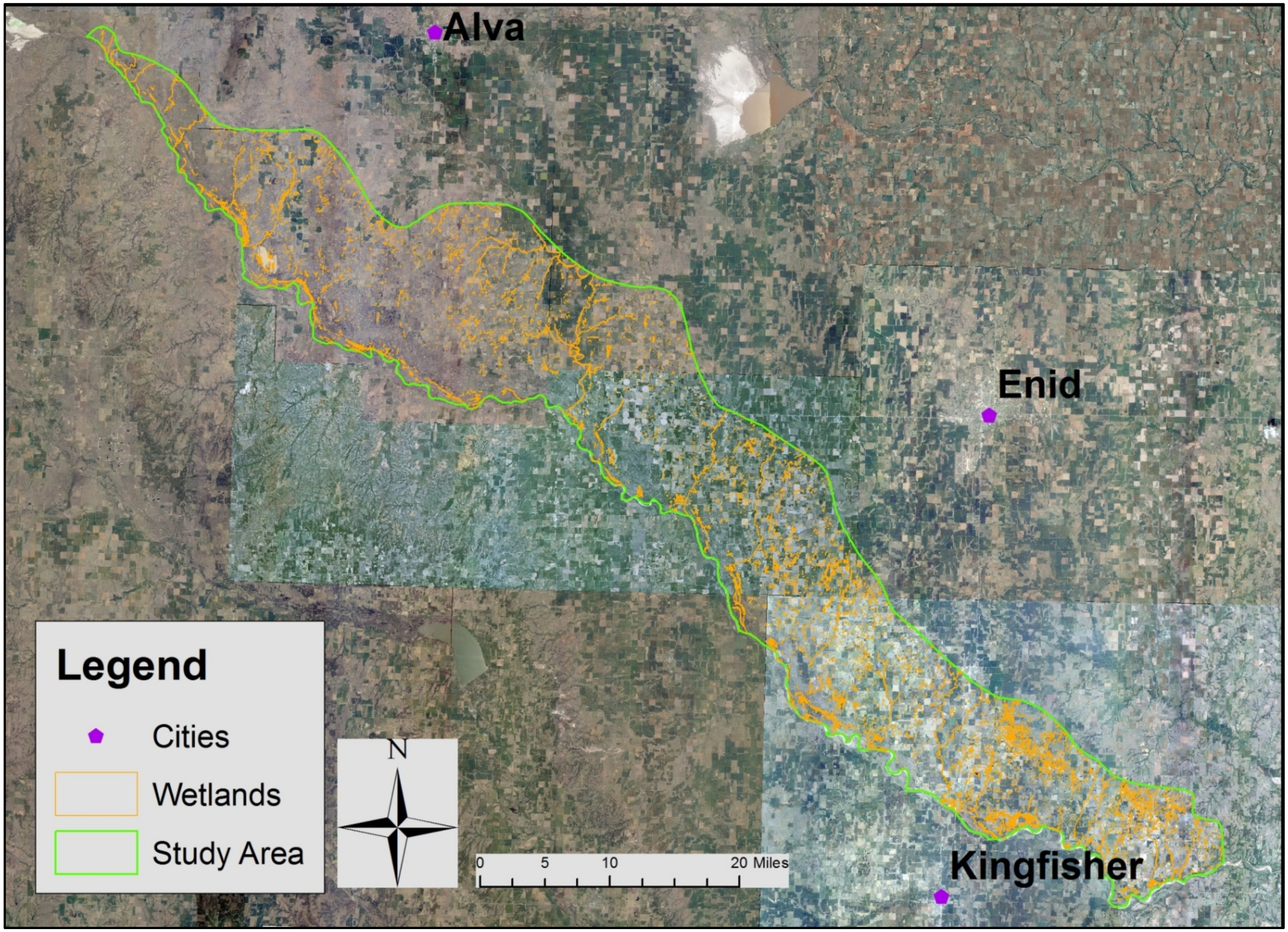


Figure 13. Map of Wetlands in the Pleistocene Sand Dunes Ecoregion of the Cimarron River in Central Oklahoma

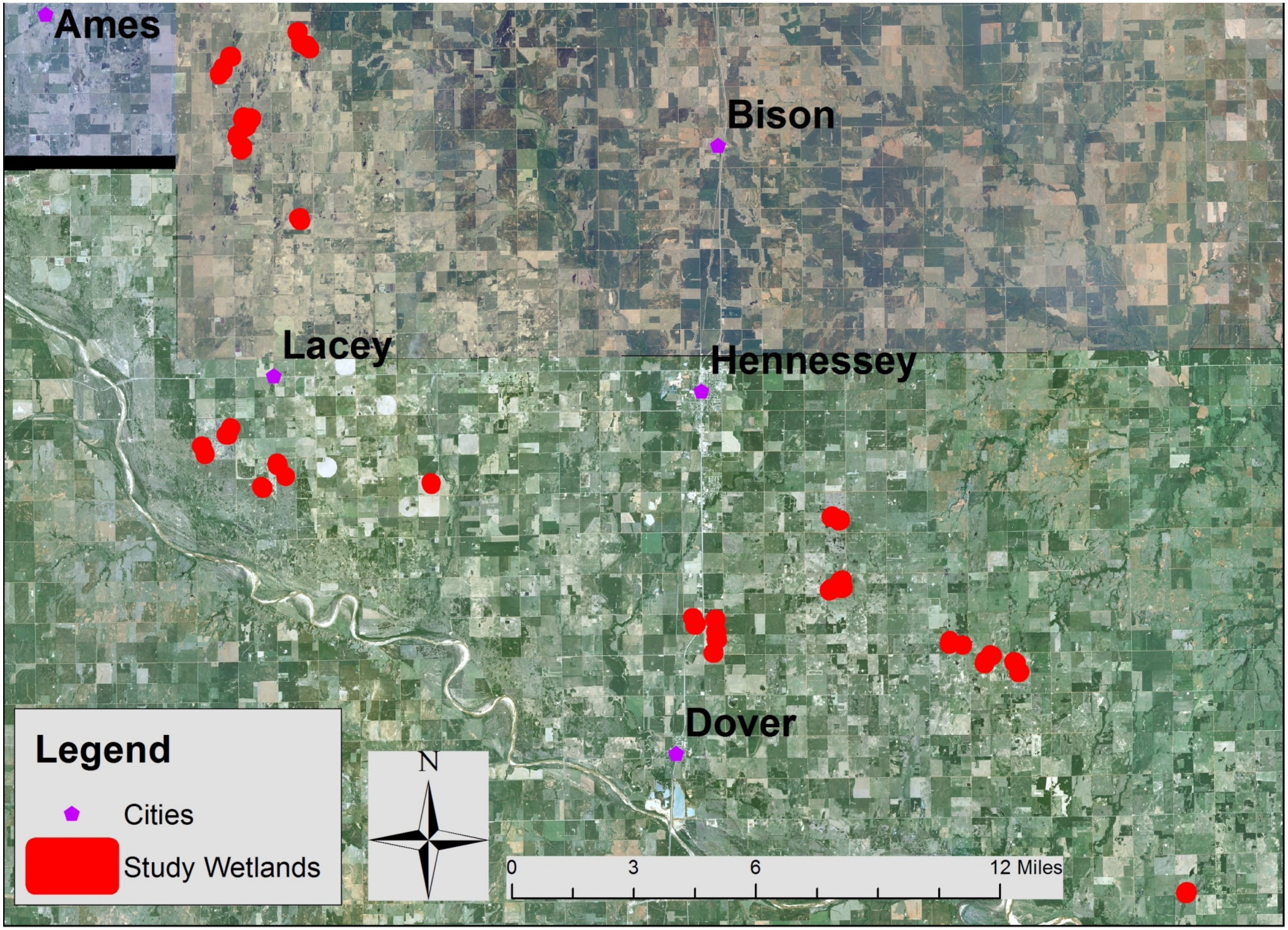


Figure 14. Location of 40 OKRAM Study Sites

(a)

(b)

Figure 15. Example of (a) Reference Interdunal Wetland and (b) Disturbed Interdunal Wetland

(a) Center pivot irrigation

(b) Nutrient inputs from cattle

(c) Rye planted through wetland

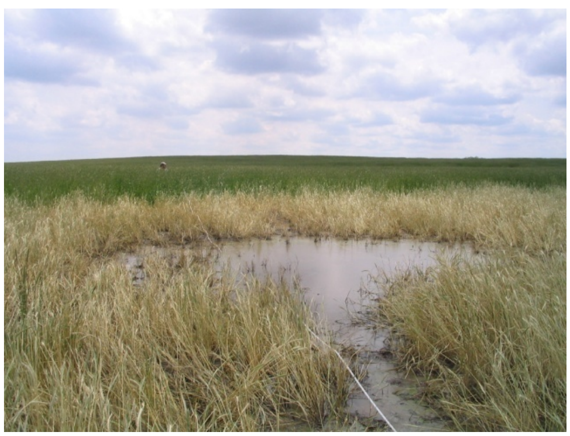


Figure 16. Examples of Common (a) Hydrologic Stressors (b) Water Quality Stressors and (c) Biotic Stressors

Data Collection

In the summer of 2013, at each of the 40 wetlands, we conducted OKRAM, the California Rapid Assessment Method (CRAM), vegetation surveys, invertebrate sampling, and collected soil samples for nutrient analysis. CRAM was applied at each site to determine if additional metrics not utilized in OKRAM could be added to improve the relationship of OKRAM score with vegetation, invertebrate and soil metrics. The point-intercept method was used to collect vegetation community data (Goodall 1952) concurrently with RAM application. Transects were located from the upland edge to the opposite upland edge in a direction that traversed all cover types (Smith and Haukos 2002) and plant species were recorded every meter. Transects were randomly assigned using GIS and at least 2 transects totaling at least 150 m were sampled at each wetland. Transect length varied with wetland width so it was not possible to sample exactly 150 m without stopping mid-transect. In order to correct for this potential sampling bias, 150 m of transect was randomly selected for inclusion in statistical analyses (Smith and Haukos 2002). Macroinvertebrates were collected by sweeps using a D-frame dip net from each habitat type within the wetland in three sampling periods (May through June, July and August). May through June sampling was conducted concurrently with RAM application. Within each habitat, two replicate 1-minute timed samples in 0.5 m^2 quadrats were collected (USEPA 2002). Once collected, each sample was stored in 1-L polyethylene jars and preserved with 70% ethanol. All macroinvertebrates were identified to family and genus, where possible. Physicochemical data were recorded concurrently (pH, DO, temperature, turbidity and conductivity) from each habitat type using a YSI® 600XL probe (YSI Inc., Yellow Springs, Ohio). A composite soil sample, comprised of five 0-10 cm depth subsamples was collected from each wetland concurrently with RAM application. Soil samples were analyzed by the Oklahoma State University Soil, Water and Forage Laboratory for nitrate, ammonium, phosphorous, pH, total soluble salts (TSS), sodium adsorption ratio (SAR), sodium and organic matter. Phosphorous was extracted using the Mehlich III method, while sodium was extracted using a 1:1 soil to water extraction. Both phosphorous and sodium values were determined using inductively coupled plasma mass spectrometry. Nitrate and ammonium were extracted using a 1M KCL extraction and calculated using a flow injection analyzer. Sodium, nitrate, ammonium, phosphorous and TSS are presented as parts per million (ppm) dry weight. Organic matter was calculated using a combustion analyzer and is presented as a percentage of dry weight.

Analysis

The effectiveness of OKRAM in identifying wetland condition was verified by comparing OKRAM attribute and overall score with vegetation, invertebrate, and soil chemistry data using Spearman's non-parametric correlations. Since no Level 3 method has been developed for Oklahoma, we relied on a number of metrics that represent the structure of wetland plant and invertebrate communities. CRAM attributes were also compared to biotic and soil chemistry data using Spearman's correlations to determine how well CRAM works on interdunal depressions. Additionally, correlation analysis was conducted between OKRAM and CRAM scores to determine the degree of similarity between the methods. Furthermore, we conducted Spearman correlations among OKRAM metrics to evaluate metric redundancy (Stein et al. 2009). We also applied Jenks natural breaks classification method to the OKRAM overall score to determine if the *a priori* determined reference sites and disturbed sites grouped together. Jenks natural breaks is a clustering method that optimizes groups by minimizing deviation from the group mean (Jenks

1967). Preliminary condition classes of "good", "fair" and "poor" were determined using the distributions of the least disturbed and high disturbance pools. The 25th percentile of the reference or least disturbed group of wetlands was the threshold for the "good" condition class. The 75th percentile of the high disturbance group was the threshold for the "poor" condition class (Sifneos et al. 2010).

Results and Discussion

The purpose of this study was to determine if OKRAM could be effectively used as a tool to assess wetland condition based on the four criteria of a rapid assessment outlined by Fennessey et al. (2004). In the development phase, OKRAM was structured to provide an overall condition score of the chemical, physical and biological attributes of a wetland based on primary literature reviews and research on other wetland RAMs. Additionally, OKRAM was designed to require metrics to be assessed in the field. As in other developed RAMs, some metrics can be scored in the office using remotely sensed materials but are verified in the field through ground-truthing. Therefore, prior to assessment, we were comfortable that OKRAM met criteria (1) and (3) from Fennessey et al. (2004). Furthermore, during the application of OKRAM to the 40 interdunal wetlands, we have not encountered any evidence to the contrary. Additionally, application of OKRAM did not require more than 4 hours of office work and 4 hours of field work for two staff people to complete the entire assessment. As a result, we are confident that OKRAM is in fact a rapid assessment and meets the time limitations required of Level II assessments.

Verification

We initially anticipated validating OKRAM with additional biotic and soil chemistry data collected from each wetland at the time of assessment. However, because a Level III assessment did not exist in Oklahoma at the commencement of this study, validation was limited to individual plant and invertebrate community metrics and soil chemistry measurements. But, if the measurements taken in OKRAM are truly reflective of wetland condition, we expect trends in the biotic community and chemistry to track predictably with attributes and overall OKRAM scores. **Table 8** presents the results of the correlation analyses between OKRAM scores and biotic community metrics as well as soil chemistry data. Scatter plots displaying the relationships between OKRAM scores and biotic community metrics and soil chemistry data are presented in **Figures 17** and **18**, respectively. Lists of plant species and invertebrate taxa identified during the study can be found in **Appendices C** and **D**, respectively. Both OKRAM biotic attribute score and OKRAM overall score had significant and predictable relationships with the plant community metrics selected, including strong to very strong positive correlations with Shannon diversity, native richness, % perennial and % wetland species (FAC, FACWET and OBL). Additionally, the OKRAM biotic attribute and overall score had strong to moderate negative correlations with % introduced. In other words, as OKRAM biotic attribute and overall scores increased indicating higher quality sites, native richness, diversity, % wetland species, % perennial species also increased, while % introduced species cover decreased.

Table 8. Spearman Correlation Coefficients (*ρ*) Between OKRAM Scores and (a) Plant Metrics, (b) Invertebrate Metrics and (c) Soil Chemistry Metrics.

(a)

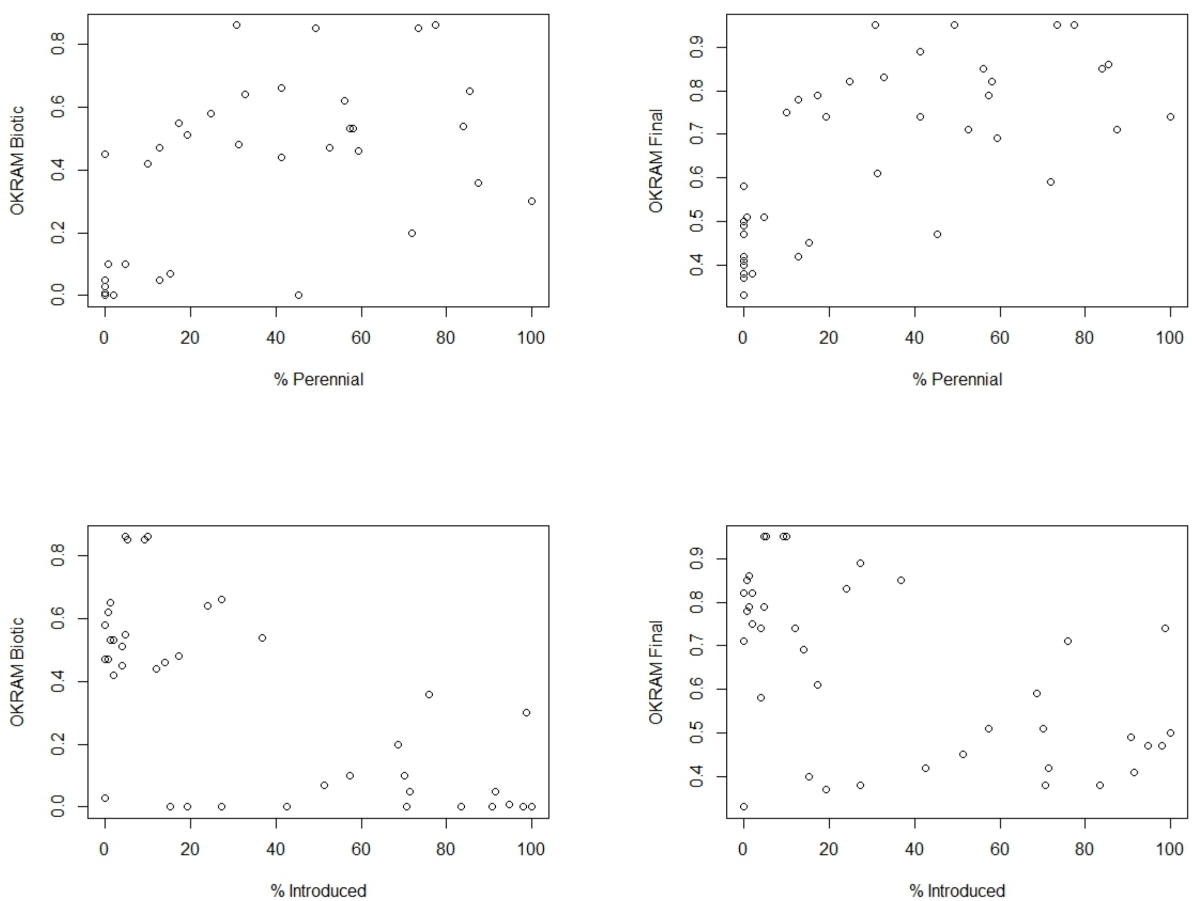
Plant Metric		OKRAM Biotic	OKRAM Final
%Perennial	*ρ*	0.679	0.728
	p-value	<0.001	<0.001
%Open	*ρ*	-0.236	-0.411
	p-value	NS	0.008
%Introduced	*ρ*	-0.601	-0.468
	p-value	<0.001	0.002
%FAC, FACWET and OBL	*ρ*	0.883	0.824
	p-value	<0.001	<0.001
Native Richness	*ρ*	0.887	0.827
	p-value	<0.001	<0.001
Shannon Diversity	*ρ*	0.806	0.715
	p-value	<0.001	<0.001

(b)

Invertebrate Metric		OKRAM Biotic	OKRAM Final
Shannon Diversity: May	*ρ*	0.731	0.209
	p-value	0.02	NS
	n	9	9
% Chironomidae: July	*ρ*	-0.74	-0.651
	p-value	0.008	0.03
	n	11	11
% Odonates: July	*ρ*	-0.67	-0.452
	p-value	0.02	NS
	n	11	11
% Coleoptera: August	*ρ*	0.378	0.467
	p-value	NS	0.02
	n	25	25
% Ephemeroptera: August	*ρ*	0.375	0.464
	p-value	NS	0.02
	n	25	25
% Shredders: August	*ρ*	-0.478	-0.364
	p-value	0.02	NS
	n	25	25

(c)

Soil Metric		OKRAM Water Quality	OKRAM Final
pH	ρ	0.0495	0.00654
	p-value	NS	NS
Nitrate (ppm)	ρ	-0.102	-0.219
	p-value	NS	NS
Ammonium (ppm)	ρ	-0.55	-0.526
	p-value	<0.001	<0.001
Phosphorus (ppm)	ρ	-0.69	-0.662
	p-value	<0.001	<0.001
% Organic Matter	ρ	0.202	0.133
	p-value	NS	NS
Sodium (ppm)	ρ	-0.236	-0.328
	p-value	NS	0.04
Total Soluble Salts	ρ	-0.243	-0.353
	p-value	NS	0.03
Sodium Adsorption Ratio	ρ	-0.419	-0.442
	p-value	<0.001	0.005


OKRAM Biotic
% Perennial
OKRAM Final
% Perennial
OKRAM Biotic
% Introduced
OKRAM Final
% Introduced

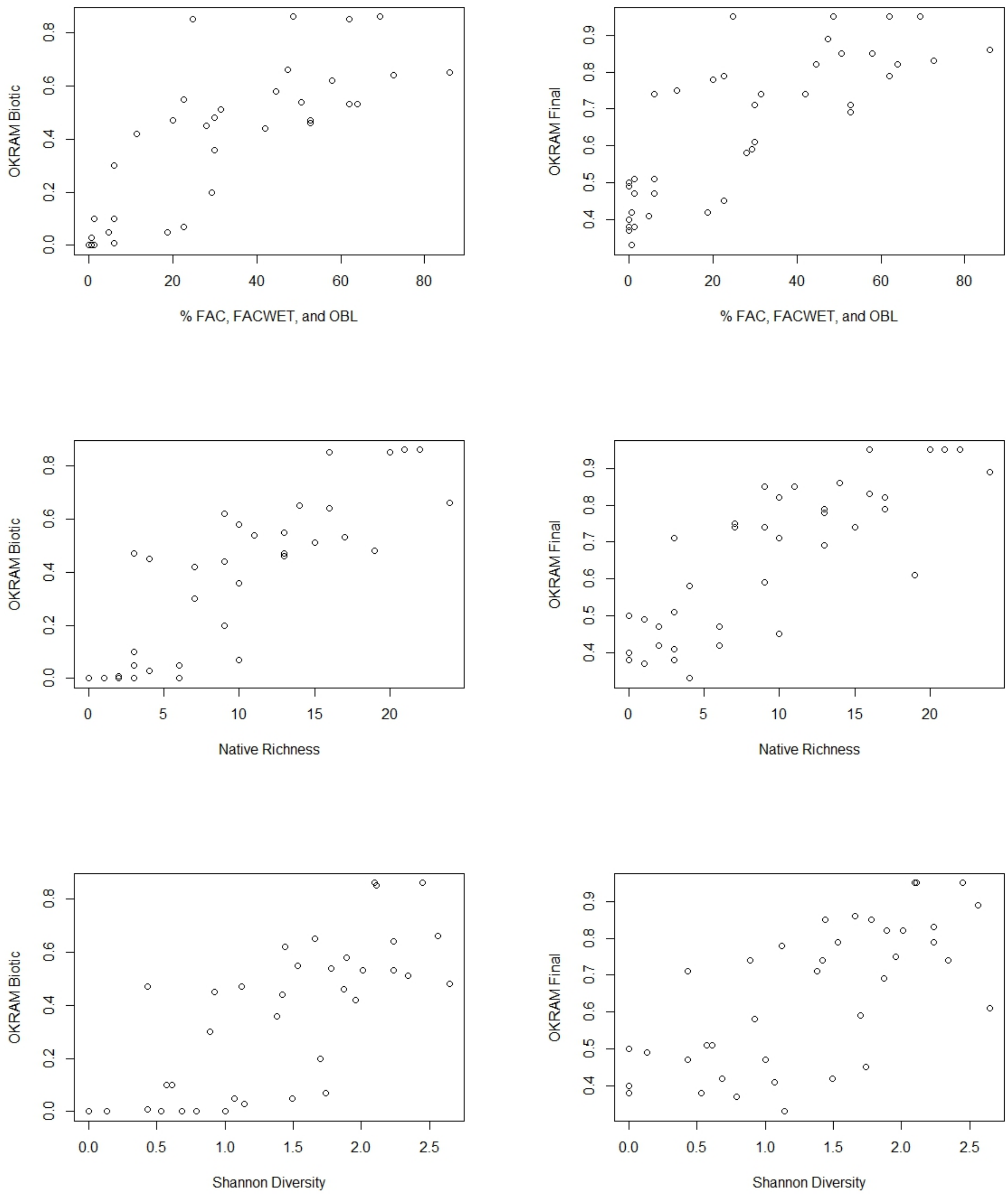


Figure 17. Scatter Plots of OKRAM Scores and Plant Community Metrics

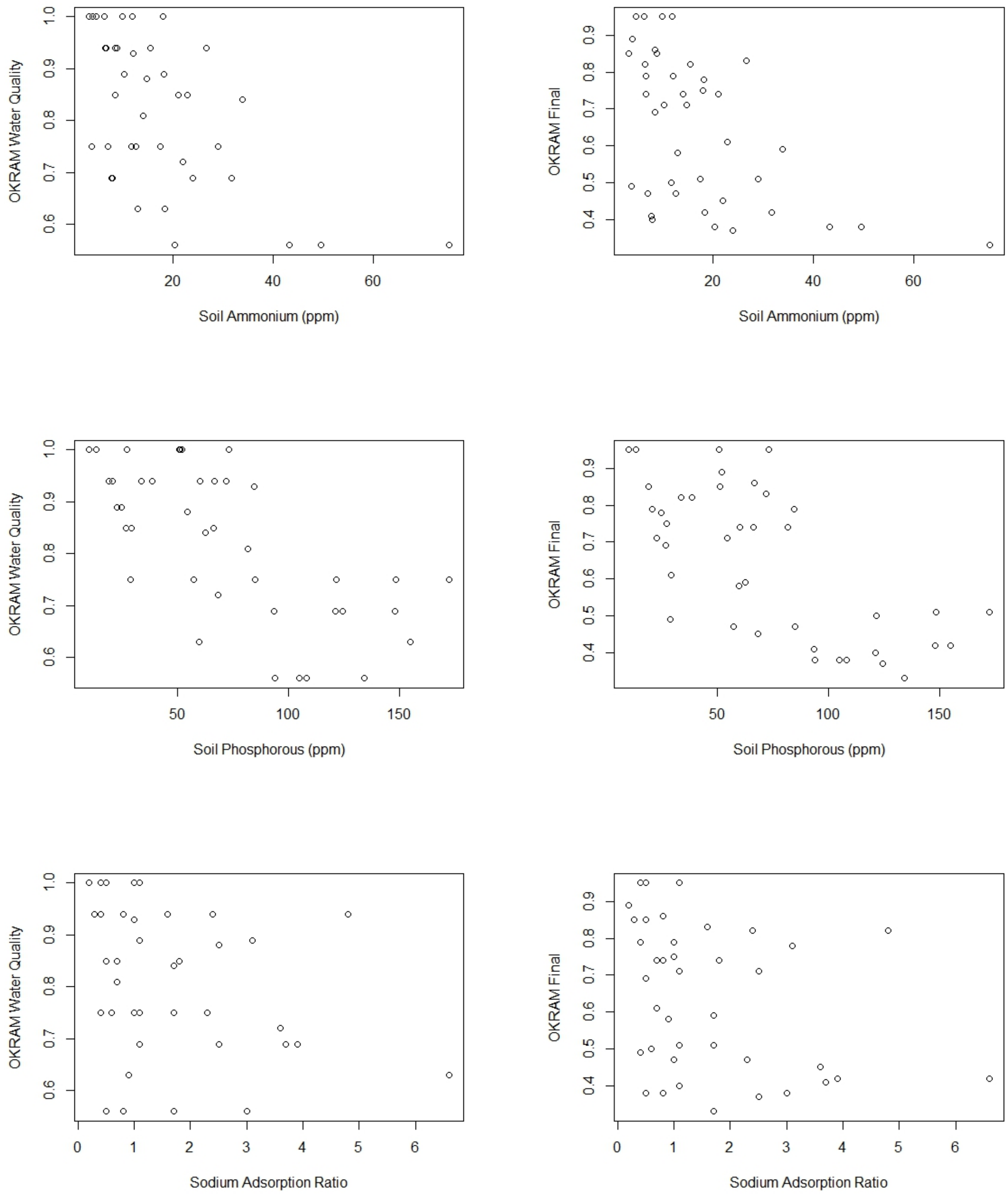


Figure 18. Scatter Plots of OKRAM Scores and Soil Chemistry Metrics

The relationships between OKRAM scores and invertebrate community metrics were less meaningful. Fourteen total metrics were evaluated from three sample periods and included % functional feeding group (filterers, gatherers, shredders and predators), % taxonomic group (Diptera, Chironomidae, Oligochaeta, Ephemeroptera, Coleoptera, Odonata), richness (total, Coleoptera), Shannon diversity and tolerance (Hilsenhoff Biotic Index). Only the significant relationships are presented in **Table 8**. However, interpretation of the results is difficult because only 9 sites in May and 11 sites in July contained adequate water to collect invertebrate samples. Furthermore, the range of condition at the wet sites was primarily from moderate to poor with many of the reference sites being dry during the spring to mid-summer period. In August, we found weak to moderate positive relationships between overall OKRAM score and the % Coleoptera and % Ephemeroptera. There was a weak negative relationship between OKRAM biotic attribute score and % shredders. Other studies of temporary depressional wetlands have found difficulties in relating aquatic invertebrate metrics to disturbance (Meyer 2008, Bird et al. 2013). Naturally variable hydroperiods and seasonal variation have the potential to increase the natural variability in invertebrate community metrics and obscure the influence of anthropogenic alteration. Indeed, anecdotally, several of the sites in this study exhibited dramatic changes in the richness, diversity and composition of the invertebrate community over the course of four months.

OKRAM water quality attribute and overall score displayed moderate to strong negative correlations with soil ammonium and phosphorous. Sites with higher OKRAM water quality scores and overall scores, tended to have less phosphorous and ammonium. These results meet with predictions as sites with lower OKRAM water quality scores should have higher inputs of nutrients.

OKRAM and CRAM

The correlations between OKRAM attribute scores and CRAM attribute scores were all moderate to strong relationships (**Table 9**). This is likely partially the result of the inclusion of metrics in OKRAM that were derived from CRAM metrics (e.g., hydroperiod, hydrologic connectivity, buffer filter, water source). Furthermore, correlations between CRAM attribute scores and overall scores also exhibited some moderate to strong relationships with several plant community metrics and soil chemistry data (**Table 10**), although, in general, they were not as strong as the relationships between OKRAM scores and those data. Some metrics included in CRAM tended to be problematic for the conditions present at the depressional wetlands included in this study. The most recent CRAM depressional guidebook acknowledges that naturally low-complexity seasonal wetlands may score low regardless of degree of disturbance (CWMW 2013). This appears to be reducing the CRAM scores at the best quality interdunal sites available in central Oklahoma, which have relatively low natural topographic complexity, horizontal complexity, structural patch richness, and vegetation structure and diversity (all metrics assessed in CRAM).

Table 9. Spearman Correlation Coefficients (ρ) Between CRAM and OKRAM Scores

		OKRAM Water Quality	OKRAM Hydrologic	OKRAM Biotic	OKRAM Final
CRAM Buffer	ρ	0.735			
	p-value	<0.001			
CRAM Hydrology	ρ		0.637		
	p-value		<0.001		
CRAM Biotic	ρ			0.417	
	p-value			0.007	
CRAM Final	ρ				0.763
	p-value				<0.001

It is important to note that the relationships between CRAM score and plant and soil metrics were likely impacted by the method we used to determine the assessment area for some of the wetlands in agricultural landscapes. CRAM is generally not applied to wetlands that lack wetland vegetation and hydrology at the time of sampling. Wetland vegetation and hydrologic indicators were lacking at many interdunal depressions that were planted to crops prior to assessment. We used prior knowledge about the site, soil attributes, basin morphology and multiple years of recent aerial and satellite imagery to determine wetland boundaries for AA placement. If CRAM guidelines were used, many sites would have been completely omitted from this study. In Oklahoma, only sampling during wet periods that preclude crop planting would be likely to overestimate the quality of wetlands in agricultural landscapes. Because agriculture is one of the dominant stressors to wetlands in Oklahoma, it will be necessary for OKRAM to be applied during periods when wetlands are cropped as well as fallow, so trends in wetland condition can be accurately determined. Therefore, delineation of AA boundaries for ephemeral depressional wetlands in Oklahoma will likely need to include observation of hydric indicators in the soil, observation of basin morphology and review of multiple recent years of aerial and satellite imagery. Appropriate methods to delineate assessment areas will continue to be refined as more data are collected.

Table 10. Spearman Correlation Coefficients (ρ) Between CRAM Scores and (a) Plant Metrics and (b) Soil Chemistry Metrics.

(a)

Vegetation Metrics		CRAM Biotic	CRAM Final
% Perennial	ρ	0.264	0.627
	p-value	NS	<0.001
%Open	ρ	-0.305	-0.309
	p-value	NS	NS
% Introduced	ρ	0.0701	-0.381
	p-value	NS	0.02
%FAC, FACWET and OBL	ρ	0.348	0.771
	p-value	0.03	<0.001
Native Richness	ρ	0.384	0.723
	p-value	0.01	<0.001
Shannon Diversity	ρ	0.397	0.704
	p-value	0.01	<0.001

(b)

Soil Metric		CRAM Buffer	CRAM Final
pH	ρ	0.0126	0.0733
	p-value	NS	NS
Nitrate (ppm)	ρ	-0.17	-0.18
	p-value	NS	NS
Ammonium (ppm)	ρ	-0.297	-0.188
	p-value	NS	NS
Phosphorous (ppm)	ρ	-0.535	-0.453
	p-value	<0.001	0.003
% Organic Matter	ρ	0.139	0.328
	p-value	NS	NS
Sodium (ppm)	ρ	-0.0233	-0.178
	p-value	NS	NS
Total Soluble Salts (ppm)	ρ	-0.157	-0.154
	p-value	NS	NS
Sodium Adsorption Ratio	ρ	-0.143	-0.326
	p-value	NS	0.04

Redundancy

We also assessed the redundancy between metrics of OKRAM to determine the degree to which each metric is measuring a unique component of wetland condition (**Table 11**). Three metrics (buffer filter, water source and biotic connectivity) were highly correlated, indicating that each metric is assessing similar aspects of the anthropogenic impact surrounding a wetland. This is not unexpected, but the degree of correlation between metrics may be inflated due to the purposeful selection of the most pristine and most degraded sites available. The highest quality sites tended to have relatively unaltered adjacent land-use at multiple scales while the opposite was true of the most degraded sites. Furthermore, the relatively small watersheds of these interdunal wetlands created a situation in which the water source metric was addressed at roughly the same scale as the buffer filter metric. The vegetation condition metric was also highly correlated with buffer filter, water source and biotic connectivity. This is likely a result of the most highly disturbed systems having the same stressors within the wetland as the adjacent upland. Many of these sites had been planted to crops prior to assessment. Continued evaluation of metric redundancy will be necessary. OKRAM should be applied to additional randomly selected wetlands to determine to what degree the redundancy is an artifact of the sites selected for this study. If redundancy continues to be prevalent, metrics may need to be rescaled, reworked or combined.

Table 11. Spearman Correlation Matrix for OKRAM Metrics.

		H20 Source	**Hydro. Con.**	**Nutrients**	**Sediment**	**Contam.**	**Buffer Filter**	**Veg.**	**Bio. Con.**
Hydroperiod	ρ	0.607	0.254	0.499	0.288	0.212	0.587	0.553	0.586
	p-value	<0.001	NS	0.001	NS	NS	<0.001	<0.001	<0.001
H_20 Source	ρ		0.143	0.263	0.343	0.192	0.876	0.691	0.926
	p-value		NS	NS	0.03	NS	<0.001	<0.001	<0.001
Hydro. Con.	ρ			0.00483	-0.119	-0.0794	0.176	0.185	0.178
	p-value			NS	NS	NS	NS	NS	NS
Nutrients	ρ				0.566	0.078	0.109	0.0742	0.261
	p-value				<0.001	NS	NS	NS	NS
Sediment	ρ					0.297	0.253	0.259	0.307
	p-value					0.06	NS	NS	NS
Contam.	ρ						0.178	0.217	0.154
	p-value						NS	NS	NS
Buffer Filter	ρ							0.808	0.904
	p-value							<0.001	<0.001
Veg.	ρ								0.708
	p-value								<0.001

Score Distributions

The range of attribute scores and overall scores for the 40 depressional wetlands are presented in histograms in **Figure 19**. The overall OKRAM scores ranged from 0.33 to 0.95, with approximately 30% of the sites falling above 0.8 and 35% below 0.5. This is not unexpected considering that the sites were selected to represent the best and the worst conditions. The distribution of water quality scores was similar to that of the overall scores. One metric in the water quality attribute that proved problematic was the chemical contaminant metric, with only one site exhibiting an indicator of anthropogenic stress. As a result, this metric provided very little information about site condition. Although rare, chemical contaminants can severely alter the condition of a wetland. So while a separate metric may be unwarranted due to the relative rarity of contamination, a way to factor contamination into the water quality attribute score is desirable. One option is to consider nutrients and chemical contaminants jointly in one metric. The biotic condition scores were positively skewed, resulting from the high disturbance sites scoring extremely poorly in both metrics. The highest score in the habitat connectivity metric was 0.76 and 32 sites scored 0.3 or below. The cause of the positively skewed distribution is likely two fold; highly disturbed sites by nature of having little to no intact natural adjacent uplands scored zero, and even the least disturbed sites were rarely connected to natural habitats at the scale assessed. This metric will need to be re-evaluated for the scale at which it is applied and how it is scored. Furthermore, additional biotic metrics may need to be considered to provide a greater range of scores. The hydrologic condition scores were negatively skewed indicating that severe alteration to interdunal wetland hydroperiod is relatively rare. Stein et al. (2009) also found negatively skewed hydrology attributes for riverine and estuarine wetlands in California. Moving forward, OKRAM will need to be applied to a larger number of randomly identified wetlands to determine if the skewed and bi-modal distributions for metrics are a function of selecting the best and worst sites available. Additionally, the metrics may need to be adjusted to provide greater resolution among sites within the least disturbed pool and the highest disturbed pool. Wetlands within these groupings tended to score similarly for a number of metrics. It may be that these wetlands truly exist in similar relative condition, or there may be differences not yet accounted for in OKRAM.

The Jenks optimization located breaks in OKRAM score at 0.75 and 0.51. The analysis placed 14 sites in the highest category, of which 13 were from the *a priori* reference sites and one was a moderate disturbance site. There were 14 sites in the lowest category, all of which were from the *a priori* high disturbance sites. The middle category included 2 reference sites, 8 moderate disturbance sites and 2 high disturbance sites. OKRAM appears to be scoring wetlands close to expectations; sites with little anthropogenic stress cluster towards the top of the range and sites with high anthropogenic stress cluster towards the low range. The thresholds between preliminary condition classes based on percentiles were similar to the natural breaks identified with Jenks optimization, but slightly more conservative. The cut-off for the “good” condition class was 0.81 and 0.48 for “poor” condition class. Using these thresholds, 11 wetlands were placed in the “good condition” class, all of which were in the *a priori* least disturbed pool and 12 wetlands were placed in the “poor condition” class, all of which were in the *a priori* high disturbance pool. As metrics will continue to be adjusted and rescored, these thresholds are likely to change but they currently provide a foundation for using OKRAM to assign condition.

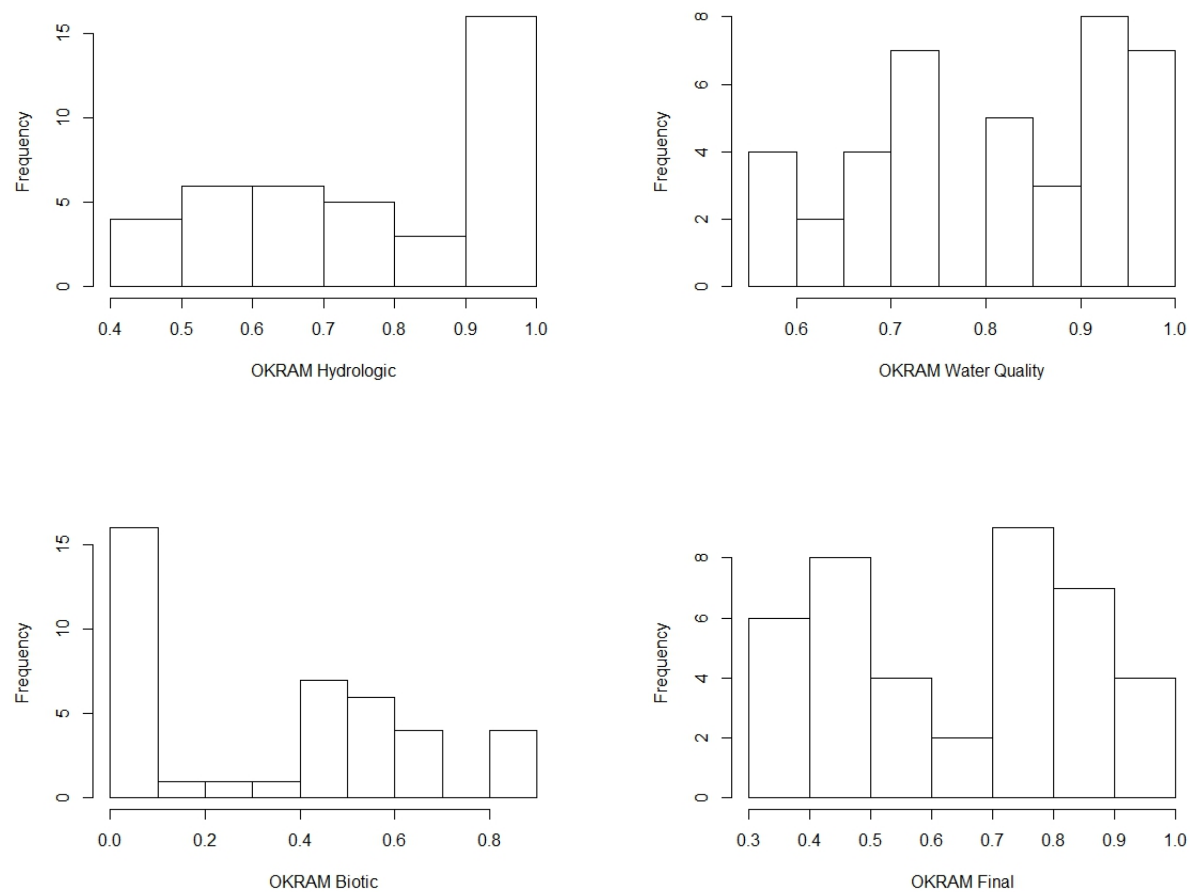


Figure 19. Histograms of OKRAM Attributes and Final Score

Conclusions

In the first evaluation of OKRAM in the field, it appears to meet all the requirements of a Level II rapid assessment. It (1) aggregates 9 metrics into a single condition score that reflects the physical, chemical and biological attributes present, (2) requires metrics to be collected or verified on-site, (3) is rapid, requiring less than one day to complete, and (4) can be verified with additional plant community and soil chemistry data. There are currently still some issues with metric redundancy and the distribution of metric, attribute and overall scores. The next step for OKRAM development will be the application of the method to a large number of randomly selected wetlands to more accurately calculate the distributions of metrics and correlation between metrics. This will provide a representative dataset to inform future rescaling, reworking, removal or addition of metrics as well as refining the condition class thresholds.

Plant community metrics in this study correlated well with the OKRAM scores. Therefore, vegetation surveys should be conducted along with OKRAM assessments to continue to calibrate and validate the method. Concurrently with this project, work has been done to advance a Floristic Quality Index for wetlands in Oklahoma (Ewing and Hoagland 2012, Bried et al. *In press*). In addition, to calculating plant community metrics, it may be possible to validate OKRAM with an actual Level 3 assessment during the next round of sampling. Furthermore, validating OKRAM with a Level 3 assessment would allow us to determine how well the two methods agree in assigning sites to condition classes, and aid in the refinement of both methods.

The draft OKRAM is still under development and will continue to be applied to, and calibrated for additional wetland types across the varied ecoregions of Oklahoma. As expected, the first systematic deployment of OKRAM identified areas that require additional work, including metric redundancy and scaling. This may require combining, moving or reorganizing existing metrics. For example the limited score distribution of the Chemical Contaminant metric may require that it is combined with other metrics, or scored in a different fashion. Additionally, due to redundancy of several of the landscape metrics, combination or removal may be necessary. Improvements in metrics can further be achieved through adding additional stress indicators and evaluating if indicators are organized into the appropriate stress severity category. Furthermore, metrics that are currently measured solely on the areal extent of stress indicators present (i.e. Water Source and Vegetation Condition) may be improved through the application of stress severity scores as in other metrics in OKRAM (i.e. Hydroperiod and Sediment). Overall metric aggregation may further be refined to place emphasis on the metrics most important in defining wetland condition. Moving forward, it may also be necessary to score individual metrics using discrete categories (e.g. A, B, C, D) rather than continuous scaling (e.g. 0-100). Scoring options will continue to be evaluated to determine how to most accurately and consistently assess condition at Oklahoma wetlands.

Metric inclusion and scaling, indicator inclusion and severity ratings, as well as metric scoring and aggregation will continue to be refined. Refinement of OKRAM will be achieved through additional deployment and calibration at wetlands across the state, dialogue with partners, and continued literature review. Metrics, indicators and scoring may also need to be adjusted to ensure that the condition of each wetland class is accurately reflected in the condition score calculated by OKRAM. Currently OKRAM is being evaluated at Lacustrine Fringe and Riverine wetlands. To date, OKRAM has only been applied at small depressional wetlands. As larger wetlands are assessed, the application of the Assessment Area will need to be evaluated, particularly, to determine the number and organization of multiple Assessment Areas.

In addition to being scientifically sound and providing an accurate reflection of wetland condition, an assessment should be clear and repeatable. To that end, it will be necessary to develop extensive user guidance material, to ensure consistent usage of OKRAM in the field. Development of guidance material will be considered a priority moving forward as the methodology is refined. Guidance will include background material on why metrics are included with justification from the primary literature and clear instructions on how to score each metric. More detailed descriptions of each stress indicator along with pictures will aid in the accurate identification of stressors. Currently, project staff is evaluating the repeatability of OKRAM at wetlands across Oklahoma. At lacustrine and riverine wetlands, multiple users are applying OKRAM independently at the same wetland at the same time to determine if indicators can be identified and metrics scored consistently.

OKRAM appears to provide a measure of wetland condition that is verifiable with plant community and soil data. However, in order to provide a robust tool for integration into Oklahoma's wetland program, the method will continue to be tested and refined.

Wetland Mapping

Introduction

Wetland mapping is an integral component of wetland monitoring and management and can greatly aid in the application of Level 2 assessments like OKRAM by aiding in the determination of the distribution and abundance of wetland classes. This knowledge is foundational when developing management strategies to ensure that the entirety of the wetland resource across the state is adequately monitored. Additionally, maps of the distribution and types of wetlands can help prioritize wetland restoration, identify unique wetlands in need of protection, track wetland loss and gain and facilitate the random selection of wetlands for ambient monitoring programs. The Cimarron River Pleistocene Sand Dunes ecoregion (CPSD) (the location of the initial field validation of OKRAM outlined in the previous section) has a high abundance and density of depressional wetlands that have formed in the valleys of dune fields on old river terraces. However, these wetlands are poorly represented in the National Wetlands Inventory (NWI). The interdunal wetlands can have short hydroperiods, and can be dry for entire years as a result of unpredictable rainfall in the semi-arid plains. As a result, NWI mapping conducted in a particularly dry period has underrepresented the resource. The goal for this project was to develop new NWI maps for the CPSD to more accurately represent the wetland resource. With more accurate maps, we can improve the monitoring and management of wetlands in the region.

Methods

The study area is a close approximation of the Omernik Pleistocene Sand Dunes ecoregion (Omernik 1987) adjacent to the Cimarron River in central Oklahoma but was modified to account for the current location of the river bank. The first terrace on the northern side of the Cimarron River was used as the southern boundary of the mapping area. The terrace was mapped by utilizing National Agricultural Imagery Program (NAIP) aerial imagery and United States Geologic Survey (USGS) digital topographic maps. Figure 10 displays the study area for mapping efforts. Within the study area, wetland maps were digitized directly into ARC Desktop (ESRI, Redlands, CA) following federal mapping standards (FGDC 2009). NAIP imagery from 2008 was used as the base image for all mapping efforts. NAIP imagery satisfies the 1 meter resolution requirements of the federal standard (FGDC 2009) and the 2008 imagery was chosen because it represents a wet year in this region. Although more recent NAIP imagery exists, wet year imagery was necessary to identify interdunal depressional wetlands with temporary hydroperiods. Additionally, 2008 imagery was supplemented with imagery from 2003, 2005, 2010 and 2013 to assist with identification of wetland locations. USGS digital topographic maps were also utilized to identify topographic basins. As maps were digitized, project staff classified each polygon according to Cowardin classification (Cowardin et al. 1979). All mapping staff completed the on-line "Wetland Mapping Training" module provided by the United States Fish and Wildlife Service (USFWS) at http://www.fws.gov/habitatconservation/nwi/wetlands_mapping_training/.

Once draft maps were completed, both manual and automated quality control (QC) protocols were conducted. Manual QC consisted of systematically reviewing all mapped areas within the study region to improve consistency of digitization and polygon attribution. Automated QC was completed using the USFWS Wetlands Data Verification Toolset (Bergeson 2011). The Data Verification Toolset interfaces directly with ARC Desktop (ESRI, Redlands, CA) and checks polygons for a number of topological and attribution errors. The final quality controlled dataset is housed in a geodatabase following the NWI schema and includes a feature class of wetland polygons and a feature class of the study region. Metadata associated with each of those layers from the federal NWI layer has been updated to reflect the activities performed during this project. The geodatabase will be submitted to the USFWS for review and potential inclusion in the federal NWI dataset.

Results

The final map layer includes 10,848 polygons (Figure 20). Of those polygons, approximately 8,539 are depressional wetlands. The approximate number of depressional wetlands was calculated by querying the total dataset to remove ponds (h and x attribution), lakes (L attribution) and rivers (R attribution). However, this number may include some wetlands associated with river systems and as a result, may be an overestimation. Most of the depressional wetlands are relatively small with more than 6,300 less than one acre in size and more than 8,100 less than 5 acres in size. The original NWI dataset for the region mapped 5,088 wetland polygons. Approximately 3,377 of those polygons are depressional wetlands based on the same queries. Of the 3,377 polygons, more than 2,100 are less than one acre and more than 3,000 are less than 5 acres. The discrepancy between layers appears to be largely based on aggregations of wetlands within the study region that were missed during the initial NWI mapping effort. These interdunal wetlands are largely invisible from aerial photography during dry periods and were likely not included in the NWI layer because of the completion of mapping during a dry period (early 1980s). Figure 20 shows an area of high wetland density where there are large differences between the original NWI map and the updated map.

Conclusion

The updated NWI map for the CPSD should be a valuable resource for monitoring and management of wetlands in an area of high wetland density. Currently, wetland maps are being updated for other areas of interdunal wetlands adjacent to the North Canadian River, Salt Fork of the Arkansas River and Kingfisher Creek. Pleistocene Sand Dune ecoregions represent some of the areas of greatest wetland density in Oklahoma. More accurate map resources will improve our understanding of wetland distribution, which can be utilized in ambient monitoring, as well as tracking wetland loss and gain.

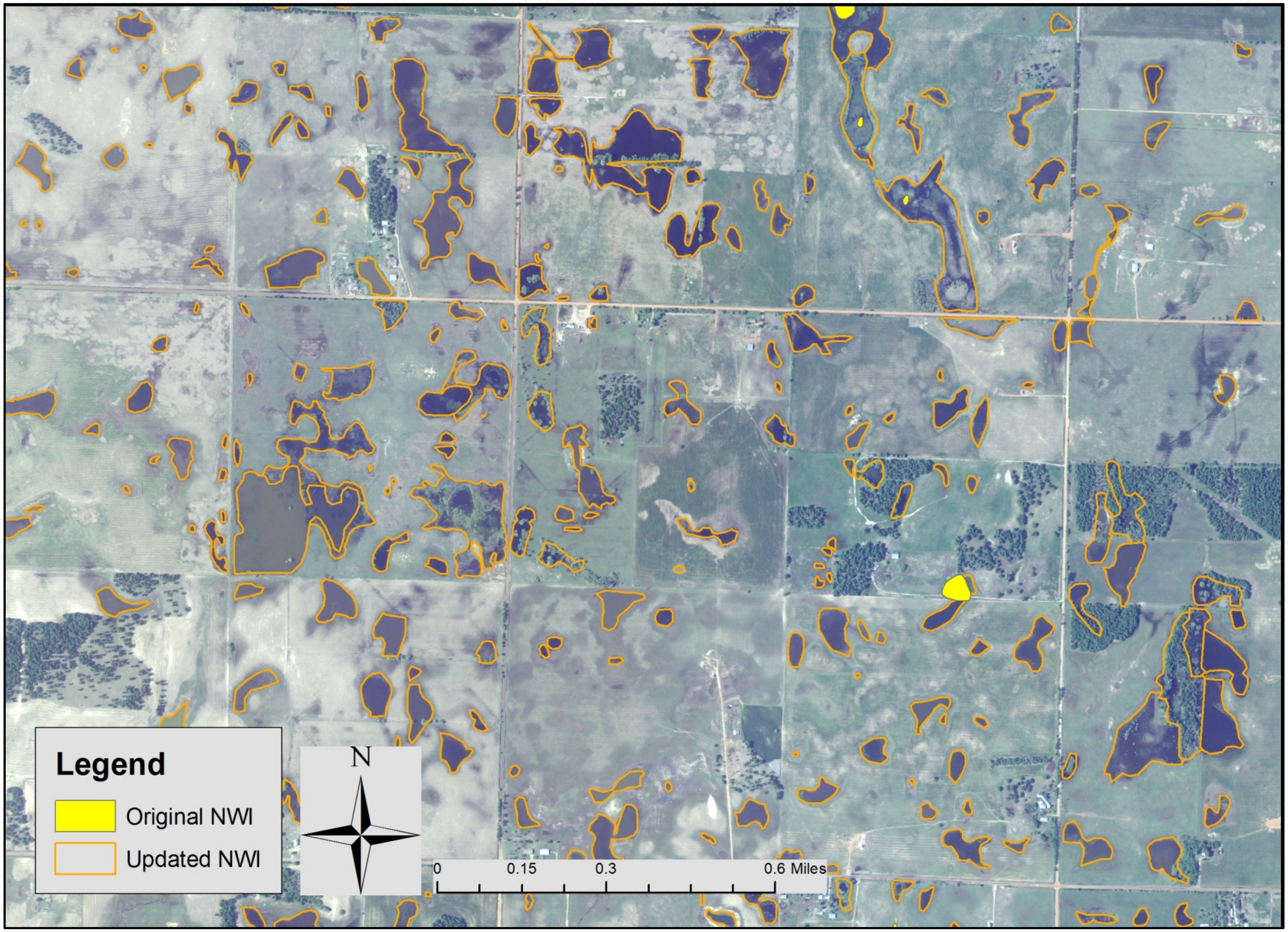


Figure 20. Area of High Discrepancy between Original NWI and Updated NWI in Kingfisher County, OK

Project Summary

Developing tools for the monitoring and management of wetland ecosystems is a priority in Oklahoma (OCC 2013). To that end, we undertook a three phased approach to evaluate the extent of oxbow and interdunal wetlands across the state, as well as to test, refine and develop appropriate assessment tools. This report represents the culmination of this project and an important step towards the development of scientifically tested monitoring tools. An important early step in the development of monitoring strategies is gaining an understanding of the distribution of types of wetland resources in the state. To that end a wetland map for oxbows was created statewide in the Phase I project. Additionally, national wetland inventory (NWI) maps were updated for the Cimarron Pleistocene Sand Dune (CPSD) ecoregion, an area of temporary depressional wetlands in high density.

Prior to developing new assessment methods, we wanted to determine how well wetlands could be assessed in the current monitoring framework for surface waters in Oklahoma. Oklahoma has the Use Support Assessment Protocols (OAC 785:46-15) of the Oklahoma Water Quality Standards (OWQS) as the standardized method of assessing whether water quality beneficial uses are impaired. USAP applies to all waters in the state, including oxbows and other wetlands. Data collected from the Phase II oxbow project were processed though USAP for impairment conclusion and then compared against concurrent Level 1 and Level 2 measures. Comparisons were counter intuitive as oxbows deemed impaired for fish and wildlife due to low dissolved oxygen, or pH graded out with higher macroinvertebrate scores. These results indicate a high possibility of concluding systems are impaired for water quality, when they actually exist under expected conditions. The consequence of this is the addition of otherwise healthy oxbows to the 303d impaired waters list. The apparent incongruities stand as a clear statement that current USAP is not an appropriate assessment method for oxbow wetlands. This also questions the validity of applying USAP to other wetland systems in Oklahoma. These results lend credence to the current effort to define beneficial uses for wetlands in a context other than how they have been used in the past. In an ongoing effort to develop water quality standards for wetlands, the state of Oklahoma, through the Oklahoma Wetlands Technical Workgroup has developed beneficial uses for wetland waterbodies that recognize and incorporate the natural functions of wetlands. Wetland Habitat & Biota, Flood Protection and Erosion Control, and Water Quality Enhancement have been proposed as “new” beneficial uses for wetland waterbodies. Level 1 assessment provides one means of assessing wetland condition, rapidly from the office using geographic information systems. We evaluated several Level 1 scoring methods and found that by combining multiple measures of landscape condition, we could predict both the water quality and biotic condition of oxbows. This method should prove useful for oxbows influenced primarily by overland flow events. Limited sample size and land-use distributions suggest further evaluation to discern differences between the use of a standardized circular buffer and delineated watershed based buffer is worthwhile. As knowledge of stressors and responses are gained and applied to additional wetlands, Level 1 assessment tools will continue to be revised and refined.

In addition to desktop tools, field based assessments are an essential part of wetland monitoring. OKRAM’s first field evaluation appears to meet all the requirements of a Level 2 rapid assessment.

It (1) aggregates nine metrics into a single condition score that reflects the physical, chemical and biological attributes present, (2) requires metrics to be collected or verified on-site, (3) is rapid, requiring less than one day to complete, and (4) can be verified with additional plant community and soil chemistry data. Plant community metrics in this study correlated well with the OKRAM scores. Therefore, vegetation surveys should be conducted along with OKRAM assessments to continue to calibrate and validate the method. The concurrent development of a plant based floristic quality index (FQI) will likely aid in the continued development of OKRAM moving forward, as the method is applied to and calibrated for additional wetlands. The draft OKRAM is still under development and will continue to be applied to, and calibrated for additional wetland types across the varied ecoregions of Oklahoma. As expected, the first systematic deployment of OKRAM identified areas that require additional work, including metric redundancy and scaling. Moving forward, this may require adjusting metric inclusion and scaling, indicator inclusion and severity ratings, as well as metric scoring and aggregation. Currently we are evaluating repeatability of OKRAM by assessing the same wetland with multiple users at the same time to determine if metrics can be scored consistently. Future goals include the development of a detailed guidebook for OKRAM

This project represents an important step in the continued development of multiple assessment tools and monitoring strategies for Oklahoma.

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Appendix A: Refined Level 1 Assessment Method

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Delineation Standard Operating Procedures (SOP)

To perform watershed delineations, it will be necessary to have access to ArcMap software and a Spatial Analyst license. It may also be helpful to create a consistent naming system for the delineation process due to the number of steps delineation and further assessments can require, particularly if delineating many oxbows. For this instruction, we will name each layer according to its function, along with a suffix of its numerical identification (e.g. "mask_123" for the layer representing the mask of oxbow 123)

Additionally, to perform delineations an elevation dataset, a stream network layer, aerial imagery, and a layer containing points of waterbodies in question will also be needed. For this project, the following were used:

- 10 meter elevation layer from USGS (dem10NED)
- Oklahoma stream network layer (OWRB_Streams)
- 1 meter NAIP Aerial Imagery (Oklahoma_2013_1m_NC)
- List of candidate oxbows (Ox_Master_List)

Using the DEM and Stream network as guidance, create a mask around the selected oxbow point to include:

I. Start by activating the DEM, Stream network, and Oxbow layers. Zoom to the selected oxbow at a spatial scale where its location in relation to its parent stream can clearly be identified and also where neighboring streams can be visually identified.

II. Create and edit a polygon shape file (mask_123) to include all of the area that could potentially drain into the oxbow point. This and the following step are done to minimize computation time of the ArcHydro tools.

III. Perform a raster clip (*ArcToolbox, Data Management, Raster, Raster Processing, Clip)*. The input raster will be the DEM layer, output extent is the mask, and the output will be the raster elevation of the mask (clip_123). Check the box stating "Use Input Features for Clipping Geometry".

ArcHydro tool will be needed for the rest of the steps in this process; make sure Spatial Analyst extension is activated, and the ArcHydro toolbar turned on.

IV. Using the ArcHydro toolbar, navigate to *Terrain Preprocessing*, *DEM Manipulation*, *Fill Sinks*. The input DEM will be the clip file (clip_123) and the output, *Hydro DEM*, will be Fil_123. This step removes all sinks from the DEM layer so that all flow will be continuous.

V. Next, select *Terrain Preprocessing, Flow Direction*. The *Hydro DEM* input file will be the fill sinks layer (Fil_123), and the *Flow Direction Grid* output will be Fdr_123. This step uses the elevation layer to determine which direction water would flow across each cell of the layer.

VI. Finally, select *Terrain Preprocessing, Flow Accumulation*. The *Flow Direction Grid* input will be Fdr_123, and the *Flow Accumulation Grid* output will be Fac_123. This step uses the outcome of the flow direction grid to find all paths that water would take across the landscape.

Once these commands are complete, turn on the Fac layer. This should be represented by a white background and a blue stream network, with darker blue indicating more flow. It will probably not match the stream network layer perfectly, but it should be close.

VII. To delineate the watershed, use the flow accumulation network to pick a point where the oxbow drains to. The point needs to be on a visible blue line of the Fac layer. Use the NAIP Aerial imagery as a guide as to where to place this point. Create a point shape file and place it on the flow accumulation grid to represent where the most downstream point of the wetland is, so that all flow to reach the wetland will be accounted for. We This point is called "pour_123".

If the flow accumulation grid does not have any visible lines to place a point on, indicating a small drainage area, OR the flow accumulation seems to not represent what is happening on the landscape at all (probably indicative of pretty flat floodplains), skip steps VIII-IX and move to step X.

VIII. In the ArcToolbox, navigate to *Spatial Analyst Tools, Hydrology, Snap Pour Point*. The input file is the pour point (pour_123), and the input accumulation raster is the fac file (fac_123). This step converts the point file you created into a raster layer on the fac grid (snap_123).

IX. Navigate to the *Watershed* tool in the same toolbox as the previous step. The input flow direction raster for this step is the fdr file (fdr_123), and the input feature pour point data is the snap layer (snap_123). This step creates the watershed (shed_123). If the raster created clearly does not represent the watershed, re-try steps VII-IX, or move on to step X.

If there does not seem to be a clear way to pick a point on the flow accumulation grid to represent the oxbow point, complete the following steps:

X. On the ArcHydro toolbar, navigate to *Terrain Preprocessing, Stream Definition.* The input will be the flow accumulation grid (Fac_123). Change the number of cells box to some value between 10-100. The smaller the number of cells entered, the finer resolution this layer will have. The layer created (str_123) will be a finer resolution stream network than the fac layer.

XI. In the same steps used to create the mask, create a polygon to represent this manually delineated watershed (mshed_123). Be sure to include all of the oxbow itself in the shed, and any of the stream definition that drains to this system.

Good resource for steps IV-IX:
http://courses.washington.edu/gis250/lessons/hydrology/exercise/#pour

Land Use Feature Scoring

Adjustments to the original Phase I condition assessment includes altering land-use coefficients and adding population, roads, and 303(d) listings as adverse influences to condition. The area of each NLCD land-use class for each watershed or buffer was calculated and weighted for potential effect on condition, with a higher value indicating lack of disturbance and a lower value indicating an adverse impact to quality from that land-use. A summation of the area in each land-use, multiplied by its coefficient, makes up the land-use score. Population density was calculated by using U.S. Census data to account for total persons within a 2 km buffer of the catchment divided by the area in square meters. These values were divided into classes and scored, with lower densities receiving higher scores. Road density values were found by dividing the length of total roads in the catchment by area in the catchment, and also were divided into classes and scored. The score for 303(d) impairments was simply a presence/absence score. If a water quality impairment was listed within 2 km upstream of the site, a 0 was entered into the equation, and if no impairments were listed, a 1 was entered. The updated equation, followed by supporting tables:

LDWT = 0.5*(a) + 0.2*(b) + 0.2*(c) + 0.1*(d)

a = Land-use Score = ∑ Land-use Coefficient *Area per Land-use

b = Road Density Score

c = Population Density Score

d = 303(d) Score

Landscape Scoring:

Parameter	Information Provided	Landscape Coefficient
Land-use (score 0-1, drainage)	Contribution of developed, cultivated, bare and buffer land cover in drainage	.50
Road Density (m/km^2, drainage)	Human access/use of drainage area as a thoroughfare Fragmentation/Connectivity	.20
Population Density (people/km^2 in drainage + 2 km buffer)	Number of humans likely to access/injure oxbow and/or drainage	.20
303(d) (presence/absence, 2 km upstream)	Impairment of water contributing to oxbow on various/periodic basis	.10

Population Density people/km^2 in drainage plus 2 km buffer	Population Density Coefficient
0	1
0<x<10	.8
10<x<20	.6
20<x<30	.4
30<x<40	.2
≥50	0

Road Density m/km^2 in delineated drainage	Road Density Coefficient
0	1
0<x<500	.75
500<x<1500	.5
1500<x<2500	.25
≥2500	0

NLCD Class #	2011 NLCD Class	Definition	Original Land-use Coefficient	Revised Land-use Coefficient
11	Water	areas of open water, generally with less than 25% cover of vegetation or soil.	1	1
21	Developed, Open Space	areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	0.6	0.3
22	Developed, Low Intensity	areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.	0.4	0.2
23	Developed, Medium Intensity	areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.	0.2	0.1
24	Developed, High Intensity	highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.	0	0
31	Barren land, Rock/Sand/ Clay	areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.	0.4	0.4
41	Deciduous Forest	areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.	1	1
42	Evergreen Forest	areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.	1	1

43	Mixed Forest	areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.	1	1
52	*Scrub/Shrub*	areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.	1	1
71	Grasslands	areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.	0.8	0.8
81	Pasture/Hay	areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.	0.5	0.4
82	Cultivated Crops	areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.	0.2	0.2
90	Woody Wetlands	areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	1	1
95	Emergent Herbaceous Wetlands	areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	1	1

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Appendix B: Draft Oklahoma Rapid Assessment Method

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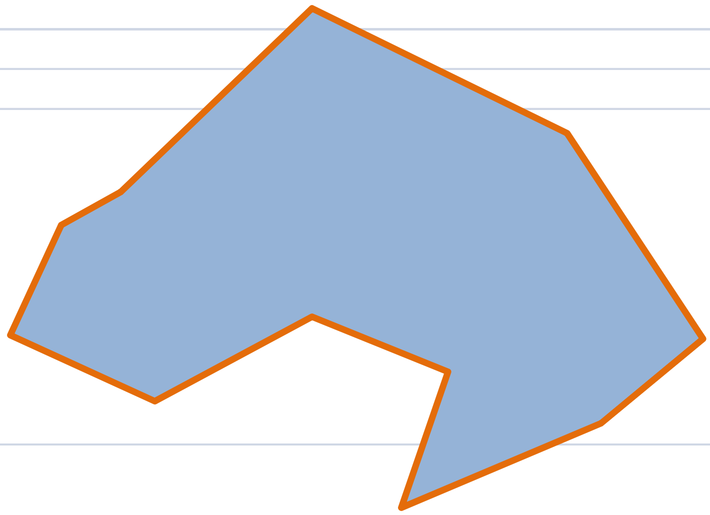
The Oklahoma Rapid Assessment Method (OKRAM) for Wetlands	
IN THE OFFICE	
Step 1: Assemble all the materials necessary to complete the assessment. Necessary geographic information systems (GIS) frame materials include: topographic quadrangles, aerial photographs, national wetlands inventory (NWI) maps, and land-use datasets. Additional relevant GIS data may be helpful and include soil maps, vegetation maps, geologic maps, hydrologic feature maps etc.	
Step 2: Classify the wetland into the appropriate Hydrogeomorphic (HGM) subclass using the included dichotomous key (Worksheet II)	
Step 3: Determine the boundary of the Assessment Area (AA). Ideally the assessment area will be 1 hectare. However, any AA size ranging from 0.1 to 1 hectares is acceptable. Delineate the boundary of the wetland. This can be completed using NWI maps or through visual assessment of aerial photography. The wetland boundary should only include one HGM subclass. If the entire wetland boundary is less than 1 hectare and greater than 0.1 hectare, conduct the assessment on the entire wetland. If the wetland is greater than 1 hectare randomly assign a point along the wetland boundary and delineate a 1 hectare AA within the wetland that contains that point. See worksheet III for assessment area diagrams.	
Step 4: Complete the site description sheet, and metrics: 1b. Water Source, 2d. Buffer Filter, and 3b. Habitat Connectivity using GIS frame materials.	
IN THE FIELD	
Step 5. Ensure that the AA boundaries are appropriate, within the wetland and within one HGM subclass. Adjust the boundaries as necessary so AA is entirely contained within one HGM subclass and as close to 1 hectare as possible.	
Step 6. Complete all OKRAM metric sheets. Check the accuracy of the metrics completed in the office and make changes to scores as necessary.	
Step 7. Calculate the final site score by combining all the metrics on Worksheet 4: Condition Score. Attribute scores are calculated for hydrology, water quality and biota. These attribute scores are then combined to produce a maximum condition score of 1.	
Step 8. In worksheet 5 record where you believe the assessment was inaccurate and how the assessment could be improved for future users.	
Step 9. Enter hard copies of data into an electronic format in excel and GIS. Archive hard copies.	

Hydrogeomorphic Wetland Subclassification Dichotomous Key

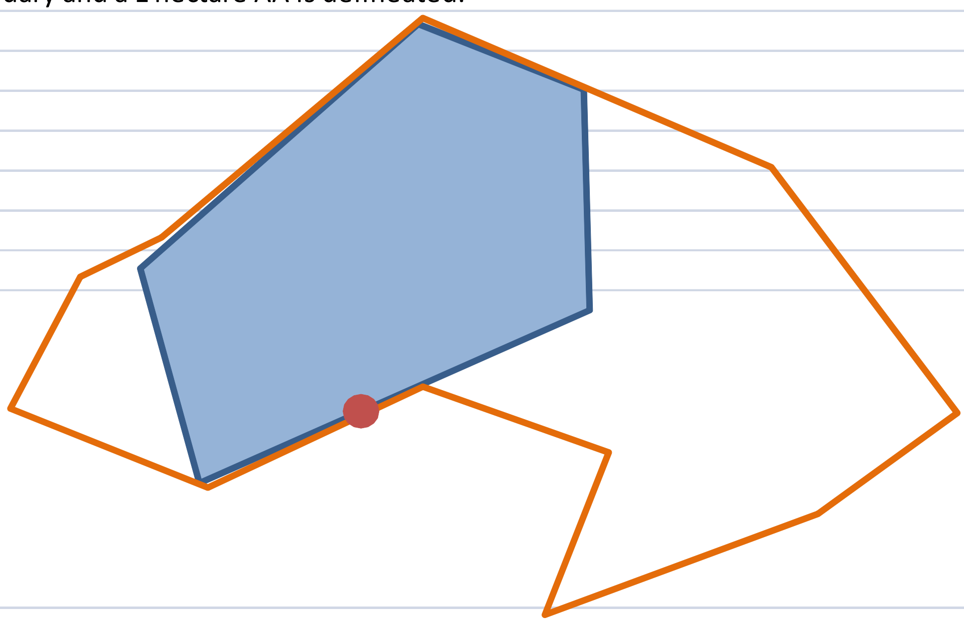
1. Wetland is within the 5 year floodplain of a river but not fringing an impounded water body.	*Riverine* (5)
1. Wetland is associated with a topographic depression, flat or slope.	2
2. Wetland is located on a topographic slope (slight to steep) and has groundwater as the primary water source. Wetland does not occur in a basin with closed contours.	*Slope* (16)
2. Wetland is located in a natural or artificial (dammed/excavated) topographic depression or flat.	3
3. Wetland is located on a flat without major influence from groundwater.	*Flat* (**Hardwood Flat**)
3. Wetland is located in a natural or artificial (dammed/excavated) topographic depression.	4
4. Topographic depression has permanent water greater than 2 meters deep.	*Lacustrine Fringe* (10)
4. Topographic depression does not contain permanent water greater than 2 meters.	*Depression* (12)
5. The wetland is a remnant river channel that is periodically hydrologically connected to a river or stream every 5 years or more frequently.	**Connected Oxbow**
5. The wetland is not an abandoned river channel.	6
6. The hydrology of the wetland is impacted by beaver activity.	**Beaver Complex**
6. The hydrology of the wetland is not impacted by beaver activity.	7
7. The wetland occurs within the bankfull channel.	**In-channel**
7. The wetland occurs on the floodplain or is adjacent to the river channel.	8
8. The wetland occurs within a depression on the floodplain.	**Floodplain Depression**
8. The wetland occurs on a flat area on the floodplain or is adjacent to the river channel.	9
9. Wetland water source primarily from overbank flooding that falls with the stream water levels or lateral saturation from channel flow.	**Riparian**
9. Wetland water source is primarily from overbank flooding that remains in the wetland due to impeded drainage after stream water level falls.	**Floodplain**
10. Wetland is associated with a remnant river channel that is hydrologically disconnected from the stream or river of origin.	**Disconnected Oxbow**
10. Wetland is associated with a reservoir or pond created by impounded or excavation.	11
11. Wetland water source is primarily from a permanent river.	**Reservoir Fringe**
11. Wetland water source is primarily from a draw or overland flow.	**Pond Fringe**
12. Wetland was created by human activity.	13
12. Wetland was not created by human activity.	14
13. Wetland does not have discernible water outlets.	**Closed Impounded Depression**
13. Wetland has discernible water outlet.	**Open Impounded Depression**
14. Wetland primary water source is groundwater.	**Groundwater Depression**
14. Wetland primary water source is surface water.	15
15. Wetland does not have any discernible water outlets.	**Closed Surface Water Depression**
15. Wetland has discernible water outlets.	**Open Surface Water Depression**
16. Wetland is hydrologically connected to a low order (Strahler <=4), high gradient, or ephemeral stream.	**Headwater Slope**
16. Wetland is hydrologically connected to a high order (Strahler >=5), low gradient river. Slope may be imperceptible or extremely gradual (includes wet meadows).	**Low Gradient Slope**

Assessment Area Diagrams

When a wetland is smaller than 1 hectare the entire wetland is the Assessment Area



When a wetland is greater than 1 hectare, a point is randomly assigned along the wetland boundary and a 1 hectare AA is delineated.



Legend

Wetland boundary   Assessment Area   Randomly selected point

Site Description

Site Name					
Date of Assessment					
Assessor Name(s)					
Assessor Affiliation(s)					
Site Latitude					
Site Longitude					
Coordinate System					
Ecoregion					
Directions					
Size of Wetland					
Assessment Area size					
Reason for Assessment					
Dominant Water Source	Surface flow	Precipitation		Groundwater	Overbank flooding
Hydrodynamics	Unidirectional	Bidirectional		Vertical	
Geomorphic Setting	Depression	Flat		Fringe	Slope
HGM Class	**Depression**	**Flat**	**Slope**	**Lacustrine**	**Riverine**
Regional Subclass	*Closed Impounded*	*Hardwood*	*Headwater*	*Disconnected Oxbow*	*Connected Oxbow*
	Open Impounded		*Low-gradient*	*Reservoir Fringe*	*Beaver Complex*
	Groundwater			*Pond Fringe*	*In-Channel*
	Open Surface Water				*Floodplain*
	Closed Surface Water				*Floodplain Depression*
					Riparian
Cowardin Class (four most dominant and area as a % of AA)	Class			% AA	
	Class			% AA	
	Class			% AA	
	Class			% AA	
Notes					

1. Hydrologic condition

a. Hydroperiod

Instructions:

1. On an aerial photograph in the field outline all areas within the AA where hydroperiod has been altered and severity of alteration. For calculations, sketches on aerial photographs can be converted to GIS or estimated from aerial photos.
2. Severity of alteration is based on indicator severity on the following worksheet.
3. Fill in the area as a percent of the AA and severity for each indicator of altered hydroperiod. Overlapping areas of indicators are only counted once and for the highest level of severity. Describe the indicator and circle all indicators on the indicator worksheet.

4. The metric is calculated by applying severity weights to the impacted area. For example a severity weight of 0.25 is applied to minor sources of impacted hydroperiod. If 50% of the AA is affected by a minor source of altered hydroperiod, the metric score would be 0.875 (1-[0.50*0.25] = 0.875).

Indicators of Reduced hydroperiod	**Minor**	**Moderate**	**Major**	**Complete Loss**	**Indicator Description**
Upstream Dams					
Fill/sedimentation					
Water pumping out of the wetland					
Water control structures					
Culverts, discharges, ditches or tile drains out of the wetland					
Beaver dam removal					
Indicators of increased hydroperiod	**Minor**	**Moderate**	**Major**	**Complete Loss**	**Indicator Description**
Downstream dams					
Excavation/Dredging/Mining					
Water pumping into the wetland					
Water control structures					
Culverts, discharges, diversions or ditches into wetland					
TOTAL IMPACTED AREA					
SEVERITY WEIGHT	**0.25**	**0.5**	**0.75**	**1**	
SEVERITY WEIGHTED AREA					
METRIC SCORE 1A					**1**

1. Hydrologic condition

a. Hydroperiod	Severity			
Indicators of Reduced hydroperiod	**Minor**	**Moderate**	**Major**	**Complete Loss**
1. Upstream impoundments (Riverine wetlands only)	Impoundment within 500 meters upstream of wetland that likely alters wetland hydrology to some extent.	Only receives inflows from channel source during large flood events and retains wetland hydrology from other water inputs (e.g. precipitation, overland flow, groundwater).	Complete loss of inflows/ flooding from channel source but still retains wetland hydrology from other water inputs (e.g. precipitation, overland flow, groundwater).	Complete loss of inflows/ flooding and wetland dried.
2. Fill/sedimentation	Silt covered vegetation, extremely turbid water, rills on adjacent uplands	Sediment splays, completely buried vegetation, silt deposits around trees	Silt deposits or fill that have greatly reduced wetland volume	Complete loss of basin.
3. Water pumping out of the wetland	Water level is properly manipulated for wetland management activities including slow, cool-season drawdowns. Desirable annual moist soil plants present.	Water is pumped out of the wetland for agricultural or other human uses *or* Water level is poorly manipulated for wetland management activities including rapid, warm-season drawdowns. Undesirable weedy plants present (e.g. cocklebur).	n/a	n/a
4. Water control structures	Water level is properly manipulated for wetland management activities including slow, cool-season drawdowns. Desirable annual moist soil plants present.	Water level is poorly manipulated for wetland management activities including rapid, warm-season drawdowns. Undesirable weedy plants present (e.g. cocklebur).	n/a	n/a
5. Culverts, discharges, ditches or tile drains out of the wetland	Old drainages present that appear to have minor influences on current wetland hydrology (e.g. old ditches that have sedimented in or tile drains that have been damaged)	Water drained only during high water events.	Water is drained from wetland at all times of the year but still retains wetland hydrology	Wetland completely dried
6. Beaver dam removal	n/a	n/a	Still retains wetland hydrology	Wetland completely dried
7. Center of wetland excavated to dry remainder of wetland	n/a	n/a	Still retains wetland hydrology	Wetland completely dried

1. Hydrologic condition

a. Hydroperiod	Severity			
Indicators of increased hydroperiod	**Minor**	**Moderate**	**Major**	**Complete Loss**
8. Downstream impoundments	Impoundment within 500 meters downstream of wetland that likely alters wetland hydrology to some extent.	Impoundment within 100 meters downstream of wetland that likely alters wetland hydrology to some extent.	Still retains wetland hydrology but hydroperiod substantially lengthened.	Wetland converted to permanent deepwater
9. Excavation/ Dredging/ Mining	n/a	n/a	Wetland excavated but still retains wetland hydrology. Hydroperiod substantially lengthened.	Wetland converted to permanent deepwater
10. Water pumping into the wetland	Water level is properly manipulated for wetland management activities including slow, cool-season drawdowns. Desirable annual moist soil plants present.	Water level is poorly manipulated for wetland management activities including rapid, warm-season drawdowns. Undesirable weedy plants present (e.g. cocklebur).	n/a	n/a
11. Water control structures	Water level is properly manipulated for wetland management activities including slow, cool-season drawdowns. Desirable annual moist soil plants present.	Water level is poorly manipulated for wetland management activities including rapid, warm-season drawdowns. Undesirable weedy plants present (e.g. cocklebur).	n/a	n/a
12. Culverts, discharges, irrigation, diversions or ditches into wetland	Old drainages present that appear to have minor influences on current wetland hydrology (e.g. old ditches that have sedimented in)	Water enters wetland from culverts, diversions or ditches only during large storm events. Water is consistently discharged into wetland from agricultural irrigation.	Water from culvert, diversion, irrigation or ditch is the dominant water source for the wetland.	Wetland converted to permanent deepwater

1. Hydrologic condition

b. Water Source

Instructions:

1. Delineate the catchment for the wetland on an aerial photograph or in GIS. Ideally the catchment for the wetland can be delineated using topographic maps and hydrologic unit maps. However, a 2 km buffer can be substituted if it is not possible to delineate a catchment.
2. On an aerial photograph or in GIS determine the percent cover of indicators of altered water source in the catchment for the wetland.
3. Fill in the % Cover of each of the indicators of altered water source.
4. This metric is calculated by dividing the percentage of unaltered land-cover by 100% cover. For example, a catchment with 20% impervious surface and 40% irrigated agricultural land would receive a score of 0.4. ([100-40-20]/100 = 0.4)

Indicators of altered water source	**% Cover**	**Description**
Impervious surface (paved roads, parking lots, structures and compacted gravel and dirt roads)		
Irrigated agricultural land (center pivot, ditch, flood etc.)		
Dryland agricultural land that is tilled		
Woody encroachment (e.g. eastern red cedar (*Juniperus virginiana*) and salt cedar (*Tamarix* sp.))		
Impounded water		
Topographic alteration (leveling, excavation, mining)		
Total Altered Cover		
METRIC SCORE 1b		

1. Hydrologic condition

c. Hydrologic Connectivity- Depressions, Flats, Lacustrine Fringes and Slopes

Instructions:		
1. On an aerial photograph in the field outline all areas within the wetland within 500 meters of the Assessment Area where hydrologic connectivity has been altered. For calculations, sketches on aerial photographs can be converted to GIS or estimated from aerial photos. 2. Fill in the percentage of the perimeter where hydrologic connectivity is impaired. 3. The metric is calculated as a percentage of unimpacted wetland perimeter. For example a wetland where 60% of the perimeter is bounded by a levee would receive a score of 0.4 ([100-60]/100 = 0.4).		
Indicators of altered connectivity	**Perimeter**	**Description**
Levees, Berms, Dams, Weirs		
Road Grades		
METRIC SCORE 1C		

2. Water Quality Condition

a. Nutrients/Eutrophication

1. On an aerial photograph in the field outline all areas within the AA where nutrient cycling has been altered and severity of alteration. For calculations, sketches on aerial photographs can be converted to GIS or estimated from aerial photos. 2. Severity of alteration is based on indicator severity on the following worksheet. 3. Fill in the area as a percent of the AA and severity for each indicator of altered nutrient cycling. Overlapping areas of indicators are only counted once and for the highest level of severity. Describe the indicator and circle all indicators on the indicator worksheet. 4. The metric is calculated by applying severity weights to the impacted area. For example a severity weight of 0.25 is applied to minor sources of impacted nutrient cycling. If 50% of the AA is affected by a minor source of altered nutrient cycling, the metric score would be 0.875 (1-[0.50*0.25] = 0.875).

Indicators of Altered Nutrient Cycling	**Minor**	**Moderate**	**Major**	**Indicator Description**
Livestock/animal waste				
Septic/sewage discharge				
Excessive algae or Lemna sp. (Do not count this metric if algae or Lemna blooms are a result of evapoconcentration of nutrients as wetland is drying.)				
TOTAL IMPACTED AREA				
SEVERITY WEIGHT	**0.25**	**0.5**	**0.75**	
SEVERITY WEIGHTED AREA				
METRIC SCORE 2a				

2.Water Quality

a. Nutrients

Indicators of Altered Nutrient Cycling	**Severity**		
	Minor	**Moderate**	**Major**
Livestock/animal waste	Sparse domestic animal feces (e.g. cow pies), evidence of sparse feral pig activity (rooting, wallows, feces)	High concentration of domestic animal feces (e.g. cow pies), evidence of large scale feral pig activity (rooting, wallows, feces)	Runoff from wastewater lagoons into wetland, Evidence of manure piles, poultry litter piles draining to wetland
Septic/sewage discharge	Residential dwellings within 200 meters of wetland	Residential dwellings within 50 meters of wetland	Discharge from sewage treatment plant
Excessive algae or Lemna sp. (Do not count this metric if algae or *Lemna* blooms are a result of evapoconcentration of nutrients as wetland is drying.)	Sparse mats or blooms of filamentous algae, Lemna, or cyanobacteria. Small contiguous patches are less than 200 square meters	Mats or blooms of filamentous algae, *Lemna* , or cyanobacteria may cover large areas but will not be contiguous for more than 0.1 hectares and will contain intermittent gaps where no mats or blooms or present.	Mats or blooms of filamentous algae, *Lemna* , or cyanobacteria that are contiguous for areas larger than 0.1 hectares.

2. Water Quality Condition

b. Sediment

1. On an aerial photograph in the field outline all areas within the AA where sediment loading has been altered and severity of alteration. For calculations, sketches on aerial photographs can be converted to GIS or estimated from aerial photos.
2. Severity of alteration is based on indicator severity on the following worksheet.
3. Fill in the area as a percent of the AA and severity for each indicator of altered sediment loading. Overlapping areas of indicators are only counted once and for the highest level of severity. Describe the indicator and circle all indicators on the indicator worksheet.

4. The metric is calculated by applying severity weights to the impacted area. For example a severity weight of 0.25 is applied to minor sources of impacted sediment loading. If 50% of the AA is affected by a minor source of altered sediment loading, the metric score would be 0.875 (1-[0.50*0.25] = 0.875).

Indicators of Altered Sediment loading	**Minor**	**Moderate**	**Major**	**Indicator Description**
Sedimentation (e.g. presence of sediment plumes, fans or deposits, turbidity, silt laden vegetation)				
Upland erosion (e.g. gullies, rills)				
TOTAL IMPACTED AREA				
SEVERITY WEIGHT	**0.25**	**0.5**	**0.75**	
SEVERITY WEIGHTED AREA				
METRIC SCORE 2b				

2.Water Quality

b. Sediment

	Severity		
Indicators of Altered Sediment Loading	**Minor**	**Moderate**	**Major**
Sedimentation (e.g. presence of sediment plumes, fans or deposits)	Excessive turbidity (in excess of expectation for the system), silt laden vegetation	Sediment plumes or fans, silt deposits less than 0.5 centimeters in thickness	Silt deposits greater than 0.5 centimeters in thickness
Upland erosion (e.g. gullies, rills)	Sparse rills connecting upland to wetland. Sediment washing down cattle/wildlife trails.	Dense rills connecting upland to wetland	Gullies connecting upland to wetland

2. Water Quality Condition

c. Chemical contaminants

1. On an aerial photograph in the field outline all areas within the AA where chemical contaminants have been introduced and severity of alteration. For calculations, sketches on aerial photographs can be converted to GIS or estimated from aerial photos.
2. Severity of alteration is based on indicator severity on the following worksheet.
3. Fill in the area as a percent of the AA and severity for each indicator of introduced chemical contaminants. Overlapping areas of indicators are only counted once and for the highest level of severity. Describe the indicator and circle all indicators on the indicator worksheet.
4. The metric is calculated by applying severity weights to the impacted area. For example a severity weight of 0.25 is applied to minor sources of chemical contaminants. If 50% of the AA is affected by a minor source of chemical contaminants, the metric score would be 0.875 (1-[0.50*0.25] = 0.875).

Indicators of Chemical Contaminants	Minor	Moderate	Major	Indicator Description
Point source discharge (wastewater plant, factory etc.)				
Stormwater inputs (discharge pipes, culverts, adjacent impervious surface or railroads)				
Increased salinity (e.g. salt crust)				
Industrial spills or dumping				
Oil sheen*				
TOTAL IMPACTED AREA				
SEVERITY WEIGHT	**0.25**	**0.5**	**0.75**	
SEVERITY WEIGHTED AREA				
METRIC SCORE 2c				

Notes:

*Oil sheen can result from petroleum spills or from a natural phenomena. If the oil sheen does not break apart when hit with a stick, it is a result of a petroleum spill and should be counted as an indicator of chemical contaminants. If the oil sheen does break apart when hit, do not count it as a chemical contaminant.

2.Water Quality

c. Contaminants	Severity		
Indicators of Chemical Contaminants	**Minor**	**Moderate**	**Major**
Point source discharge (wastewater plant, factory etc.)	n/a	Discharge from wastewater/sewage treatment plant or industrial factor to adjacent water body that is intermittently connected to wetland	Direct discharge from wastewater treatment plant or industrial factory
Stormwater inputs (discharge pipes, culverts, adjacent impervious surface or railroads)	Adjacent impervious surfaces such as paved roads or railroads (within 10 meters of wetland)	Stormwater inputs from culverts or discharge pipes	n/a
Increased salinity (e.g. salt crust, excessively high conductivity)	Oil and gas exploration within 30 meters of wetland (e.g. pumpjacks, tank batteries)	Salt crust present on soil surface (excludes saline wetlands such as those in the Great Salt Plains of Alfalfa County)	n/a
Industrial spills or dumping	55 gallon drums present but otherwise no signs of chemical contamination, metal objects or other potentially harmful trash dumped within the wetland. Evidence of drilling mud application.	n/a	Knowledge or evidence of industrial spill within or directly adjacent to the wetland
Oil sheen	Oil sheen present but not contiguous over areas exceeding 200 square meters, likely a result of motorcraft use within or adjacent to the wetland	Oil sheen contiguous over moderate areas within the wetland exceeding 200 square meters, likely a result of a spill or adjacent exploration	Oil sheen contiguous over large areas within the wetland exceeding 0.1 hectares, likely a result of a spill or adjacent exploration

2. Water Quality Condition

d. Buffer filter

Instructions:

1. On an aerial photograph or in GIS, draw eight evenly spaced 250 m lines emanating from the AA boundary starting at due North. If the AA is directly adjacent to permanent open water exclude that portion of the boundary from buffer calculations.
2. Calculate the distance until human impacted land-use (see table below). For high impact land-use the buffer must be 250 m in length to be fully functioning. For moderate impact land-use the buffer must be 100 m in length to be fully functioning and for low impact land-use the buffer must be 30 m to be considered fully functioning.
3. For each buffer line calculate the percentage of intact buffer distance. For example if the buffer is intact for 80 meters before intersecting a golf course the buffer is 80% of fully functioning (80/100). On the other hand, if the buffer is intact for 80 meters before intersecting a feedlot the buffer is only 32% functioning (80/250).
4. For the overall buffer filter score, take the average of all eight buffer lines.

Land-uses that can be included in a functioning buffer: natural uplands, water bodies not directly adjacent to AA, wildland parks, bike trails, foot trails, horse trails, gravel/dirt roads, railroads

Land use category	**Types of Land-use Beyond Buffer**	**Buffer width**
High Impact	Intensive livestock (feedlot, dairy farm, pig farm) or urban area	250m
Moderate Impact	Conventional tilled agriculture, landscaped park, golf course, suburban area, active construction sites, areas of vegetation removal, earth moving operations	100m
Low Impact	No till agriculture, hay meadow, paved road	30m
Buffer	Required Distance (based on first encountered land-use)	Intact Distance
1		
2		
3		
4		
5		
6		
7		
8		
METRIC SCORE 2d		

3. Biotic Condition

a. Vegetation condition

Instructions:
1. Conduct a visual assessment of the percent cover of each vegetation layer and % cover of indicators of altered vegetation community in each vegetation layer.
2. Vegetation condition score is based on the percent of unimpacted vegetation cover relative to the overall vegetation cover.

	Vegetation Layers			
Indicators of altered vegetation community (% cover in each layer)	**Tree**	**Shrub/sapling**	**Herbaceous/ Emergent**	**Submergent/ Floating leaved**
Invasive species and crop/pasture grasses*				
Native monoculture (only emergent and submergent layers) **				
Vegetation removal (e.g. tree harvest, brush hogging, haying, mowing) ***				
Excessive grazing (only emergent and submergent) ****				
Herbicide impacted area				
Mechanical disturbance from structures (e.g. rip-rap, right of ways and roads etc.)				

Percent Cover of Layer				
Percent disturbed cover per layer				
METRIC SCORE 4a				

Notes:

* Invasive species include all plant species listed on the Oklahoma Non-Native Invasive Plant Species List developed by OK Native Plant Society, OK Biological Survey and OSU Natural Resource Ecology and Management. A species is considered invasive if it is listed as a problem in border states as well. http://ok-invasive-plant-council.org/images/OKinvasivespp.pdf

** Native monocultures occur when more than 50% of a an assessment area is covered by one native perennial species including cattails (*Typha* sp.)*, river bulrush (Schoenoplecuts fluviatis)* , giant cutgrass (*Zizaniopsis miliacea)* , and reed canary grass (*Phalaris arundinacea).* Native monoculture cover is scored as the percent cover greater than 50%. For example a wetland with 70% cover reed canary grass would receive a score of 20% (70-50= 20).

*** Vegetation removal can be an effective management strategy for improving the quality of wetland vegetation by removing invasive species or native monocultures. Vegetation removal for invasive species or monoculture control should not be included in this field.

**** Excessive grazing represents areas where vegetation is eaten to the ground. Grazing can be an effective management strategy for improving the quality of wetland vegetation by removing invasive species or native monocultures. Grazing for invasive species or monoculture control should not be included in this field.

3. Biotic Condition

b. Habitat connectivity

Instructions: 1. On an aerial photograph or in GIS delineate the connected habitat surrounding the AA within a 2500 m buffer. Connected habitat does not include any of the dispersal barriers below. 2. Calculate the metric by dividing the total connected area by the total area in the 2500 m buffer.	
Included in connected habitat	
open water	
other wetlands	
natural uplands	
nature or wildland parks	
bike trails	
railroads	
roads not hazardous to wildlife	
swales and ditches	
vegetated levees	
open range land	
Dispersal Barriers not included in connected habitat	
Commercial Developments	
Fences that interfere with animal movements	
intensive agriculture (e.g. row crops, orchards, vineyards)	
dryland farming	
paved roads	
lawns	
parking lots	
intensive livestock production (e.g. horse paddocks, feedlots, chicken ranches etc.)	
residential areas	
sound walls	
sports fields	
traditional golf courses	
urbanized parks with active recreation	
pedestrian/bike trails with near constant traffic	
Area of Connected Habitat	
Area within 2500 m buffer	
METRIC SCORE 4c	

4. OKRAM Overall Condition Score

	Metric	Score	
1	***Hydrology***		
1a.	Hydroperiod		
1b.	Water source		
1c.	Hydrologic Connectivity		(This metric needs to be manual input for riverine wetlands)
	Hydrology Attribute		*(metric 1a +metric 1b + metric 1c)/3*
2	***Water Quality***		
2a.	Nutrients		
2b.	Sediment		
2c.	Contaminants		
2d.	Buffer Filter		
	Water Quality Attribute		*(metric 2a +metric 2b + metric 2c + metric 2d)/4*
3	***Biota***		
3a.	Vegetation		
3b.	Habitat Connectivity		
	Biota Attribute		*(metric 3a + metric 3)/2*
Overall Condition Score			*(Hydrology Attribute + Water Quality Attribute + Biota Attribute)/3*

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Appendix C: List of Plant Species

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Collected May/June 2013

Plant Species	**# of Sites**
Achillea millefolium	3
Agalinis fasciculata	7
Agrostis perennans	5
Alopecurus carolinianus	11
Ambrosia psilostachya	16
Ambrosia trifida	1
Amorpha fruticosa	1
Andropogon virginicus	4
Apocynum cannabinum	1
Bacopa rotundifolia	4
Bromus arvensis	1
Bromus catharticus	2
Bromus racemosus	4
Bromus secalinus	2
Bromus tectorum	8
Carex festucacea	6
Celtis occidentalis	1
Cephalanthus occidentalis	4
Cerastium pumilum	1
Chenopodium album	9
Chenopodium pratericola	1
Cocculus carolinus	1
Conyza canadensis	21
Coreopsis tinctoria	7
Cornus drummondii	1
Cynodon dactylon	9
Cyperus acuminatus	1
Cyperus strigosus	1
Dichanthelium acuminatum	2
Dichanthelium oligosanthes	7
Echinochloa crus-galli	4
Eleocharis compressa	1
Eleocharis lanceolata	4
Eleocharis obtusa	1
Eleocharis palustris	3
Eleocharis parvula	2
Eleocharis rostellata	1

Plant Species	**# of Sites**
Eragrostis spectabilis	1
Eragrostis trichodes	2
Gamochaeta purpurea	2
Geranium carolinianum	1
Helianthus petiolaris	2
Heteranthera limosa	2
Hordeum jubatum	2
Hordeum pusillum	12
Juncus interior	8
Juncus marginatus	1
Juniperus virginiana	2
Lactuca serriola	1
Lamium amplexicaule	4
Lepidium densiflorum	5
Lepidium oblongum	1
Lepidium virginicum	5
Leptochloa fusca	1
Lolium perenne	2
Ludwigia palustris	1
Marsilea vestita	6
Melothria pendula	1
Myosurus minimus	1
Oenothera laciniata	6
Oxalis dillenii	1
Panicum virgatum	2
Parthenocissus quinquefolia	1
Paspalum distichum	2
Phyla lanceolata	1
Phyla nodiflora	6
Physalis pumila	1
Phytolacca americana	3
Plantago virginica	2
Poa annua	4
Polygonum amphibium	6
Polygonum convolvulus	2
Polygonum hydropiperoides	7
Polygonum pennsylvanicum	6
Polygonum persicaria	6
Polygonum ramosissimum	5
Polypogon monspeliensis	2

Plant Species	# of Sites
Populus deltoides	4
Potamogeton nodosus	1
Ranunculus sceleratus	4
Rayjacksonia annua	1
Rorippa palustris	4
Rorippa sessiliflora	2
Rubus oklahomus	1
Rumex altissimus	4
Rumex crispus	4
Sagittaria latifolia	2
Salix nigra	13
Schoenoplectus acutus	4
Schoenoplectus pungens	3
Schoenoplectus tabernaemontani	5
Secale cereale	12
Sibara virginica	1
Sisyrinchium angustifolium	1
Solanum dimidiatum	1
Solidago canadensis	6
Sorghum halepense	1
Sphenopholis obtusata	2
Symphoricarpos orbiculatus	2
Teucrium canadense	6
Triticum aestivum	3
Typha angustifolia	3
Ulmus americana	2
Verbena bracteata	1
Veronica peregrina	7
Vicia sativa	1
Vitis riparia	1
Vulpia octoflora	5
Xanthium strumarium	3
Zea mays	2

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Appendix D: List of Invertebrate Taxa

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(a)May/June 2013 Samples

Phylum	Class	Order	Family	Genus	Lowest Taxonomic Resolution	# of Sites
Annelida	Hirudinea	Arhynchobdellida	Erpobdellidae		Erpobdellidae	1
	Oligochaeta				Oligochaeta	7
Arthropoda	Branchiopoda	Diplostraca			Cladocera	10
	Insecta	Coleoptera	Carabidae		Carabidae	1
			Curculionidae		Curculionidae	4
			Dytiscidae	Laccophilus	Laccophilus	5
				Thermonectus	Thermonectus	2
			Gyrinidae	Dineutus	Dineutus	1
			Hydrophilidae	Berosus	Berosus	5
				Tropisternus	Tropisternus	5
		Diptera	Ceratopogonidae		Ceratopogonidae	1
				Culicoides	Culicoides	1
			Chironomidae		Chironomidae	8
			Culicidae	Aedes	Aedes	1
			Dolichopodidae		Dolichopodidae	1
		Ephemeroptera	Baetidae		Baetidae	1
			Caenidae	Caenis	Caenis	1
		Hemiptera	Belostomatidae		Belostomatidae	1
			Corixidae		Corixidae	3
				Trichocorixa	Trichocorixa	4
			Notonectidae	Notonecta	Notonecta	1
		Odonata	Aeshnidae	Anax	Anax	1
			Coenagrionidae	Coenagrion/Enallagma	Coenagrion/Enallagma	1

Phylum	Class	Order	Family	Genus	Lowest Taxonomic Resolution	# of Sites
Arthropoda	Insecta	Odonata	Libellulidae	Sympetrum	Sympetrum	1
	Maxillopoda				Copepoda	1
	Ostracoda				Ostracoda	5
Mollusca	Gastropoda	Basommatophora	Planorbidae	Helisoma	Helisoma	1
Nematoda					Nematoda	7

(b) July 2013 Samples

Phylum	Class	Order	Family	Genus	Lowest Taxonomic Resolution	# of Sites
Annelida	Oligochaeta				Oligochaeta	7
Arthropoda	Branchiopoda	Diplostraca			Cladocera	6
	Insecta	Coleoptera	Carabidae		Carabidae	1
			Curculionidae		Curculionidae	2
			Dytiscidae	Eretes	Eretes	1
				Laccophilus	Laccophilus	8
				Thermonectus	Thermonectus	5
			Haliplidae	Peltodytes	Peltodytes	1
			Helophoridae	Helophorus	Helophorus	4
			Hydrophilidae	Berosus	Berosus	7
				Enochrus	Enochrus	1
				Paracymus	Paracymus	3
				Tropisternus	Tropisternus	7
			Staphylinidae		Staphylinidae	2
		Diptera	Ceratopogonidae		Bezzia/Palpomyia	2
				Culicoides	Culicoides	1

Phylum	Class	Order	Family	Genus	Lowest Taxonomic Resolution	# of Sites
Arthropoda	Insecta	Diptera	Ceratopogonidae	Dasyhelea	Dasyhelea	2
			Chaoboridae	Chaoborus	Chaoborus	6
			Chironomidae		Chironomidae	10
			Culicidae	Aedes	Aedes	5
				Anopheles	Anopheles	3
				Culiseta	Culiseta	2
			Dolichopodidae		Dolichopodidae	1
			Ephydridae		Ephydridae	1
			Stratiomyidae		Odontomyia/Hedriodiscus	3
				Stratiomys	Stratiomys	1
			Tabanidae		Tabanidae	1
				Tabanus/Whitneyomyia	Tabanus/Whitneyomyia	4
		Ephemeroptera	Baetidae		Baetidae	5
				Callibaetis	Callibaetis	4
		Hemiptera	Belostomatidae		Belostomatidae	3
				Belostoma	Belostoma	3
			Corixidae		Corixidae	2
				Trichocorixa	Trichocorixa	9
			Gerridae		Gerridae	1
				Gerris	Gerris	1
			Hydrometridae	Hydrometra	Hydrometra	1
			Mesoveliidae	Mesovelia	Mesovelia	1
			Notonectidae	Notonecta	Notonecta	4
		Odonata	Aeshnidae	Anax	Anax	2
			Coenagrionidae		Coenagrionidae	2
				Coenagrion/Enallagma	Coenagrion/Enallagma	3

Phylum	Class	Order	Family	Genus	Lowest Taxonomic Resolution	# of Sites
Arthropoda	Insecta	Odonata	Libellulidae	Orthemis	Orthemis	2
				Pachydiplax	Pachydiplax	1
				Pantala	Pantala	1
				Plathemis	Plathemis	1
				Tramea	Tramea	2
	Malacostraca	Amphipoda	Hyalellidae	Hyalella	Hyalella	1
	Maxillopoda				Copepoda	1
	Ostracoda				Ostracoda	7
Nematoda					Nematoda	9

(c) August 2013 Samples

Phylum	Class	Order	Family	Genus	Lowest Taxonomic Resolution	# of Sites
Annelida	Hirudinea	Arhynchobdellida	Erpobdellidae		Erpobdellidae	1
	Oligochaeta				Oligochaeta	16
Arthropoda	Arachnida	Trombidiformes	Arrenuridae	Arrenurus	Arrenurus	2
			Lebertiidae	Lebertia	Lebertia	1
	Branchiopoda	Diplostraca			Cladocera	10
	Insecta	Coleoptera	Carabidae		Carabidae	2
			Curculionidae		Curculionidae	9
			Dytiscidae	Agabus	Agabus	1
				Copelatus	Copelatus	5
				Hydrovatus	Hydrovatus	1
				Laccophilus	Laccophilus	22

Phylum	Class	Order	Family	Genus	Lowest Taxonomic Resolution	# of Sites
Arthropoda	Insecta	Coleoptera	Dytiscidae	Liodessus	Liodessus	3
				Thermonectus	Thermonectus	15
				Uvarus	Uvarus	3
			Elmidae	Dubiraphia	Dubiraphia	2
			Gyrinidae	Dineutus	Dineutus	6
			Helophoridae	Helophorus	Helophorus	7
			Hydrophilidae	Berosus	Berosus	23
				Enochrus	Enochrus	3
				Hydrophilus	Hydrophilus	2
				Laccobius	Laccobius	1
				Paracymus	Paracymus	8
				Tropisternus	Tropisternus	24
			Staphylinidae		Staphylinidae	2
		Diptera	Ceratopogonidae		Bezzia/Palpomyia	8
					Ceratopogonidae	2
				Culicoides	Culicoides	1
				Dasyhelea	Dasyhelea	9
				Forcipomyia	Forcipomyia	2
			Chaoboridae		Chaoboridae	4
				Chaoborus	Chaoborus	18
			Chironomidae		Chironomidae	25
			Culicidae		Culicidae	3
				Aedes	Aedes	15
				Anopheles	Anopheles	12
			Dolichopodidae		Dolichopodidae	6
			Ephydridae		Ephydridae	8

Phylum	Class	Order	Family	Genus	Lowest Taxonomic Resolution	# of Sites
Arthropoda	Insecta	Diptera	Ephydridae	Ephydra	Ephydra	6
			Muscidae		Muscidae	1
			Psychodidae		Psychodidae	4
			Stratiomyidae		Odontomyia/Hedriodiscus	8
				Odontomyia	Odontomyia	1
				Stratiomys	Stratiomys	1
			Tabanidae		Tabanidae	4
				Tabanus/Whitneyomyia	Tabanus/Whitneyomyia	11
			Tipulidae	Helius	Helius	3
		Ephemeroptera	Baetidae		Baetidae	3
				Callibaetis	Callibaetis	19
				Caenis	Caenis	2
		Hemiptera	Belostomatidae		Belostomatidae	15
				Belostoma	Belostoma	9
			Corixidae		Corixidae	12
				Trichocorixa	Trichocorixa	6
			Gerridae		Gerridae	5
				Gerris	Gerris	2
			Hydrometridae	Hydrometra	Hydrometra	1
			Mesoveliidae	Mesovelia	Mesovelia	2
			Nepidae	Ranatra	Ranatra	1
			Notonectidae	Notonecta	Notonecta	8
			Veliidae		Veliidae	4
		Odonata	Aeshnidae	Anax	Anax	14
				Boyeria	Boyeria	1
			Coenagrionidae		Coenagrionidae	6

Phylum	Class	Order	Family	Genus	Lowest Taxonomic Resolution	# of Sites
Arthropoda	Insecta	Odonata	Coenagrionidae	Coenagrion/Enallagma	Coenagrion/Enallagma	13
				Ischnura	Ischnura	3
			Libellulidae		Libellulidae	1
				Orthemis	Orthemis	2
				Pachydiplax	Pachydiplax	3
				Pantala	Pantala	14
				Plathemis	Plathemis	1
				Sympetrum	Sympetrum	1
				Tramea	Tramea	3
		Trichoptera	Leptoceridae		Leptoceridae	1
				Oecetis	Oecetis	1
	Malacostraca	Amphipoda			Amphipoda	1
			Hyalellidae	Hyalella	Hyalella	1
	Maxillopoda				Copepoda	1
	Ostracoda				Ostracoda	13
Mollusca	Bivalvia				Bivalvia	1
	Gastropoda	Basommatophora	Physidae	Physa	Physa	3
			Planorbidae	Helisoma	Helisoma	3
Nematoda					Nematoda	14

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Appendix E: Metrics by Site

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(a)Plant Metrics

Site	% Perennial	% Open	% Introduced	%FAC, FACWET and OBL	Native Richness	Shannon Diversity
38	0.00	29.33	70.67	0.00	0	0.00
39	15.33	27.33	51.33	22.67	10	1.74
42	0.00	0.00	94.67	6.00	2	0.43
43	0.00	16.67	83.33	0.00	0	0.00
46	0.00	56.00	42.67	0.67	2	0.68
59	57.33	14.00	1.33	62.00	17	2.24
71	19.33	40.00	4.00	31.33	15	2.34
72	58.00	8.00	2.00	64.00	17	2.01
82	0.00	7.33	91.33	4.67	3	1.07
84	12.67	25.33	71.33	18.67	6	1.49
85	0.67	31.33	57.33	1.33	3	0.61
86	4.67	27.33	70.00	6.00	3	0.57
96	0.00	90.00	0.00	0.67	4	1.14
115	0.00	0.00	100.00	0.00	0	0.00
128	59.33	35.33	14.00	52.67	13	1.87
135	32.67	22.00	24.00	72.67	16	2.24
156	87.33	1.33	76.00	30.00	10	1.38
157	30.67	5.33	4.67	48.67	22	2.45
158	73.33	6.00	5.33	62.00	16	2.11
159	41.33	4.67	27.33	47.33	24	2.56
174	0.00	80.67	19.33	0.00	1	0.79

Site	% Perennial	% Open	% Introduced	%FAC, FACWET and OBL	Native Richness	Shannon Diversity
175	0.00	84.67	15.33	0.00	0	0.00
182	52.67	46.00	0.00	52.67	3	0.43
183	12.67	6.00	0.67	20.00	13	1.12
185	72.00	0.00	68.67	29.33	9	1.70
186	31.33	52.00	17.33	30.00	19	2.65
187	45.33	1.33	98.00	1.33	6	1.00
205	84.00	3.33	36.67	50.67	11	1.78
209	17.33	0.67	4.67	22.67	13	1.53
210	24.67	9.33	0.00	44.67	10	1.89
221	0.00	6.67	90.67	0.00	1	0.13
222	41.33	13.33	12.00	42.00	9	1.42
223	56.00	20.67	0.67	58.00	9	1.44
224	85.33	11.33	1.33	86.00	14	1.66
226	2.00	72.00	27.33	1.33	3	0.53
228	10.00	86.00	2.00	11.33	7	1.96
229	49.33	14.00	9.33	24.67	20	2.11
230	77.33	7.33	10.00	69.33	21	2.10
231	0.00	70.00	4.00	28.00	4	0.92
232	100.00	0.67	98.67	6.00	7	0.89

(b) Soil Metrics

Site	NH4 (ppm)	NO3(ppm)	P (ppm)	OM (%)	Na (ppm)	TSS (ppm)	SAR	pH
38	49.60	0.5	94	1.84	13	461.34	0.8	5.7
39	21.86	12.5	68	4.41	262	3223.44	3.6	6.2
42	12.53	51	85	3.71	47	2098.80	1	5.3
43	43.30	1.5	108	2.42	10	512.82	0.5	5.6
46	18.26	19.5	155	4.78	883	10137.60	6.6	7.5
59	12.04	10	84.5	2.64	34	916.74	1	5.4
71	14.00	2	81.5	1.35	11	475.20	0.7	6.1
72	6.39	4	38.5	2.49	74	429.66	4.8	5.8
82	7.65	21	93.5	1.64	99	877.14	3.7	6.1
84	31.72	47	148	2.66	158	2096.82	3.9	6.4
85	29.07	6.5	172.5	1.65	16	708.84	1.1	6.2
86	17.47	26	148.5	2.35	34	1334.52	1.7	5.8
96	75.25	1	134	1.48	44	841.50	1.7	7.7
115	11.61	16	121.5	1.93	14	534.60	0.6	6
128	8.33	9.5	26.5	1.71	13	449.46	0.5	6.2
135	26.63	4.5	72	3.15	75	1061.28	1.6	6.5
156	10.14	12	22.5	1.87	45	708.84	1.1	8.2
157	4.60	8.5	73	1.97	15	655.38	0.4	8
158	6.17	8	50.5	2.55	15	788.04	0.4	7.3
159	3.82	6.5	52	3.05	7	481.14	0.2	7.7
174	23.85	19.5	124.5	2.81	86	1027.62	2.5	6.9
175	7.89	26	121	1.70	33	813.78	1.1	6.7
182	14.80	1.5	54.5	2.30	79	653.40	2.5	7.5
183	18.17	0.5	24.5	1.79	56	355.61	3.1	6.3
185	33.86	27	62.5	9.05	115	2574.00	1.7	7.3

Site	NH4 (ppm)	NO3(ppm)	P (ppm)	OM (%)	Na (ppm)	TSS (ppm)	SAR	pH
186	22.86	12.5	29	4.74	25	512.82	0.7	6.1
187	6.90	12	57	2.97	121	1564.20	2.3	7.9
205	3.20	10.5	51	3.65	21	685.08	0.5	7.8
209	6.56	2	20.5	0.80	6	230.08	0.4	6
210	15.43	4.5	33.5	1.83	45	403.92	2.4	6.2
221	3.78	9.5	28.5	1.62	11	459.36	0.4	7.1
222	21.05	0.5	66	1.51	30	319.38	1.8	6
223	8.84	8	19	1.55	7	333.04	0.3	6.2
224	8.39	9	66.5	3.10	21	544.50	0.8	6.1
226	20.31	0.5	105	1.80	66	473.22	3.0	7.4
228	18.01	8	27	2.38	41	938.52	1.0	4.9
229	9.91	3	10	3.70	34	445.5	1.1	6
230	11.78	5	13	4.04	16	516.78	0.5	6.2
231	12.94	0.5	59.5	0.91	10	220.37	0.9	5.2
232	6.63	5	60	1.52	16	362.14	0.8	5.7

(c) CRAM and OKRAM Metrics

Site	CRAM Buffer	CRAM Hydrology	CRAM Physical	CRAM Biotic	CRAM Final	OKRAM Hydrology	OKRAM Water Quality	OKRAM Biotic	OKRAM Final
38	25	100	38	56	55	0.58	0.56	0.00	0.38
39	48	100	38	64	62	0.57	0.72	0.07	0.45
42	25	92	25	58	50	0.67	0.75	0.01	0.47
43	25	100	38	56	55	0.58	0.56	0.00	0.38
46	38	100	38	28	51	0.63	0.63	0.00	0.42
59	78	100	63	44	71	0.91	0.93	0.53	0.79
71	68	100	63	53	71	0.91	0.81	0.51	0.74
72	68	100	63	33	66	1.00	0.94	0.53	0.82
82	38	75	25	58	49	0.50	0.69	0.05	0.41
84	25	75	38	47	46	0.53	0.69	0.05	0.42
85	25	92	25	61	51	0.67	0.75	0.10	0.51
86	25	100	25	61	53	0.67	0.75	0.10	0.51
96	25	67	25	33	38	0.42	0.56	0.03	0.33
115	25	100	25	58	52	0.75	0.75	0.00	0.50
128	63	92	25	67	61	0.78	0.85	0.46	0.69
135	68	100	88	61	79	0.91	0.94	0.64	0.83
156	45	92	38	36	53	0.90	0.89	0.36	0.71
157	56	100	63	75	73	1.00	1.00	0.86	0.95
158	56	100	63	56	68	1.00	1.00	0.85	0.95
159	56	100	75	58	72	1.00	1.00	0.66	0.89
174	25	67	50	36	44	0.42	0.69	0.00	0.37
175	38	75	25	33	43	0.50	0.69	0.00	0.40
182	81	100	63	33	69	0.78	0.88	0.47	0.71

Site	CRAM Buffer	CRAM Hydrology	CRAM Physical	CRAM Biotic	CRAM Final	OKRAM Hydrology	OKRAM Water Quality	OKRAM Biotic	OKRAM Final
183	53	100	63	33	62	1.00	0.89	0.47	0.78
185	61	100	63	69	73	0.73	0.84	0.20	0.59
186	42	75	88	69	69	0.52	0.85	0.48	0.61
187	25	100	25	50	50	0.67	0.75	0.00	0.47
205	56	100	75	69	75	1.00	1.00	0.54	0.85
209	48	100	38	61	62	0.90	0.94	0.55	0.79
210	60	100	63	61	71	0.93	0.94	0.58	0.82
221	38	83	25	61	52	0.71	0.75	0.00	0.49
222	53	100	63	50	66	0.93	0.85	0.44	0.74
223	56	100	38	61	64	1.00	0.94	0.62	0.85
224	56	100	38	69	66	1.00	0.94	0.65	0.86
226	25	92	38	36	48	0.58	0.56	0.00	0.38
228	68	83	38	44	58	0.85	1.00	0.42	0.75
229	56	100	38	61	64	1.00	1.00	0.85	0.95
230	56	100	50	69	69	1.00	1.00	0.86	0.95
231	25	100	38	33	49	0.67	0.63	0.45	0.58
232	56	100	25	25	51	1.00	0.94	0.30	0.74

(e) Invertebrate Richness, Diversity and HBI

Site	May Richness	Jul. Richness	Aug. Richness	May Coleoptera Richness	Jul. Coleoptera Richness	Aug Coleoptera Richness	May Diversity	Jul Diversity	Aug Diverstiy	May HBI	Jul HBI	Aug HBI
38	3	23	30	1	4	11	n/a	2.23	1.81	7.00	6.78	6.90
39	n/a	7	29	n/a	1	6	n/a	1.02	1.74	n/a	5.83	5.43
43	4	23	21	1	4	8	0.06	1.74	1.32	7.00	5.98	6.37
46	n/a	n/a	28	n/a	n/a	5	n/a	n/a	1.40	n/a	n/a	4.96
59	n/a	n/a	22	n/a	n/a	4	n/a	n/a	1.60	n/a	n/a	5.38
71	6	9	18	0	3	5	0.70	0.19	1.80	6.04	6.85	5.34
72	n/a	n/a	27	n/a	n/a	6	n/a	n/a	1.47	n/a	n/a	5.02
84	n/a	13	15	n/a	4	4	n/a	0.60	1.36	n/a	6.08	6.49
85	n/a	n/a	32	n/a	n/a	8	n/a	n/a	1.52	n/a	n/a	5.96
86	n/a	19	24	n/a	5	6	n/a	1.92	2.01	n/a	5.48	5.77
96	8	10	21	1	1	7	0.56	0.76	1.46	6.01	6.00	6.30
115	n/a	n/a	20	n/a	n/a	6	n/a	n/a	1.59	n/a	n/a	5.29
135	n/a	8	24	n/a	4	5	n/a	1.48	1.70	n/a	7.14	5.80
174	n/a	15	15	n/a	5	4	n/a	1.63	1.24	n/a	6.79	6.26
175	n/a	23	29	n/a	7	7	n/a	1.60	1.64	n/a	6.29	5.81
182	7	n/a	21	2	n/a	5	1.13	n/a	1.22	6.31	n/a	4.72
183	11	n/a	16	3	n/a	3	0.67	n/a	1.77	6.46	n/a	5.41
185	n/a	n/a	17	n/a	n/a	5	n/a	n/a	1.77	n/a	n/a	5.94
186	19	n/a	21	5	n/a	9	1.39	n/a	1.31	8.07	n/a	7.41
187	n/a	n/a	12	n/a	n/a	6	n/a	n/a	1.99	n/a	n/a	6.55
210	n/a	n/a	20	n/a	n/a	5	n/a	n/a	1.98	n/a	n/a	6.45
222	10	n/a	13	5	n/a	3	0.27	n/a	1.67	6.81	n/a	5.94
224	n/a	n/a	12	n/a	n/a	4	n/a	n/a	0.41	n/a	n/a	5.99
226	6	n/a	9	1	n/a	2	0.60	n/a	0.61	6.13	n/a	6.64
231	7	13	15	4	4	5	1.25	0.40	1.62	6.87	6.90	5.39

n/a= no water at time of wetland sampling event

(f) Invertebrate % Functional Feeding Groups

Site	May %Filterer	May %Gatherer	May % Predator	May % Shredder	Jul % Filterer	Jul % Gatherer	Jul % Predator	Jul % Shredder	Aug % Filterer	Aug % Gatherer	Aug % Predator	Aug % Shredder
38	0.00	0.00	100.00	0.00	0.69	38.16	60.39	0.28	0.00	53.47	46.11	0.15
39	n/a	n/a	n/a	n/a	0.00	88.03	11.54	0.00	0.04	77.92	21.14	0.04
43	0.00	98.99	1.01	0.00	1.29	70.66	27.51	0.47	0.00	70.42	28.32	1.18
46	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.53	89.03	8.81	0.00
59	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.10	68.40	29.98	0.00
71	0.00	98.78	1.22	0.00	0.00	98.37	1.59	0.00	0.00	77.37	21.01	0.00
72	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.60	85.65	12.21	0.10
84	n/a	n/a	n/a	n/a	0.00	93.41	6.35	0.24	15.55	62.73	20.11	0.27
85	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.13	83.00	16.12	0.08
86	n/a	n/a	n/a	n/a	0.45	57.42	37.12	4.39	1.45	66.30	31.28	0.10
96	0.00	99.75	0.13	0.13	0.00	98.97	0.86	0.17	0.32	81.48	17.23	0.16
115	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00	80.63	16.03	0.32
135	n/a	n/a	n/a	n/a	0.00	75.00	23.21	0.00	0.50	71.64	26.96	0.00
174	n/a	n/a	n/a	n/a	0.00	56.59	42.05	0.10	0.00	86.08	13.38	0.00
175	n/a	n/a	n/a	n/a	0.00	72.59	26.89	0.03	0.05	74.42	25.15	0.33
182	0.00	78.95	15.79	0.00	n/a	n/a	n/a	n/a	0.00	81.14	15.70	0.00
183	0.00	91.91	6.94	0.00	n/a	n/a	n/a	n/a	0.00	78.35	21.06	0.00
185	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00	70.05	23.91	0.97
186	0.00	9.69	74.78	0.88	n/a	n/a	n/a	n/a	0.00	18.70	79.86	0.14
187	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00	58.62	25.86	1.72
210	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.75	34.65	62.50	0.00
222	0.00	96.65	3.17	0.09	n/a	n/a	n/a	n/a	0.00	45.38	54.10	0.51
224	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.10	95.32	4.37	0.00
226	0.00	93.20	6.80	0.00	n/a	n/a	n/a	n/a	0.00	93.09	6.73	0.00
231	0.00	50.79	44.44	3.17	0.00	95.41	4.59	0.00	0.00	77.51	20.68	0.00

n/a = no water at time of wetland sampling event

(g) Invertebrate % Taxonomic Group

Site	May % Coleo	Jul % Coleo	Aug % Coleo	May % Ephem	Jul % Ephem	Aug % Ephem	May % Odon	Jul % Odon	Aug % Odon	May % Chiron	Jul % Chiron	Aug % Chiron
38	100.0	1.5	5.4	0.0	22.7	0.0	0.0	40.2	36.2	0.0	10.9	51.7
39	n/a	0.9	3.8	n/a	19.9	55.4	n/a	0.0	16.5	n/a	68.2	17.9
43	1.0	5.4	2.5	0.0	28.5	0.0	0.0	16.7	22.5	0.0	41.5	68.1
46	n/a	n/a	5.6	n/a	n/a	57.3	n/a	n/a	1.4	n/a	n/a	28.3
59	n/a	n/a	10.6	n/a	n/a	57.1	n/a	n/a	2.4	n/a	n/a	10.6
71	0.0	0.6	15.6	0.0	0.0	43.9	0.0	0.0	0.4	66.1	1.5	27.3
72	n/a	n/a	7.9	n/a	n/a	56.1	n/a	n/a	2.0	n/a	n/a	28.3
84	n/a	4.0	2.9	n/a	0.9	0.3	n/a	0.0	3.8	n/a	4.2	60.3
85	n/a	n/a	4.3	n/a	n/a	4.7	n/a	n/a	5.2	n/a	n/a	64.8
86	n/a	30.0	5.8	n/a	45.8	21.5	n/a	0.8	20.3	n/a	8.8	41.9
96	0.1	0.2	13.0	0.0	0.5	0.2	0.0	0.0	2.1	22.2	36.3	46.9
115	n/a	n/a	13.3	n/a	n/a	47.0	n/a	n/a	2.5	n/a	n/a	30.8
135	n/a	21.4	7.9	n/a	0.0	25.8	n/a	0.0	3.4	n/a	0.0	45.3
174	n/a	9.1	1.9	n/a	4.0	4.0	n/a	0.4	8.9	n/a	36.9	65.8
175	n/a	12.0	0.9	n/a	7.3	21.4	n/a	0.3	15.6	n/a	55.6	51.5
182	15.8	n/a	7.4	0.0	n/a	75.8	0.0	n/a	2.6	63.2	n/a	4.7
183	5.8	n/a	11.0	0.0	n/a	43.1	0.0	n/a	2.4	6.9	n/a	26.6
185	n/a	n/a	18.4	n/a	n/a	18.8	n/a	n/a	2.4	n/a	n/a	48.8
186	3.5	n/a	6.6	1.8	n/a	5.8	67.6	n/a	0.1	5.3	n/a	12.8
187	n/a	n/a	39.7	n/a	n/a	0.0	n/a	n/a	0.0	n/a	n/a	27.6
210	n/a	n/a	45.6	n/a	n/a	8.8	n/a	n/a	5.3	n/a	n/a	25.9
222	2.7	n/a	48.2	0.0	n/a	29.7	0.0	n/a	0.5	1.5	n/a	11.8
224	n/a	n/a	2.9	n/a	n/a	2.7	n/a	n/a	0.1	n/a	n/a	92.6
226	1.9	n/a	2.0	0.0	n/a	0.7	0.0	n/a	0.0	83.5	n/a	7.1
231	11.1	1.4	16.9	0.0	0.5	44.3	0.0	0.0	2.9	50.8	2.3	32.8

n/a = no water at time of sampling event

Coleo=Coleoptera, Ephem=Ephemeroptera, Odon=Odonata, Chiron= Chironomidae