Assessment of Floodplain Wetlands of the Lower Missouri River Using a Reference-based Study Approach: Part I, Determination of reference condition.

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Introduction

Floodplain wetlands are critical elements of riverine ecosystems, sustaining biodiversity, storing water and sediments, and ameliorating flood events. Floodplain wetlands of big rivers have been impacted by many anthropogenic activities, including draining, conversion, and chemical and physical alteration resulting from land and water management practices. Within our study area of the lower Missouri River floodplain (Figure 1), agriculture is the greatest landscape stressor; channelization is the primary regional stressor. If this reach lacked dams, seasonal flow in the lower Missouri River could approximate historic conditions. However, historic hydrologic patterns have been altered by flow regulation, bed degradation, and levee construction. The cumulative affects of these management activities have reduced the diversity and abundance of wetlands in this reach, and the ecological health of remnant wetlands continues to decline due to surface water loss, reduced groundwater levels, siltation, and land conversion. Additionally, encroachment of woody vegetation into herbaceous wetlands is an ongoing problem. Despite the importance of floodplain wetlands, there are few site-specific data about their physical, biological, and chemical attributes. Trend data about wetland populations also are limited.

Study Plan

A reference-based study approach was employed that would allow development, testing, and deployment of assessment tools with wide applicability and impact. The project design matched closely with the regional needs and priorities of the US Environmental Protection Agency (EPA). The assessment tools will be most useful for Level 1 (landscape assessment using a geographic information system (GIS) and remote sensing) studies but could be applicable to Level 2 and Level 3 studies (see Fennessy *et al.* 2004).

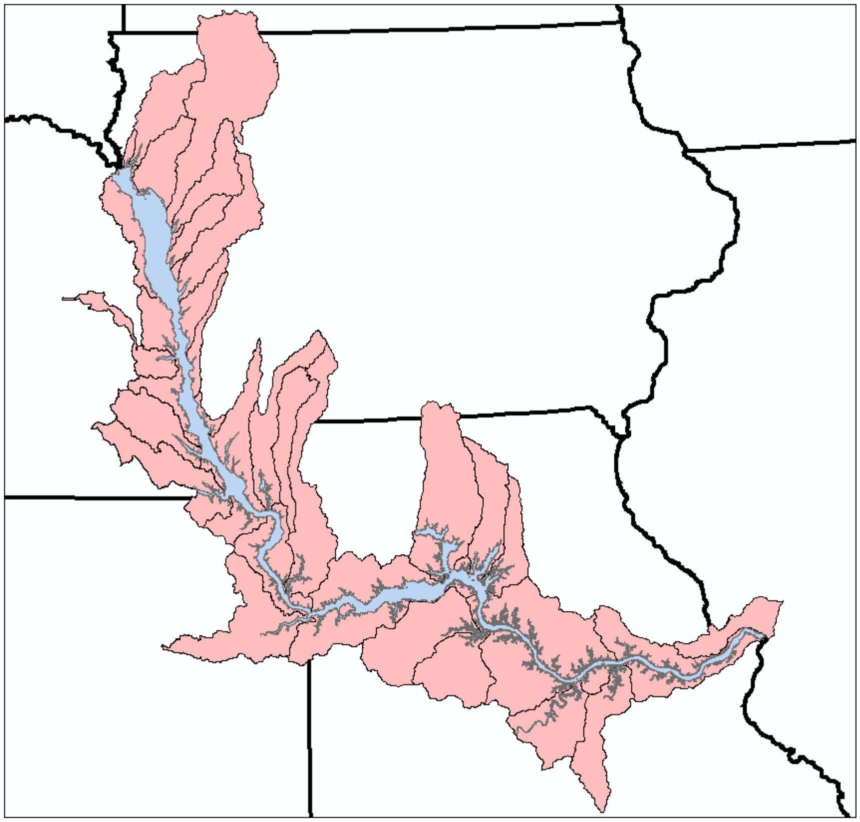

Figure 1. Missouri River wetlands study area showing 20-m floodplain (light blue) and 8-digit HUC's that constitutes the local drainage areas of the lower Missouri River region (pink).

For our study, a subset of reference wetlands in the lower Missouri River valley was the resource of interest. The monitoring objective was to find and examine the best remaining wetlands to help develop rapid assessment tools that ultimately can be used for region-wide summaries both within and outside the Missouri River valley. Limitations included seasonal time frames and availability of staff and/or equipment. National Wetlands Inventory flood maps (http://www.fws.gov/nwi) and a flooding algorithm developed by Jude Kastens of the Kansas Biological Survey (Appendix 1) were used to narrow the target area and to select suitable study sites within it. Subpopulations were then defined by imposing class and size selection criteria.

Sample sites were selected within a spatially hierarchical sampling framework to guarantee spatial balance across the landscape.

From a mapping perspective, wetlands and lakes were manageable as discrete polygons (as opposed to streams and estuaries, which are continuous). In this study, the population was sampled as a discrete population such that large and small reference wetlands had the same probability of being selected.

The reference-based study philosophy also extended to field methods. Field methods developed by the EPA Aquatic Resource Monitoring (ARM) group emphasize the use of quantitative metrics or presence/absence scores that have known precision and accuracy (http://www.epa.gov/nheerl/arm/). ARM has not developed methods explicitly for wetlands, so a suite of proven field techniques that yield quantitative measurements were used for this study. Our methods were adapted from the EMAP ARM techniques and the 2006 EPA Nutrient Criteria Technical Guidance manuals for wetlands which can be found at http://www.epa.gov/waterscience/criteria/nutrient/guidance/wetlands/index.html.

The goal of the study was to develop rapid assessment tools by examining about 40 reference sites for water quality and physical, floristic, and landscape attributes. Objectives were to (1) identify candidate reference sites using GIS screening tools; (2) verify and evaluate reference sites (contact landowners, verify site suitability, and conduct evaluations); (3) develop assessment tools (enumerate assessment criteria and metrics, develop assessment protocols and instruments); and (4) produce a final report and project deliverables (Figure 2).

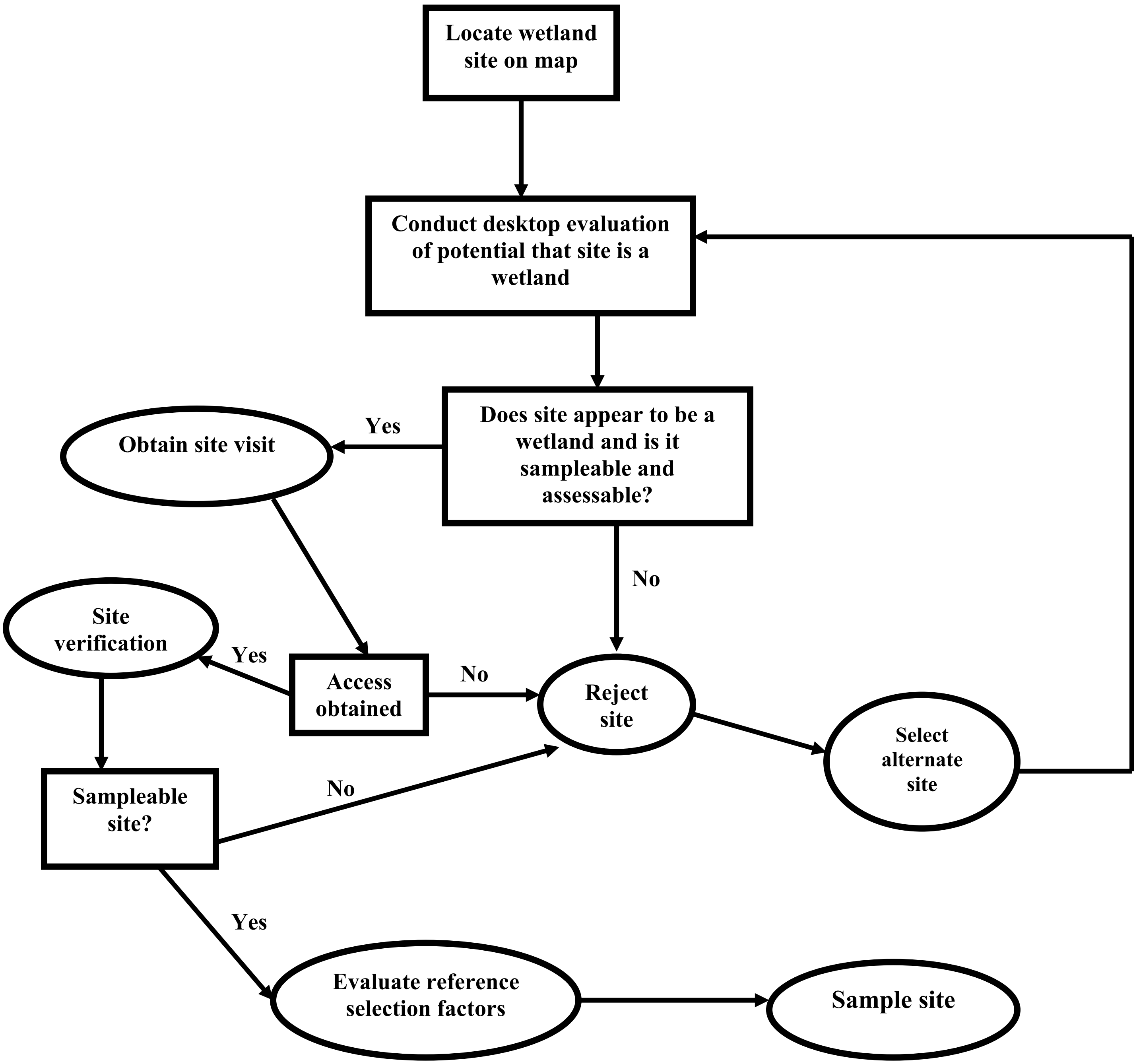

Figure 2. Missouri River floodplain wetland assessment site evaluation process used in this study. TopoZone, GoogleEarth^{TM}, and NWI maps were used to locate potential wetlands of interest.

Methods and Materials

GIS-based Wetland Identification

The first step was to identify candidate reference sites using GIS screening tools. The historic floodplain is generally the area contained by the upland valley walls and as such can be defined by drawing or digitizing the most visual breaks between the flat lowland adjacent the river course and the upland areas. This graphic delineation process often is facilitated by rather discrete lowland to upland changes in land use/land cover and topography. In this study, the Missouri River valley (i.e. 20-meter flood prone region) was estimated using an algorithm, and a map of flood-prone areas was produced (see Appendix 1 for details). This map aided identification and verification of wetlands and revealed potential connections to the river channel. The flooding algorithm was developed to simulate flood prone areas associated with various stage heights above the channel height as defined by the 30-meter digital elevation model (DEM) for the lower Missouri River valley.

Our primary source of wetland data came from the National Wetlands Inventory (NWI), which was accessed using the U.S. Fish & Wildlife Service's online Wetland Mapper tool (http://wetlandsfws.er.usgs.gov/index.html). Data from 14 separate extraction tiles were needed to obtain full coverage of the Missouri River floodplain from Sioux City, IA to St. Louis, MO. Next, the downloaded NWI data were merged into a single coverage. Two classes of wetlands (as defined by Cowardin et al. 1979) were selected for study – lacustrine and non-woody palustrine. In addition, only individual wetlands ≥10 acres in size, as determined by their polygon area, were considered for inclusion in the study. This size criterion was selected for four reasons: 1) it ensured a higher likelihood of open water during spring to early summer; 2) larger sites had a higher probability of being correctly classified in the NWI database; 3) larger sites generally supported greater levels of native biodiversity, more wetland functions, and greater wildlife values; and 4) larger sites were more likely to be in public ownership and therefore more likely to have been studied in the past. To insure that we selected enough potential wetlands of reference quality, we first over-selected by using a 5-acre threshold. Thus, all wetlands <5 acres in size were removed from each data tile. Riverine and woody palustrine polygons also were removed from the data tiles. As a result of these actions, all remaining polygons possessed a unique area attribute. The 14 tiles then were merged using ArcMap. To eliminate tile overlap, polygons were dissolved using the "area" attribute. The result was seamless wetland coverage of selected wetland polygons that spanned the study area floodplain and consisted of no spatially redundant information (i.e., no overlapping or duplicate polygons).

At this point, the wetland data were intersected with the known floodplain. A vector coverage was created capturing the extent of the 20-m floodplain raster, which was estimated using DEM data from the study area and a floodplain identification algorithm. A centroid point coverage was extracted from the wetland polygon coverage. These two coverages were intersected, and wetland polygons with centroids lying within the floodplain were retained for further analysis.

The wetland polygons were restricted to include only lacustrine and selected palustrine wetlands. Following this step, two coverages were generated, one using the 10-acre threshold and the other using the 5-acre threshold. Final tallies were 1717 polygons (168 lacustrine, 1549 palustrine) using the 10-acre threshold, and 3549 polygons (183 lacustrine, 3366 palustrine) using the 5-acre threshold. Due to apparent sample sufficiency, the decision was made to proceed according to the original plan and use the 10-acre threshold.

Wetland polygon buffers were reclassified as "reference wetlands" or "non-reference wetlands" based on buffer conditions determined from existing land use/land cover classes within the United States National Land Cover Dataset (NLCD 1992). Using the conterminous NLCD raster that we assembled for another project, the study area was subset from this dataset. NLCD classes 11 (open water), 41 (deciduous forest), 42 (evergreen forest), 43 (mixed forest), 51 (shrubland), 71 (grasslands/herbaceous), 81 (pasture/hay), 91 (woody wetlands), and 92 (emergent herbaceous wetlands) were assigned to the "reference wetland" class, and all other classes were assigned to the "non-reference wetland" class.

The wetland coverage was converted to raster with 30-m pixels, matching the DEM and NLCD data. Wetland polygon identifications were assigned to 30-m pixels with centroids in their footprints. Next we eliminated wetlands that did not lie entirely within the identified floodplain. This action, which was performed using raster layers, resulted in the retention of 1679 wetlands (1523 palustrine, 156 lacustrine).

For each wetland, a "reference class fraction" was computed within a 250-m buffer, excluding the wetland interior pixels. The operating assumption was that the greater this value, the more likely the wetland is in a reference state due to its greater isolation from human-altered landscapes. The wetlands were then stratified into upper, middle, and lower segments of the river. The upper segment runs from Sioux City, IA, to a point in southeast Nebraska between the confluences of the Big Nemaha River and Little Nemaha River with the Missouri River. The middle segment begins where the upper segment ends and ends at a point between Miami and New Frankfort, MO, just after the Missouri River attains its northern-most position in the interior of Missouri. The lower segment begins where the middle segment ends and ends at the confluence of the Missouri River with the Mississippi River near St. Louis, MO.

Finally, an attempt was made to use hydric soil data to identify potential reference wetlands (PRWs) within the floodplain. Hydric soil data were obtained in county-level tiles from the Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (http://soildatamart.nrcs.usda.gov/Default.aspx) and mapped within the delineated floodplain to determine how these data intersected with the wetland polygons from the NWI data. The final assessment was that these data were found to be of little utility for the task of reference wetland class assignment for two reasons: 1) hydric soils dominated much of the Missouri River valley, so that these data had marginal discriminatory ability; and 2) several county boundary seams in the data presented prohibitive discontinuities. Consequently, the hydric soils data were not investigated further in the study.

On-Site Verification of Wetlands

Using the results of the GIS analyses, fieldwork was initiated to determine the veracity of our predictions about potential reference wetlands in the floodplain. The first step in fieldwork was to verify the existence of the PRW as mapped using GIS-based NWI data. On the wetland evaluation form (Appendix 2), a stressor checklist identified factors that have caused degradation of the wetland, thus compromising its value as a reference wetland. The wetland evaluation form was completed prior to initiating any detailed, on-the-ground assessments. After completing the form, it was determined if the wetland qualified as a PRW. If the PRW did not meet requisite standards, it was eliminated from further consideration and the completed wetland evaluation form was kept as a part of the permanent project record.

Procedures for determining boundaries of the PRW generally followed those in Mack (2001). Hydrology was the primary criterion used to determine the boundaries of the PRW. Areas with a high degree of hydrologic interaction were treated as a single wetland. Boundaries between contiguous or connected wetlands were established where the volume, flow, source, or velocity of water moving through the wetland changed significantly, as might be caused by berms, dikes, rapids, falls, confluences of rivers, and other features limiting hydrologic interactions. Artificial boundaries, such as property lines, political boundaries, roads, and embankments were not used to establish PRW boundaries unless those boundaries coincided with areas where the hydrologic regime changes.

Wetlands forming a mosaic on the landscape were difficult to delineate. As a general guideline, if the area of wetlands in the patchwork was at least 50% of the total area of the landscape and the average distance between wetlands was <30 meters, the boundary of the PRW was set around the entire mosaic. However, if the area of wetlands was <50% of the total area of the landscape or the average distance between wetlands was ≥30 meters, the boundary of the PRW was set around the individual wetlands. In such cases, one wetland (usually the largest one that is least impacted by anthropogenic factors and of an appropriate wetland class) was selected as the PRW.

Some wetlands were contiguous with streams, rivers, or ditches. As a general guideline, wetlands contiguous to a stream, river, or ditch were treated as distinct if they were separated from each other by either 1) non-wetland corridors >61 m (200 ft); or 2) wetland corridors >61 m (200 ft) long and <15 m (50 ft) wide, including the stream or river channel at its widest point. Wetlands located on opposite sides of a steam or river were scored as a single unit unless the stream bed or its meander channel averaged >61 m (200 ft) wide.

For this study, only lacustrine and non-woody palustrine wetlands were to be characterized. During the GIS-based portion of the assessment, only those wetlands identified on NWI maps as lacustrine or non-woody palustrine wetlands were included. However, successional changes or mapping errors meant that a PRW may not currently support vegetation characteristic of one of those two classes. General visual inspections of the site were performed to determine the vegetation class or classes represented. If the PRW did not support the appropriate vegetative community, the wetland was eliminated from further consideration, and the completed wetland evaluation form was kept as a part of the permanent project record.

The final step in the PRW evaluation was to determine the size of the wetland. The size of each PRW was estimated during the GIS-based portion of the assessment and had to be verified in the field. Each PRW must have been ≥10 acres in size to be considered further. If the PRW met the minimum size criterion, the rapid assessment part of the protocol proceeded. If the PRW did not meet the minimum size criterion, the wetland was eliminated from further consideration, and the completed wetland evaluation form was kept as a part of the permanent project record.

Water Chemistry

A composite water sample was collected from each wetland by combining equal volumes (250 ml) of water from a random transect point on each of four transects placed across the width of the wetland. The four 250 ml sub-samples were combined into a brown glass jar and stored on ice until delivered to the CPCB chemistry laboratory for analysis. In the lab the following nutrients concentrations were measured: NO_3+NO_2, NO_2, NH_3, total nitrogen (TN), organic nitrogen (ON), PO_4, total phosphorus (TP), organic phosphorous (OP), chlorophyll *a*, pheophytin *a*, total organic carbon (TOC), and dissolved organic carbon (DOC). The following herbicides and their associated metabolites were also measured: desisoprophylatrazine, desethylatrazine, simazine, atrazine, metributzin, alachlor, metolachlor, and cyanazine.

In situ measurements of water temperature, pH, specific conductance, turbidity, and dissolved oxygen (DO) were obtained with a Horiba® U-10 Water Checker. Measurements were taken at the water's median depth. Horiba measurements were taken near transect points where water grab samples were taken for the composite water sample after the water samples were taken. Thus, there were three separate sets of in situ measurement for each wetland. All observations were recorded on the water chemistry data sheet (Appendix 3). To ensure accuracy of measurements, the Horiba was calibrated according to the Horiba manual procedures prior to every sampling trip or once every other week in field season depending on which came first.

Vegetation/Floristic Quality Assessment

The first step was to draw the approximate boundaries of each lacustrine or non-woody palustrine plant community at the site on the aerial photo provided with field forms. To be mapped, a plant community had to be ≥3 acres in size. Plant communities <3 acres in size were identified and listed as present, but not mapped separately. Rather they were included within a larger, surrounding or adjacent plant community.

A floristic quality assessment (FQA) was performed at each study site for each mapped plant community. Assessments from the same site but representing different plant communities were kept separate. FQA was conducted by the field team botanist, who was assisted by other team members where possible. It was the responsibility of the team botanist to confirm all identifications reported to him/her by other team members, and he/she had the final say in all determinations. A master species checklist was used for palustrine or lacustrine communities to document each native and naturalized species observed within each plant community (Appendix 4). Species not on the master checklist but observed within a plant community were added. In lacustrine communities dominated by submerged aquatic macrophytes, it sometimes was possible to identify the representative species by walking the shoreline, or by wading in the shallow water near the shoreline. In deeper water, a canoe was used along with a rake or dip net to obtain samples of submerged vegetation from scattered locations.

At each site, plants that could not be identified definitively by the field team during FQA were collected, pressed, and taken to the R.L. McGregor Herbarium, University of Kansas (KANU), where they were identified. Once identified, these species were added to the FQA field survey form for the appropriate site. Vouchers were collected of all flowering/fruiting vascular plants observed at every 5th reference site. Vouchers for all flowering/fruiting graminoids (grass-like plants, primarily members of the Cyperaceae, Juncaceae, and Poaceae) observed at every 3rd site were collected. Potential identification problems were noted and the field team was notified. All vouchers were deposited, databased, and maintained at KANU.

After the FQA was completed, a 10 m^2 circular plot was placed within each primary plant community. A pin or stake was placed at the centroid of the plot. The centroid of the plot was recorded with a GPS. A plant community survey form listing all species growing in the plot was recorded. Canopy cover of each species in the plot was visually estimated and recorded to the nearest five percent. Canopy cover data was used later to confirm plant community identifications by comparing the data against descriptions available in regional and national plant community classifications. At lacustrine sites where macroplot data could not be collected due to deep water, this step was skipped, or if the water clarity was high enough it was performed from a canoe.

After returning from the field, presence/absence data from FQA was entered into an Excel application loaded with state-specific coefficients of conservatism. The following site metrics were calculated: total species richness, percent non-native species, mean conservatism (all species), mean conservatism (native species only), floristic quality index (all species), floristic quality index (native species only), and number of state-rare species.

All water chemistry and vegetative/FQA data were used to assess the effectiveness of the GIS-based protocols to identify potential reference wetlands. Data also were used to compare water chemistry and FQA to determine the reference potential of wetland sites.

Results

GIS-based Wetland Identification

The floodplain algorithm yielded a map showing the entire floodplain flooded 20 meters above base flow height (Figure 1). Wetland scientists and river ecologists can use this approach to examine large reaches of the floodplains in identifying how connected floodplain features (e.g., wetlands, oxbow lakes, and bottomland forests) are to both historic and current river flows.

The intersection of the NWI wetland data with the modeled floodplain raster created wetland polygons with centroids lying within the floodplain (Figure 3). These wetland polygons were restricted to include only lacustrine and non-woody palustrine wetlands. Two coverages were generated, one using the 10-acre threshold and the other using the 5-acre threshold. Final tallies were 1717 polygons (168 lacustrine, 1549 palustrine) using the 10-acre threshold, and 3549 polygons (183 lacustrine, 3366 palustrine) using the 5-acre threshold. Due to perceived sample sufficiency, we decided to proceed according to the original plan and use the 10-acre threshold.

Wetland polygons were reclassified as "reference wetland" or "non-reference wetlands" based on United States National Land Cover Data (NLCD). Using the conterminous NLCD raster that we assembled for another project, the study area was subset from this dataset. NLCD classes 11 (open water), 41 (deciduous forest), 42 (evergreen forest), 43 (mixed forest), 51 (shrubland), 71 (grasslands/herbaceous), 81 (pasture/hay), 91 (woody wetlands), and 92 (emergent herbaceous wetlands) were assigned to the "reference wetland" class, and all other classes were assigned to the "non-reference wetland" class (Figure 4).

The wetland coverage was converted to raster with 30-m pixels, matching DEM and NLCD. Wetland polygon IDs were assigned to 30-m pixels with centroids in their footprints. Next, we eliminated wetlands that did not lie entirely within the identified floodplain. This action, which was performed using raster layers, resulted in the retention of 1679 wetlands (1523 palustrine, 156 lacustrine).

Finally, of the remaining 1679 wetlands, those with polygons confined to public lands were targeted for sampling. It was believed that sites on public land would be more accessible and more likely to exhibit the requisite characteristics of a PRW due to public land management practices. The possibility that wetlands on public lands were likely to have been studied previously also was considered as a positive reason to focus, at least initially, on sites on public land (Table 1).

Attempts to utilize hydric soils data to back up the NWI data-derived wetlands failed largely due to incongruencies between the classification of hydric soils between states and even between counties in the same state (Figure 5 and Figure 6).

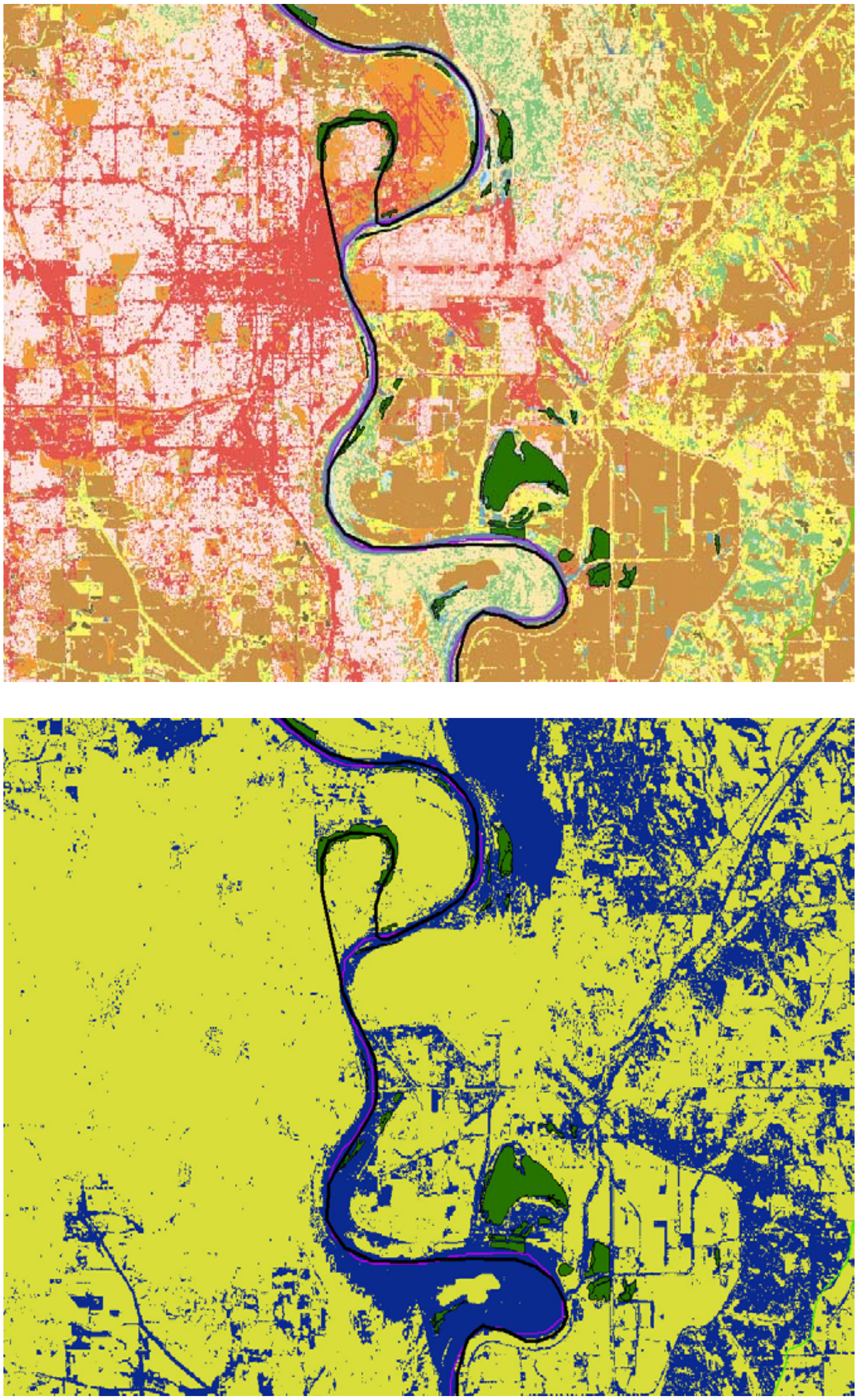

Figure 4. Missouri River wetlands study area just downstream of Omaha-Council Bluffs region. Omaha and Council Bluffs are located in the center of the image. TOP MAP: Actual LULC map using NLCD categories described in text. BOTTOM MAP: LULC map showing reference (blue) and non-reference (yellow) land cover categories. In both maps the identified wetland polygons are in green.

Table 1. Selected potential reference wetlands located on public land.

NAME	REFERENCE VALUE	WETLAND ID	STATE	COUNTY
Browns Lake State Park	0.90	701	IA	Woodbury
Browns Lake State Park	0.87	1584	IA	Woodbury
Browns Lake State Park	0.76	1295	IA	Woodbury
Browns Lake State Park	0.76	1586	IA	Woodbury
Browns Lake State Park	0.75	1202	IA	Woodbury
Browns Lake State Park	0.71	939	IA	Woodbury
County Park	1.00	374	MO	Saint Louis
County Park	0.98	548	MO	Saint Louis
County Park	0.94	1371	MO	Saint Louis
County Park	0.85	1347	MO	Saint Louis
Creve Coeur Lake Mem Park	0.80	1703	MO	Saint Louis
De Soto NWR	0.83	1624	NE	Washington
De Soto NWR	0.76	1714	NE	Washington
Decatur Bend Park	0.77	1387	IA	Monona
Decatur Bend Park	0.75	1680	IA	Monona
Decatur Bend Park	0.74	1092	IA	Monona
Huff Access County Park	0.73	571	IA	Monona
Huff Access County Park	0.73	1363	IA	Monona
Huff Access County Park	0.71	1616	IA	Monona
Lewis and Clark State Park	0.81	746	IA	Monona
Lewis and Clark State Park	0.78	1187	IA	Monona
Lewis And Clark State Park	0.76	1608	IA	Monona
Lewis and Clark State Park	0.75	1662	IA	Monona
Riverfront Park	0.79	957	MO	Jackson
Swope Park	0.89	1084	MO	Jackson
Tyson Island State WMA	0.94	1043	IA	Harrison
Tyson Island State WMA	0.90	1238	IA	Harrison
Tyson Island State WMA	0.90	1594	IA	Harrison
Tyson Island State WMA	0.88	1074	IA	Harrison
Tyson Island State WMA	0.87	1317	IA	Harrison
Tyson Island State WMA	0.82	498	IA	Harrison
Tyson Island State WMA	0.78	1394	IA	Harrison
Van Meter St Park	0.72	196	MO	Saline
Weldon Spring WA	0.72	46	MO	Saint Charles

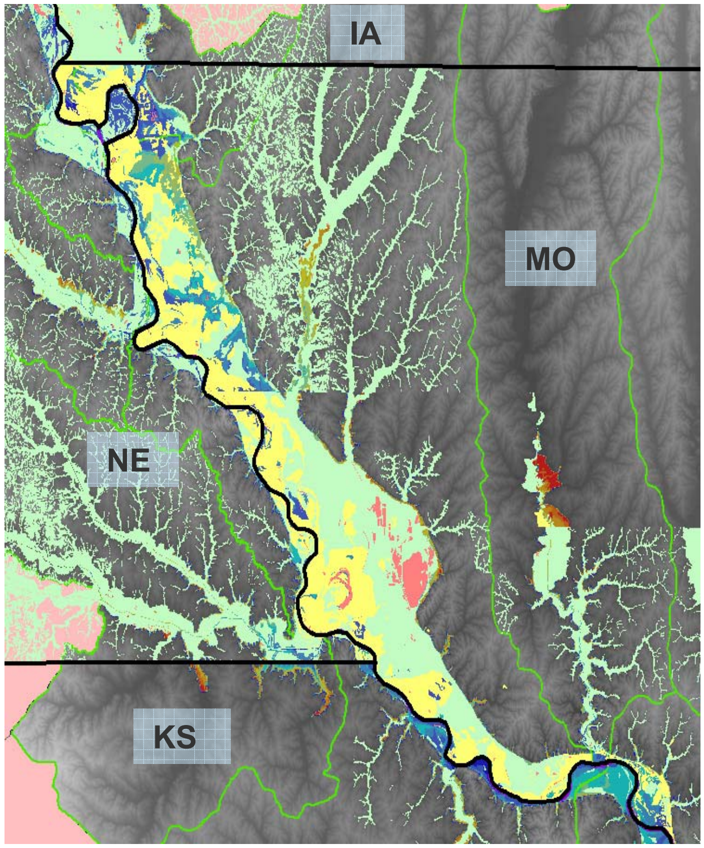

Figure 5. Hydric soils maps from the Missouri River valley study area showing discontinuities in hydric soils classification between states.

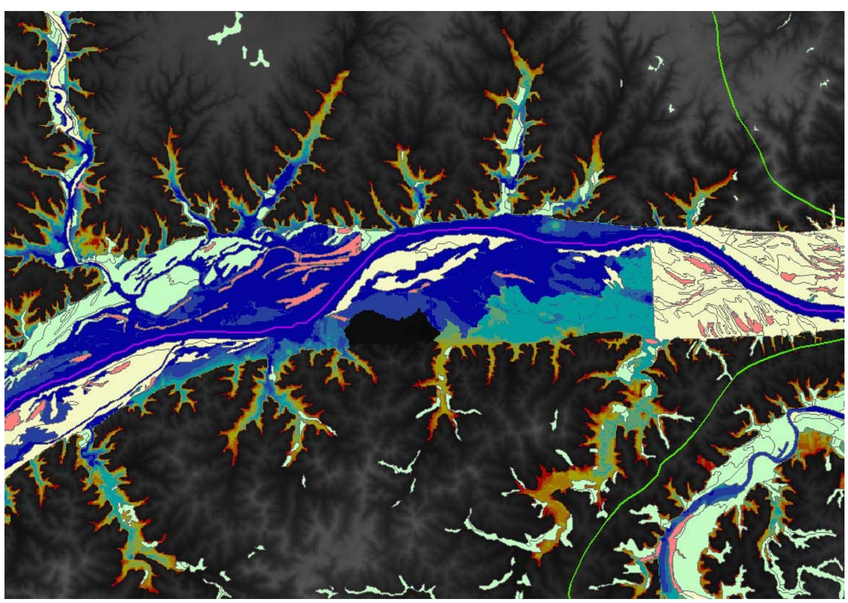

Figure 6. Hydric soils maps from the Missouri River valley study area showing discontinuities in hydric soils classification between counties in central Missouri.

On-Site Verification of Wetlands

First, 15-25 sites identified by the GIS procedures were eliminated as PRWs through examination of aerial photos and satellite images in the laboratory, which suggested that these sites no longer existed as wetlands. Sampling was concentrated on the upper (18 sites) and middle (10 sites) sections of the lower Missouri River (Table 2) and occurred primarily on public lands, such as national wildlife refuges and state wildlife management areas. Twenty-eight PRW sites were visited between mid-July and late August of 2005. Upon on-site evaluation, two sites were eliminated from consideration because of access issues (Table 2), while four sites were rejected as PRWs because they no longer existed as wetlands (two sites), or were highly managed for conservation and thus not representative of a natural reference wetland (two sites). Of the remaining 22 sites, nine of the sites were misclassified by the NWI (Cowardin 1979): two classified as palustrine were really lacustrine, and seven classified as lacustrine were really palustrine (Table 2). Four of these 22 sites contained no open water at the time of visit, so only FQA data was collected. Only 18 sites (10 lacustrine and 8 palustrine) were examined for both FQA and water chemistry.

Table 2. List of visited and evaluated potential reference wetlands. The sites labeled with a (*) indicate the sites that were sampled and then determined to be non-reference in the analysis. Sites labeled with a (^) indicate the sites that were evaluated and determined to be misclassified by the NWI. See Appendix 9 for explanation of the NWI habitat classification scheme.

Site Names	Site_ID	NWI Habitat Classification	Lat.	Long.	FQA performed	Water sampled	Rejected
Big Lake*	UL1413	L2UBKGh	41.29599	-95.86308	x	x	
Blackbird Bend	UP1642	L1UBHh	42.0629	-96.2687			x inaccessible
Blue Lake	UL1608	L2EM2KG	42.04803	-96.17571	x	x	
Blue Lake	UL1662	L1UBKh	42.03449	-96.17746	x		
Browns Lake	UP701	PEMC	42.30553	-96.33112	x	x	
Cooley Lake^	ML1677	PUBFd	39.25091	-94.2316	x	x	
DeSoto Lake^	UL962b	PEMAd	41.49416	-96.00577	x	x	
DeSoto Sand Chute^	UL1402	PUBKGh	41.52271	-96.09557	x	x	

Site Names	Site_ID	NWI Habitat Classification	Lat.	Long.	FQA performed	Water sampled	Rejected
Forney Lake	UP1398	PEMF	40.85327	-95.78052	x		
Grand Pass Complex (3+ wetlands)	MP13	PEM/FO1A	39.3046	-93.3298			x highly managed
Hamburg Bend	UP303	L2UBG	40.6009	-95.765			x inaccessible
Jackass Bend Complex (3+ wetlands)	MP1357	PEMAh	39.2161	-94.2026			x highly managed
Keg Lake*^	UP1081	L1UBH	40.98954	-95.8053	x	x	
Little Bean Marsh^	MP1494	L2UBG	39.50008	-95.02899	x	x	
Middle Decatur Bend	UL1658	L1UBH	42.00844	-96.19015	x	x	
MO River - C.B.	UP1014	PUBH	41.2158	-95.9173			x not wetland
MO River - C.B.	UP117	PUBH	41.2126	-95.9207			x not wetland
Round Lake	UP1302	PEMA	41.74194	-96.03114	x	x	
Snyder Bend Lake	UP1583	PEM/FO1Ax	42.27663	-96.33191	x	x	
Squaw Creek^	ML1276	PEMC	40.0962	-95.23602	x	x	
Squaw Creek^	ML1709	PEMC	40.0698	-95.26411	x	x	
Squaw Creek	MP1449	PEMFx	40.09353	-95.24734	x		
Swan Lake^	ML1715	PEMF	39.62194	-93.23465	x	x	
Swan Lake	MP1005	PEMC	39.60701	-93.15128	x	x	
Swan Lake	MP276	PEMF	39.61183	-93.203	x	x	
Tieville-Decatur Bend*	UP868	PUBF	42.00829	-96.23383	x	x	
Tyson Island^	UL1238	PEMCh	41.61032	-96.11201	x		
Wilson Island	UP962a	PEMF	41.4814	-96.00095	x	x	

Water Chemistry Attribute Data

Nutrient and phytoplankton pigment analyzes was completed for the 18 wetland that were sampled for water chemistry. Except for NO_2, most forms of nitrogen and phosphorus were analyzed for and found to occur at or above the detection limits (Appendix 5). Two wetlands had concentrations of TN and TP that were well above the rest of the wetlands sampled. In addition, herbicide concentrations from these wetlands suggested that nearly all of these water bodies were not contaminated by agricultural herbicides (Appendix 5). The major exception was the occurrence of low levels of atrazine and its metabolites in six of the wetlands (Appendix 5). The only other herbicide to occur above their detection limit was metolachlor, and it had quantifiable concentration in five of the 18 wetlands (Appendix 5).

Analysis was performed to determine if any significant correlations could be detected between variables. Correlations ≥0.50 were considered potentially interesting and regression analysis was performed on these variables. Regression analysis of the FQA and water chemistry data showed some correlations with R^2 values ≥0.25 (Table 3). Organic N and TN were negatively correlated with native richness (R^2 = 0.25 and 0.27, respectively). Total N and OP were negatively correlated with total richness (R^2 = 0.27 and 0.25, respectively). pH was positively correlated with percent non-native (R^2 = 0.46) and negatively correlated with mean conservatism all species and mean conservatism native species (R^2 = 0.42 and 0.39, respectively). Finally, DO was positively correlated with percent non-native species (R^2 = 0.29).

An examination of potentially significant correlations between laboratory-measured water chemistry variables was performed. There were numerous significant correlations and R^2-values ≥0.25 (Table 4). Organic N was significantly positively correlated with TN (R^2 = 0.97), OP (R^2 = 0.64), TP (R^2 = 0.54), TOC (R^2 = 0.61), DOC (R^2 = 0.45), chlorophyll-a (R^2 = 0.33), and pheophytin-a (R^2 = 0.64). Total N was significantly positively correlated with OP (R^2 = 0.68), TP (R^2 = 0.55), TOC (R^2 = 0.45), DOC (R^2 = 0.46), chlorophyll-a (R^2 = 0.38), and pheophytin-a (R^2 = 0.60). Organic P was significantly positively correlated with TP (R^2 = 0.57), DOC (R^2 = 0.48), chlorophyll-a (R^2 = 0.28), and pheophytin-a (R^2 = 0.35). Finally, chlorophyll *a* was significantly positively correlated with pheophytin *a* (R^2 = 0.84).

Table 3. Correlation matrix of water chemistry variables with percent reference buffer class and floristic variables. Only correlations greater than 0.5000 are reported. Numbers in () are the R^2 value for the relationship, those in bold are greater than 0.25.

	Organic N	Total N	Organic P	Total P	Chlor-a	Pheo- a	pH	Water Temp.	Conductivity	Turbidity	DO
Percent Reference Buffer Class								0.5003 (0.21)		0.5847 (0.15)	
Total Richness		**-0.5556 (0.27)**	**-0.6529 (0.25)**	-0.7367 (0.21)	-0.5349 (0.24)	-0.5277 (0.24)		-0.5134 (0.22)			
Native Richness	**-0.5000 (0.25)**	**-0.5888 (0.27)**	-0.6209 (0.21)	-0.6973 (0.23)	-0.5444 (0.23)	-0.5093 (0.21)					
Percent Non-Native							**0.6147 (0.46)**				**0.5279 (0.29)**
Mean Conservatism All Species				0.5250 (0.06)			**-0.6415 (0.42)**		-0.6581 (0.04)		
Mean Conservatism Native Species				0.5624 (0.09)			**-0.5253 (0.39)**		-0.6594 (0.02)		

Table 4. Correlation matrix of the water chemistry variables. Only correlations greater than 0.5000 are reported. Numbers in () are the R^2 value for the relationship, those in bold are greater than 0.25.

	NO_3-NO_2	NH_3	Organic N	Total N	PO_4	Organic P	Total P	Tot. Org. C	Dis. Org. C	Chlor-a	Pheo-a
NO_3-NO_2	**1.0000**										
NH_3	0.5232 (0.08)	**1.0000**									
Organic N			**1.0000**								
Total N			**0.9762 (0.97)**	**1.0000**							
PO_4					**1.0000**						
Organic P			**0.6725 (0.64)**	**0.6945 (0. 68)**		**1.0000**					
Total P			**0.7159 (0.54)**	**0.7337 (0.55)**		**0.8947 (0.57)**	**1.0000**				
Tot. Org. C			**0.7122 (0.61)**	**0.7475 (0.45)**			0.5028 (0.13)	**1.0000**			
Dis. Org. C			**0.5607 (0.45)**	**0.5368 (0.46)**		**0.5123 (0.48)**	**0.7328 (0.42)**	0.5567 (0.19)	**1.0000**		
Chlor-a			**0.6446 (0.33)**	**0.6925 (0.38)**		**0.6945 (0.28)**	0.5645 (0.08)			**1.0000**	
Pheo-a			**0.7758 (0.64)**	**0.7585 (0.60)**		**0.6821 (0.35)**	0.6842 (0.17)			**0.7957 (0.84)**	**1.0000**

Further analysis was performed on the in situ water chemistry variables (Table 5). Secchi depth was significantly negatively correlated with TP (R^2 = 0.39), TOC (R^2 = 0.26), conductivity (R^2 = 0.54), and turbidity (R^2 = 0.28). Wetland pH values were significantly positively correlated with DO levels (R^2 = 0.47). Finally turbidity was significantly positively correlated with TOC (R^2 = 0.85) and water temperature (R^2 = 0.31).

Table 5. Correlation matrix of *in situ* water chemistry data with lab measure water chemistry data and in situ water chemistry data. Only correlations greater than 0.5000 are reported. Numbers in () are the R^2 value for the relationship, those in bold are greater than 0.25.

	Secchi Depth	pH	Conductivity	Turbidity	Dissolved O	Water Temp.
Organic P		-0.6305 (0.03)				
Total P	**-0.6446 (0.39)**	-0.6821 (0.01)	-0.5666 (0.03)		-0.5067 (0.06)	
Tot. Org. C	**-0.6212 (0.26)**			**0.5772 (0.85)**		
Dis. Org. C	-0.6178 (0.19)					
Chlorophyll-a						0.5142 (0.18)
Pheophytin-a						0.5039 (0.11)
Secchi Depth	**1.0000**					
pH		**1.0000**				
Conductivity	**0.5052 (0.54)**	0.6533 (0.08)	**1.0000**			
Turbidity	**0.7490 (0.28)**		-0.5955 (0.02)	**1.0000**		
Dissolved O		**0.7193 (0.47)**			**1.0000**	
Water Temp.			-0.5670 (0.21)	**0.7620 (0.31)**	0.7193 (0.01)	**1.0000**

Analysis revealed some potentially interesting non-significant relationships found between the water chemistry variables and two groups of wetlands, reference and non-reference. The two groups resulted from the misclassification of wetlands using the percent reference buffer classification. For the 18 sites with water chemistry data, three were obviously non-reference based on on-site evaluations using our site evaluation forms (Appendix 2). These three sites were classified as PRW using the GIS techniques, but were eliminated from consideration as PRWs during the on-site evaluations. Using these two groups, NH_3, chlorophyll-a, and TN were higher in the non-reference groups while total P was higher in the reference group (Appendix 6).

Vegetation/FQA Attribute Data

Statistical analysis of the FQA data revealed no significant relationship between nutrient concentration and percent reference buffer class (Appendix 7). Among the sites sampled, total richness ranged from 11-67 species, and native richness from 11-60 species. Percent non-native species ranged from 0-20%; it generally was lower than values seen in terrestrial plant communities in the region (Freeman unpublished data). Mean conservatism and FQI values calculated with all species usually are not used in Floristic Quality Assessment because they include non-native species. Nevertheless, we provide these values in Appendix 7. Mean conservatism and FQI values calculated with native species only ranged from 2.25-5.09 and 11.02-29.31, respectively.

Analysis was performed to determine if any significant correlations could be detected between FQA variables (Table 6). Correlations that were >0.50 were considered potentially interesting and regression analysis was performed on these variables. Regression analysis of the FQA data showed some correlations with R^2 values ≥ 0.25. Total richness was very highly positively correlated with native richness ($R^2 = 0.98$). Percent non-native was significantly negatively correlated with mean conservatism all species ($R^2 = 0.71$), FQI all species ($R^2 = 0.45$), mean conservatism native species ($R^2 = 0.56$), and FQI native species ($R^2 = 0.30$). Mean conservatism all species was significantly positively correlated with FQI all species ($R^2 = 0.47$), mean conservatism native species ($R^2 = 0.97$) and FQI native species ($R^2 = 0.41$). FQI all species was significantly positively correlated with mean conservatism native species (R^2 = 0.39) and FQI native species (R^2 = 0.99). Finally, mean conservatism native species was significantly positively correlated with FQI native species (R^2 = 0.40).

Analysis revealed some potentially interesting non-significant relationships found between the FQA variables and two groups of wetlands, reference and non-reference. The 18 sites sampled for FQA could be separated into two groups, reference condition and non-reference, for the same reasons listed above. Total plant species richness, mean conservatism, and FQI all species was higher in the reference sites and the percent non-native plants species was greater in the non-reference group (Appendix 8).

Table 6. Correlation matrix of the floristic variables. Only correlations greater than 0.5000 are reported. Numbers in () are the R^2 value for the relationship, those in bold are greater than 0.25.

	Total Richness	Native Richness	Percent Non-Native	Mean Conservatism All Species	FQI All Species	Mean Conservatism Native Species	FQI Native Species
Total Richness	**1.0000**						
Native Richness	**0.9898 (0.98)**	**1.0000**					
Percent Non-Native			**1.0000**				
Mean Conservatism All Species			**-0.7992 (0.71)**	**1.0000**			
FQI All Species			**-0.6243 (0.45)**	**0.6486 (0.47)**	**1.0000**		
Mean Conservatism Native Species			**-0.6712 (0.56)**	**0.9695 (0.97)**	**0.5697 (0.39)**	**1.0000**	
FQI Native Species			**-0.5513 (0.30)**	**0.5808 (0.41)**	**0.9887 (0.99)**	**0.5054 (0.40)**	**1.0000**

Discussion

The water chemistry analysis results for the group of potential reference wetlands were consistent with our initial expectations. Nutrient criteria for wetlands have not been established for EPA Region 7, and only a small amount of data from other comparable wetlands is available for comparison. A comparable study was performed on the Garrison reach of the Missouri River in North Dakota (Chipps et al. 2002). Their study had two groups of wetlands, seasonal and temporary. For comparison, their "seasonal wetlands" appear to be more similar to the type of wetlands examined in our study on the lower Missouri River. Based on the author's description, the seasonal wetlands in their study appear to be shallower and more ephemeral than the wetlands we examined; temporary wetlands typically contain water only for a few weeks during the spring. Furthermore, the seasonal wetlands in Chipps et al. (2002) were divided into three groups, reference (n = 5), impaired (n = 8), and random sample of wetlands (n = 16). Another study examined three remnant wetlands in Missouri, two of which, Little Bean Marsh and Forker Oxbow, were located in the Missouri River floodplain (Heimann and Femmer 1998). Finally, a different multiyear study was performed on Little Bean Marsh that provides comparable data to our study (Blevins 2004). The Blevins (2004) study collected data year round. For comparison, only data collected by Blevins between May and August was examined, as this time period corresponds with our sampling period.

A comparison of the data obtained from the studies mentioned above showed that the observed differences in the water chemistry of the wetlands were small for most variables (Table 7). Levels of TP in the reference wetlands in our study (404.0 μg/L) were more similar to the impaired and random samples of wetlands from the Chipps et al. (2002) study (600.0 and 300.0 μg/L, respectively). The reference wetlands from Chipps et al. (2002), Heimann and Femmer (1998), and Blevins (2004) exhibited lower levels of TP (100.0 μg/L, 191.0 μg/L, and 163.0 μg/L, respectively) (Table 7).

The only other comparable variable that exhibits a noteworthy difference is the level of chlorophyll-a (Table 7). Chlorophyll *a* levels were comparable in our study and the Blevins (2004) study (67.7 μg/L and 46.2 μg/L, respectively). Little Bean Marsh, the wetland studied by

Table 7. Comparison of data from this study and data from comparable wetlands studies in the Missouri River floodplain. When possible, only data from April-August from the comparable studies were used to determine means allowing for a better comparison to our study. A "-" indicates that no data were available for that variable.

		Chipps et al. (2002)				
	This study reference (n = 15)	Reference (n = 5)	Impaired (n = 8)	Random (n = 16)	Heimann and Femmer (1998) (n = 2)	Blevins (2004) (n = 1)
Mean $NO_3 + NO_2$ (mg/L)	0.1	0.1	0.2	0.0	.016	.002
Mean NH_3 (ug/L)	100.0	200.0	0.0	0.0	107.0	56.0
Mean Total N (mg/L)	2.0	1.1	1.4	1.7	0.93	1.07
Mean Total P (ug/L)	404.0	100.0	600.0	300.0	191.0	163.0
Mean Dissolved O_2 (mg/L)	7.42	9.2	9.3	10.5	6.25	5.3
Mean pH (standard units)	8.5	7.6	7.5	7.9	7.5	7.58
Dissolved Organic C (mg/L)	9.8	-	-	-	-	7.2
Turbidity (NTU)	285	-	-	-	14	-
Turbidity (FTU)	-	-	-	-	-	12
TSS (mg/L)	-	-	137	78.5	-	38.3
Chlorophyll-a (ug/L)	67.7	9.8	12.5	15.1	-	46.2

Blevins (2004), was included in our study as a site in the lower Missouri River floodplain. A similarity in the level of chlorophyll *a* was not unexpected. The means of these two studies were noticeably higher than the means from the study in North Dakota (Chipps et al. 2002) (reference = 9.8, impaired = 12.5, random = 15.1). Based on the data comparison above, the wetlands selected in our study as potential reference wetlands appear to be in relatively good condition given the current state of all Missouri River floodplain wetlands as a whole.

In the process of locating and accessing PRWs in the Missouri River floodplain, we estimate that conservatively the NWI misclassified approximately 35% of the floodplain wetlands in our study area and potentially as high as 82%, including the PRWs eliminated using aerial photos and satellite images in the laboratory.

The findings of this project were reported on three occasions. Dr. Don Huggins presented the broad scope of the project as well as initial results at the MoRap Wetlands/Aquatic Natural Resources meeting in Columbia, MO in August 2006. James Kriz presented the entire project and results at the Great Plains Limnological Society Meeting in Manhattan, KS in October 2006 and as part of the Kansas Biological Survey Seminar Series in Lawrence, KS in December 2006. The Central Plains Center for BioAssessment hosts the project's webpage at http://www.cpcb.ku.edu/research/html/wetland.htm.

Our study serves as a baseline for the reference condition of floodplain wetlands of the lower Missouri River. Further sampling of nutrient levels and floristic communities in non-reference randomly selected wetlands within the Missouri River floodplain is needed to assess the validity of what we determined to be reference condition. By sampling more wetlands in the floodplain, we could achieve a better assessment of the current state of the remaining floodplain wetlands in an overall effort to conserve high quality and restore perturbed wetlands.

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Appendix 1 - Remote sensing manuscript.

<u>Title</u>: Raster-based Floodplain and Channel Width Estimation Using Digital Elevation Models

<u>Abstract</u>: This paper describes a simple algorithm for floodplain estimation using Digital Elevation Models (DEMs) and DEM-derived hydrology information. Qualitative comparisons are made between derived floodplain boundaries and a FEMA Q3 Flood Data map for Shawnee County, Kansas, as well as a Landsat 5 scene from July 1993 portraying an actual flood event. We also demonstrate how the method can be used for estimating stream channel width, quantitatively comparing results to channel width information obtained from a Landsat 7 image and from National Hydrology Database (NHD) information.

Introduction

Floodplain delineation is an important component in assessing "what if" scenarios in hydrologic modeling, as well as for assessing flood risk and inundation extent. As defined by FEMA (FEMA 1999, p.B-6), a floodplain is "any area susceptible to inundation by water from any source." While the floodplains of many rivers (especially large rivers) are visually recognizable in most aerial photography and digital images, the actual delineation of floodplains and flood-prone areas is achieved using either extremely simple or complex procedures.

The historic floodplain is generally the area contained by the upland valley walls and as such can be defined by drawing or digitizing the most visual breaks between the flat lowland adjacent the river course and the upland areas. This graphic delineation process is often facilitated by rather discrete lowland to upland changes in land cover and topography. However, this procedure is prone to measurement errors and is difficult to reproduce due to numerous interpretational uncertainties encountered during manual floodplain identification. The other approach to identifying flood-prone areas is by using hydraulic and hydrologic models requiring numerous input variables or manual surveying methods; both approaches are expensive and time consuming to implement. The cost for such detailed studies can be more than $8000 per linear mile (Lear et al. 2000), and thus the mapping of long stream segments can become prohibitive.

The delineation of floodplains and flood prone areas within them for major river reaches is necessary and desirable at some level of accuracy to address a number of needs. Floodplain areas adjacent to and within nearly all major municipalities have been mapped using Federal Emergency Management Agency (FEMA) methods, other hydrological and hydraulic methods, or Natural Resources Conservation Service (NRCS) soils maps. FEMA maps are often dated and restricted to very localized floodplain areas because of their high cost. More rapid and affordable methods are necessary to identify flood prone areas over extensive river reaches to provide information about flood potentials that can affect floodplain development by individuals, and private and public organizations.

The method we propose has the ability to identify flood prone areas based on any number of user-determined river stage heights (e.g., 1 m, 3 m, 20 m) that exceed the estimated stream surface height. This technique allows natural resource scientists, managers, and engineers to estimate or calculate how much of the floodplain landscape would be flooded at any stage height, how often it might be flooded (if flood frequency and stage heights relationships have been determined), and how long an area might stay inundated relative to nearby areas. Wetland scientists as well as river ecologists can use this approach to examine large reaches of the floodplains in identifying how connected floodplain features (e.g., wetlands, oxbow lakes, bottomland forests) are to both historic and current river flows.

The maintenance of the natural hydrological connectivity between the river and its floodplain is critical to the health of both systems as well as wetlands and riparian areas that are found in the floodplain (Buijse et al. 2002). However, the damming, diking, and diversion of water to and from the river and its floodplains is so extensive that riverine floodplains are among the most endangered landscapes in the world (Olson and Dinerstein 1998, Tockner et al. 2002). Studies of the dynamic ecological interplay between rivers, their floodwaters, and the floodplain landscape are few. Knowing the frequency and extent of flooding within the floodplain may be useful in determining the many relationships that did exist between river and floodplain. Our technique allows scientists to examine extensive floodplain areas under numerous flood scenarios, which may lead to new understandings of river/floodplain relationships including those of floodplain wetlands.

A more immediate need and use for this flooding algorithm is the creation and use of buffers derived from elevation data as apposed to commonly used fixed-width buffers that can be generated using various GIS mapping programs. Buffers used in landscape and watershed research are most often used to examine relationships based on geospatial proximity. At best, fixed-width buffers offer an artificial buffering approach that does not take into account land use and ecological features associated with elevation and topography (e.g., soil types, natural vegetation, floodplains). In watershed management programs, fixed-width buffer strip recommendations tend to be made based on a single parameter or function. They are easier to enforce and administer by regulatory agencies but often fail to provide for many ecological functions (Castelle et al. 1994). Buffers derived with respect to local elevation and inferred drainage characteristics are more likely to represent actual landscape features such as floodplains, hill slopes, or upland areas that embody topographical landscape conditions.

The primary goal of this research is to develop an efficient algorithm for floodplain delineation that relies solely on raster elevation information. Such data are publicly available for all of the conterminous United States as well as many other parts of the world, reducing costs (in both labor and expenses) and supporting the general applicability of the method. A secondary goal is to apply the method to obtain point estimates of stream channel width, which is demonstrated. For the method to produce useful results, widths of desired floodplains (or channels) must be large enough to be meaningfully expressed in terms of the input DEM resolution. This includes both elevation resolution and grid cell size. Flow and flood dynamics are not explicitly considered in this research.

Previous Research

Traditionally, quantitative floodplain analysis involves the use of a vector lattice of (x,y,z) spatial data points to create a polygonal interpolation of the land surface in the region of interest. This surface, combined with stream reach lines (e.g., thalweg lines or channel center lines), stream cross section information (e.g., channel width, channel depth, channel capacity, cross section orientation), and a dynamic flow model, is then used to simulate flows and flooding at various flood heights and for different flooding scenarios. This modeling approach frequently requires optimization of some multiple-parameter system of equations, in addition to specialized data and field measurements necessary for model calibration.

Such GIS-based methods commonly depend on the triangulated irregular network (TIN) method for surface approximation. The TIN method uses a set of spatial data points (nodes) and corresponding surface values (typically elevation values when hydrologic modeling is the research context) to create a continuous, piecewise triangular approximation to the surface.

Consequently, the surface corresponding to each triangular component is approximated by a plane, which has the effect of capturing terrain variation present in the network of nodes but smoothing variations occurring between nodes. More points are needed where more detail is desired, such as in areas of complex relief. Moderate-to-high resolution raster elevation data may alleviate some of the detail problems, but these suffer other limitations due to the uniform grid spacing. For example, flat areas are inefficiently over-modeled (increasing computation time), and in some cases appear more or differently variable than they truly are because of measurement and/or estimation error. For a succinct discussion about the problems associated with digital topographic representation, see Carter (1988). For an examination of the effects of DEM resolution and accuracy on drainage area and runoff volume estimation, see Kenward et al. (2000).

Techniques exist for preserving natural breaklines and boundaries in TINs, as well as for accommodating ancillary information such as known hydrologic features (for example, see Vivoni et al. 2004 and references therein). Some researchers have combined multiple resolution data sources to achieve desired results. Tate et al. (2002) use output from the U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) to seamlessly integrate high resolution stream channel data with more accurate (but lower resolution) DEM data. The output is a TIN model of the terrain specifically designed to provide a more realistic and detailed representation of the physical geography near and within the stream channel than would be obtained using a TIN derived from the DEM alone.

Bates and Roo (2000) specifically seek to approximate inundation extent using a dynamic flow model applied to raster elevation data. Exploring different spatial extents, resolutions, and model specifications, in addition to a couple of alternative methods, the maximum correspondence between predicted and actual inundation that they were able to obtain was just over 80%, looking at a single flood event in their study area. See Table 1 of Bates and Roo (2000) for a summary of other models that have been used in the literature to simulate floodplain routing and inundation.

Horritt and Bates (2001) use DEMs of varying spatial resolution to estimate inundation area and flood wave travel times using a dynamic model. They found that obtaining accurate inundation extent was dependent on model calibration but largely independent of spatial resolution. On the other hand, they found model calibration to be dependent on spatial resolution when optimizing the model to obtain accurate flood wave travel time.

For a summary of the use of GIS in floodplain mapping and management and descriptions of some of the currently available software packages used toward this end, see Shamsi (2002). Lacking in existing research is a method for floodplain identification that can be rapidly applied to large extents using readily available digital elevation data. Besides one example in Vivoni et al. (2004) where the data were coarsely resampled to ensure computability, all of the research discussed in this section involved study areas of small spatial extent (less than 1000 km^2). The method presented in this research has been designed precisely to achieve the goal of large area applicability.

Data Description and Study Area

Raw DEM data for 4-digit hydrologic unit code (HUC) 1027 (Kansas River) from the National Elevation Database (NED; Gesch et al. 2002) were acquired from http://gisdasc.kgs.ku.edu/ for the eastern Kansas study area (see Figure 1). The NED, which is updated bimonthly, comprises a mosaic of best-available DEM data derived from United States Geological Survey (USGS) 1:24,000 topographical quadrangle maps. Stream network data (also derived from USGS 1:24,000 topographical quadrangle maps) for HUC 1027 were obtained from the National Hydrology Database (http://nhd.usgs.gov/index.html) and were used to improve the positional accuracy of hydrology information derived from the DEM.

The DEM was processed as follows to obtain regional raster hydrology information. First, the NHD stream reach network was "burned" into the DEM using the AGREE model (Hellweger 1997), resulting in a conditioned DEM. Pixels along the NHD stream reach were prescribed a burn depth of 20 m, and a 10-m gradient was imposed on a three-pixel, two sided (i.e., three pixels on each side) stream buffer region to minimize paralleling of stream network segments later in the procedure. The sinks in the conditioned DEM were filled, and a flow direction map was generated from the filled, conditioned DEM (Jenson and Domingue 1988). Using the flow direction map, we derived a flow accumulation map by tabulating the size (in pixels) of the reach (inflow) of each pixel in HUC 1027. Finally, using a flow accumulation value of 1500 pixels, a synthetic stream network was extracted from the flow accumulation map. Fill, flow direction, and flow accumulation were calculated using hydrologic functions found in

ArcInfo GRID. The AGREE model was implemented using ArcInfo commands programmed using ARC Macro Language (AML).

The use of the NHD stream conditioning procedure improves the correspondence between the derived synthetic stream network and the NHD network, which is assumed to be accurate (see Saunders 1999 for a comparison of different DEM conditioning methods). However, streams (particularly those with relatively flat floodplains) can meander and change path over the course of just a few years, degrading positional correspondence of the NHD data with the actual network. Such mismatches can inhibit accuracy of any subsequent hydrologic analysis. See Figure 2 for two of the most severe discrepancies of this nature occurring in our study area, which we now describe.

A small sub-basin, 8-digit HUC 10270102 (Middle Kansas River), was extracted from all of he data layers described above (see Figure 1). This drainage basin comprises our study area. The portion of the synthetic stream network corresponding to the Kansas River lying within this sub-basin was extracted and used for the analysis.

Floodplain Delineation Algorithm

We propose a simple technique for floodplain delineation that requires a surface elevation raster, its derivative flow direction and stream network rasters (or, instead of the stream network raster, a set of stream seed coordinates that can be propagated through the DEM using the flow direction map), and needs only a single user-defined input parameter. This parameter (denoted by h) can be thought of as "maximum flood height" or "maximum stream height above normal", with normal determined using the DEM elevation values of the individual stream pixels. In this simple procedure, floodplain reach is determined in a manner that is localized to individual stream points. The technique iterates through specified stream network pixels using the following steps:

1. Obtain the "normal stream height" value (n), which is the value of the surface elevation map at the iteration pixel.
2. Identify the unique inflow reach for the iteration pixel, ceasing a particular upland reach path once the elevation map value exceeds $h + n$. Exclude upstream pixels (and their associated

reaches) that are part of the stream network being iterated upon to avoid spatial redundancy in processing.

3. Record the location of the retained pixels (along with the pixel-specific quantities $h_p = n_p - n$, where n_p is the elevation map value for pixel p in the reach) as part of the floodplain and iterate.

Once these steps are completed for all pixels in the input stream network, the union of the retained reaches is designated as the floodplain corresponding to flood height h. The values h_p can be thought of as measures of local flood potential (or flood risk) within the identified floodplain, in the sense that the lower the value, the greater the potential for inundation compared to nearby pixels with similar downstream flow characteristics. A potentially desirable algorithm modification might attempt to scale flood height h as a function of local flow accumulation or some other quantity indicative of local stream size or stream order. Some complexities can be added to the algorithm in an attempt to improve its flexibility in this regard, but these will not be addressed in this paper.

Example Application of the Floodplain Delineation Algorithm

To examine the floodplain delineation algorithm, we have chosen the Middle Kansas River drainage basin (HUC 10270102), which comprises the drainage basin of the segment of the Kansas River roughly flowing between Manhattan, KS, and Lawrence, KS (straight line distance of approximately 100 km). This region was selected for several reasons. Most importantly, it contains a large, through-flowing waterway (the Kansas River) that possesses a large river valley. Both the channel width of the Kansas River and the river valley width are large enough so that the 30-m resolution of the input DEM is sufficient for analysis. Other desirable features of this watershed are that it contains no major reservoirs to complicate the resident stream network, and it receives inflow from just one adjacent basin (Upper Kansas River). These characteristics help simplify any DEM-derived hydrologic analysis that is performed on this watershed.

The Kansas River segment was subset from the synthetic stream network so that it could be isolated for floodplain delineation. Using the raw DEM and the accompanying flow direction map, the 20-m floodplain was identified for the Kansas River using the described algorithm.

Partitioning the floodplain pixels by their h_p values into five classes (0-4 m, 4-8 m, 8-12 m, 12-16 m, and 16-20 m), a "flood zone" map was generated, which can be seen in Figure 3(a).

In an effort to qualitatively assess the validity of the flood zone map, Federal Emergency Management Agency (FEMA) Q3 Flood Data were obtained from http://gisdasc.kgs.ku.edu/ for Shawnee Co, KS, which lies almost entirely within the study area. Similar data were unavailable for other counties intersecting the study area (see http://msc.fema.gov/statemap.shtml for a map displaying counties for which FEMA Q3 Flood Data are available). FEMA Q3 Flood Data provide digital representation of information found in FEMA Flood Insurance Rate Maps (FIRMs), which are available only in paper format. Relevant information captured in Q3 Flood Data are 100-year and 500-year floodplain boundaries, flood insurance zone designations, and floodway boundaries (see http://www.fema.gov/fhm/fq_q3.shtm and references therein for a more thorough description of these data). The latter two feature classes were derived using actual flood event data but also take into account human modification of the drainage topography, such as levees and other objects designed to control hydrologic flow and dispersion. Such information is not expected to be captured in the DEM, confounding correspondence between the Q3 Flood Data and information derived from the DEM.

A Landsat 5 Thematic Mapper (TM) scene (path 28, row 33) from July 30, 1993, depicting extensive flooding in the study area was also obtained. For comparison, a Landsat 7 Enhanced Thematic Mapper (ETM+) scene (path 28, row 33) from July 9, 2000, was acquired to portray normal flow conditions. Though not a rigorous comparison, patterns in each scene can be identified and compared to patterns in the other scenes to see if any obvious correspondences exist (see Figures 3(b)-(e)). Given that the maps contain information collected at different times using different methods and for different purposes, it is to be expected that patterns between images do not match precisely. Though we do not quantitatively evaluate correspondences between these scenes, by examining Figure 3 there is little doubt that the similarities that can be discerned are not due to chance. On the other hand, much dissimilarity is also present, which can be attributed to data error and data differences as well as method shortcomings.

Estimating Channel Width

The DEM data acquired for our study area consist predominantly of 30-m level 2 data, with the exception of the region encompassing Topeka, KS, for which higher quality 10-m data (resampled to 30-m by USGS for the NED) were used (Gesch et al., 2002). The distinction between these two source data sets can be seen clearly in the DEM and the flood zone map (see Figure 4(a)).

For this part of the analysis, the study area is the segment of the Kansas River located between the U.S. Highway 75 Kansas River bridge in west Topeka, KS, and the confluence of Muddy Creek with the Kansas River east of Topeka (see Figure 4(b)). There is a straight-line distance of approximately 17.7 km between these points. This study area lies completely within the region possessing 30-m data resampled from high quality 10-m DEM data, alleviating some concerns regarding DEM data accuracy. There are 741 stream pixels in this segment, and channel width was estimated at every tenth point (giving 75 points, beginning with the first point) using both a Landsat image and NHD channel boundary lines.

The Landsat 7 ETM+ image data (path 27, row 33) were collected on July 21, 2001. To display this scene for visual analysis, band 4 was assigned to both green and blue in a false color composite, and band 5 was assigned to red. Band 4 is commonly used to identify water because radiation from the portion of the electromagnetic spectrum from which its values are obtained is heavily absorbed by water, and thus water appears nearly black in the display. Band 5 was included to help highlight sand bars (which are considered part of the channel in this study) and thus improve the accuracy of channel width estimation. At each of the 75 points, a width was estimated using the "measure" feature of ArcMap 9.0 by connecting the two opposite bank points deemed to best represent the cross section at the stream point in question. Though contextual information was visible to assist placement of cross section endpoints during measurement, accuracy was limited by the 30-m pixel resolution of the Landsat scene.

Subjective estimation of channel width was also performed using the high resolution NHD water boundary polygon coverage. Channel cross section widths were obtained for the 75 points in a similar fashion as with the Landsat data, but with less guesswork regarding cross section end point placement because of the vector format of the data. The correlation coefficient between the Landsat-derived channel width series and the series derived from the NHD coverage was 0.843 ($R^2 = 0.71$). Due to differences in source data and map resolutions, such a seemingly low correlation was expected.

To calculate the synthetic river channel, a 1-m floodplain was derived for the study area using the raw DEM (see Figure 4(b)). The choice of 1-m (rather than 0-m) served to fill in most channel holes (predominantly caused by sand bars) while not overflowing the channel. The resulting map was presumed to represent the spatial extent of the Kansas River channel. To estimate cross sectional area at a particular stream pixel, we used the following method:

1. Extract a square window of size *d*-by-*d* (*d* in terms of pixels) from the floodplain map, centered on the target stream pixel. To simplify placement of the square window, we examine only odd values for *d*.
2. Count the number of floodplain pixels in the window and divide this number by scaling factor *s* (also in terms of pixels). The resultant value gives an estimate of channel width (in pixels) at the target stream point.

The window size *d* should be tailored to the study area. The smaller the value for *d*, the more localized the estimate, which is generally desired. However, *d* should be large enough to exceed all but perhaps a small number of the largest cross section widths that might be encountered. A quick inspection of the Landsat scene suggested that Kansas River channel width rarely exceeded 360 m in the study area, providing a first estimate for *d*. Also, it is common to see the stream reach positioned near a channel bank rather than the stream center, which suggests that a window size be at least approximately twice the average encountered channel width to accommodate such asymmetries. Considering results we obtained from two data sources (NHD and Landsat), average channel width was likely in the range of 220-250 m in our study area, suggesting a box size in the range of 440-500 m. Taking the maximum of the two window size estimates, we expected the best results to occur with $d = 15$ or 17 pixels (restricting *d* to odd values), where it is reasoned that the best balance between box size and channel width for this study area should occur.

It is preferable to have an automated method for estimation of window size. One way to do this is to first attempt to estimate the average cross section width, and then multiply this by an appropriate scaling factor (such as two, as described above). To obtain an average cross section width, we first determined the minimum sized rectangular bounding box in the image that contained all of the stream pixels in the segment under investigation. The number of floodplain pixels within the bounding box was then counted, and divided by the number of stream pixels in the bounding box to obtain a rough estimate for average cross section width. Applying this procedure to the 741-point stream segment under investigation, we determined that the average cross section width to be 8.2767 pixels. Multiplying this number by two (obtaining 16.5534) suggested that we should use an odd-integer window size of either 15 or 17 pixels, corroborating the estimate obtained from NHD and Landsat data.

We investigate two choices for the scaling factor *s*, one static and one dynamic. The first choice is setting $s = d$. This assumes that the stream cuts straight through the window center, either vertically or horizontally. Generally speaking, using a small window helps reduce stream curvature within the window, which helps support the assumption of straightness. Thus we expect (and observe; see Figure 5) that as window size grows, more meanders will be captured by the window, which should have the effect of increasing the channel width estimates.

The other choice used for *s* is setting it equal to the number of stream pixels within the window. This method allows *s* to vary with the target stream pixel in a manner that is expected to mitigate negative effects of the straightness assumption necessary when using the static choice $s = d$. This spatially dynamic choice for *s* represents a simple attempt to account for local stream geometry. The same "increasing channel width with increasing window size" effect described above was observed with this approach, though to a lesser degree than with the static scaling method (see Figure 5).

We evaluated odd window sizes ranging from $d = 9$ pixels (270 m) to $d = 29$ pixels (870 m) for both scaling methods. With the static scaling method ($s = d$), the largest correlations (R = 0.659 with Landsat, R = 0.667 with NHD) were obtained using a window of width 15 pixels (450 m). This choice for *d* also resulted in the closest match between average Landsat channel width (240.5 m) and average model estimated channel width (241.1 m), but not the closest match with average NHD channel width (228.3 m). As the DEM spatial resolution (30-m, like Landsat) dictates the resolution of the derived channel map, this latter outcome was not entirely unexpected.

With the dynamic scaling method (*s* = number of stream pixels in window), maximum correlations (R = 0.676 with Landsat, R = 0.689 with NHD) were obtained using $d = 17$ (510 m), but the closest match between average Landsat channel width and average floodplain-derived channel width was once again obtained with $d = 15$. Figure 6 shows the channel width series obtained from Landsat and the model results using $d = 15$ and dynamic scaling. Table 1 shows four estimation performance measures (root mean squared error, mean absolute percent error, mean absolute error, and linear correlation) relating NHD widths, Landsat widths, and widths obtained using $d = 15$ in both static scaling and dynamic scaling models. Though all of the results are not presented here, it is worth noting that several window sizes in the neighborhood of $d = 15$ yield reasonable results, which serves as a testament to the robustness of the complete method. Using a circular window should theoretically provide an improvement, as this may reduce the undesirable effects of stream orientation on the estimate. There may well be a better method for estimating channel width from the derived channel map, perhaps capitalizing on the channel geometry.

Conclusion

The raster-based floodplain delineation method introduced in this research is, at the very least, appropriate for floodplain simulation and identification of historic floodplain extent. We have presented visual evidence that also supports its use for flood-stage dependent floodplain estimation, though more work is needed to rigorously establish the validity of the method in this regard. The method is extremely simple and fast to implement, allowing it to be applied to continental scale DEM data without the need for down sampling. We have also shown how to use the method for channel width estimation and presented quantitative results supporting this application.

The method, like all such methods, is dependent on the age, quality, and resolution of the elevation data, as well as the quality of the derived flow direction and stream network layers. For the method to be useful, widths of floodplains (or channels) under investigation must be large enough so that expressions in terms of input DEM resolution have sufficient acuity. Furthermore, DEMs typically provide poor representation in urban areas and other areas where humans have strongly influenced the drainage and inundation topography, cautioning the use of flood zone maps derived from DEM data for such regions.

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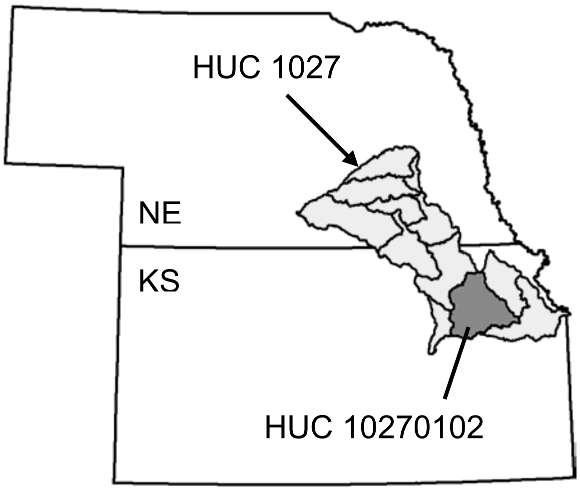
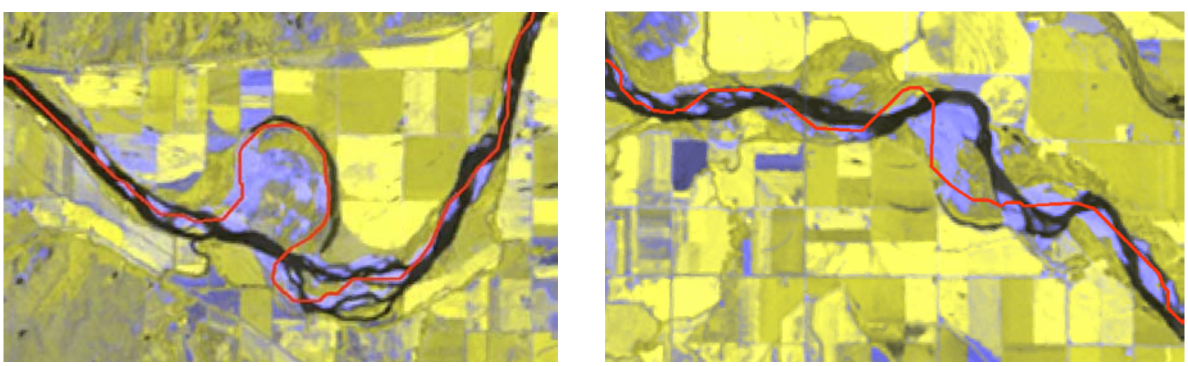


Figure 1. The study area, HUC 10270102, is located in northeast Kansas.



(a) (b)

Figure 2. This graphic shows the two most severe mismatches (in HUC 10270102) between the NHD stream flow line (red line) and actual stream location as indicated by a Landsat image from 2000. Data errors such as these negatively impact subsequent hydrologic analysis. (a) Former stream channel is now an oxbow lake. (b) Misalignment due to bad data, bad processing, or stream meander that has occurred since collection of the base data used for the NHD.

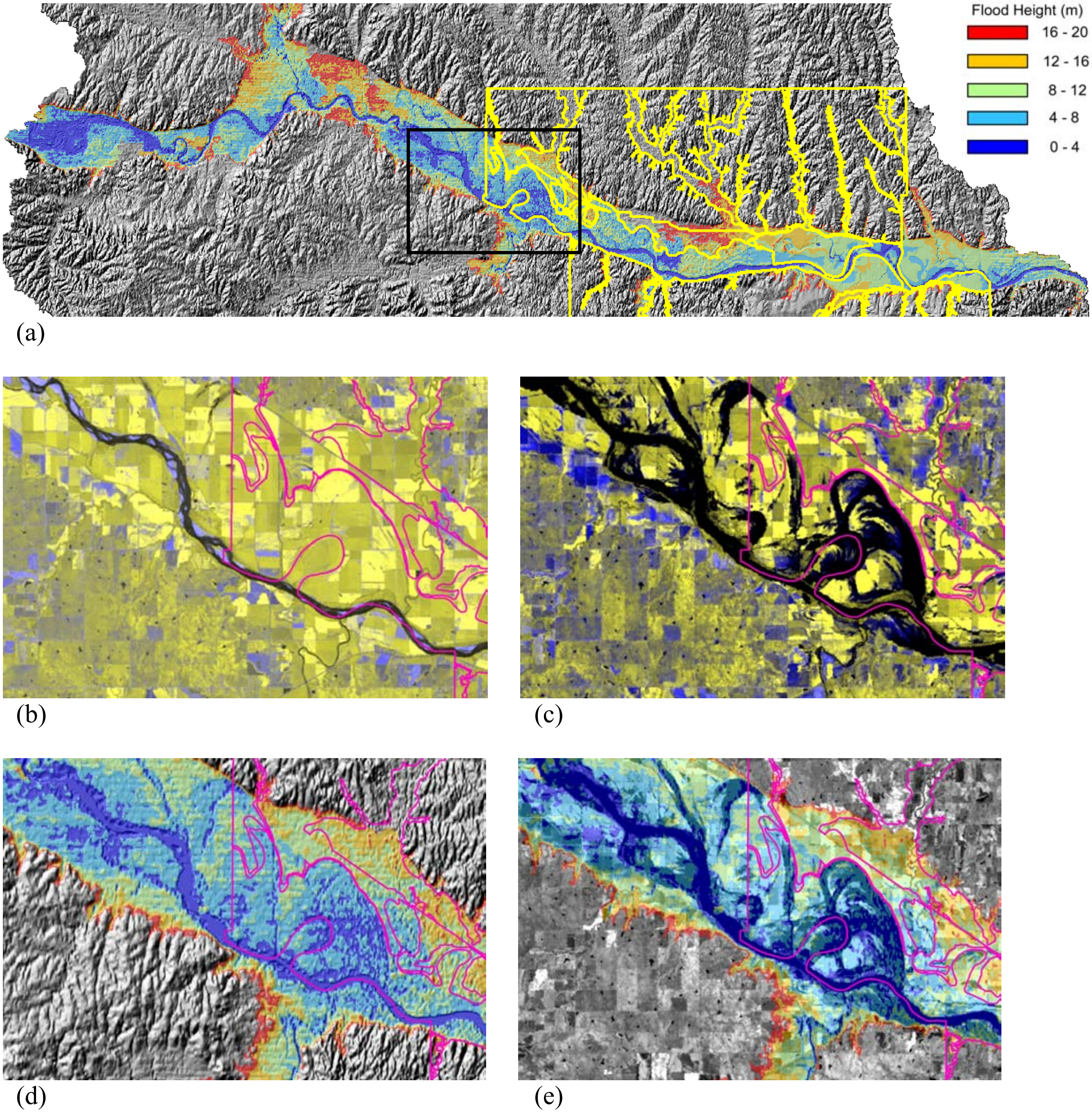
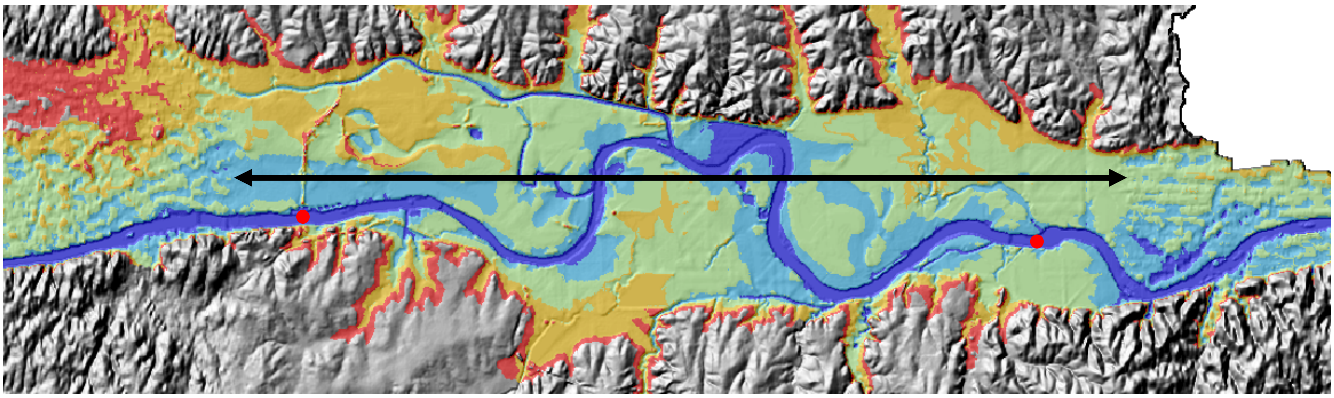
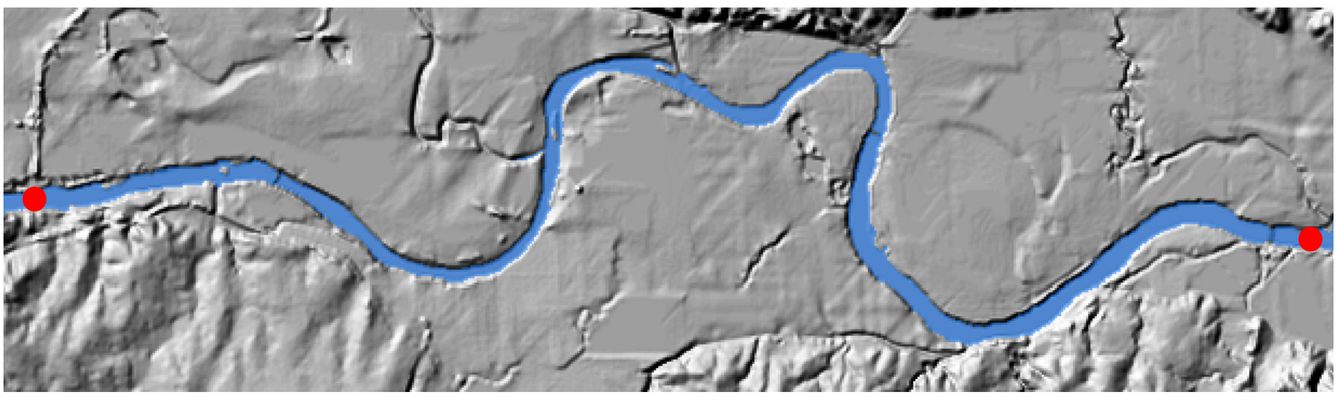


Figure 3. (a) Kansas River floodplain through HUC 10270102 (Middle Kansas River) derived using a maximum flood height of 20 m, draped over the raw DEM (shown in a hillshade relief format). The yellow linework depicts the FEMA Q3 Flood Data for Shawnee County, KS. The black box indicates the extent of the region subset depicted in (b)-(e). (b) Landsat ETM false color composite from July 9, 2000, showing near-normal river conditions (red, green = band 4, blue = band 6). The pink linework illustrates the FEMA Q3 Flood Data. (c) Landsat TM false color composite showing flooding (dark areas) along the Kansas River on July 30, 1993 (red, green = band 4, blue = band 7). (d) Floodplain transparency overlain on the raw DEM. (e) Floodplain transparency overlain on band 4 (the primary water absorption band) of the 1993 Landsat image.



(a)



(b)

Figure 4. (a) DEM (shown in hillshade relief format) with 20-m flood zone map (see legend on Figure 3(a)). The left half of the image spans the northern part of Topeka, KS. The black line indicates the extent of higher quality DEM data. (b) Channel width estimation study segment. The straight-line distance between the two endpoints (red markers) is approximately 17.7 km. The left point lies near the U.S. Highway 75 Kansas River bridge crossing, and the right point lies near the confluence of Muddy Creek with the Kansas River. The blue fill in (b) denotes the 1-m floodplain determined using the raw DEM. In the analysis, local channel width was estimated using this pixel subset.

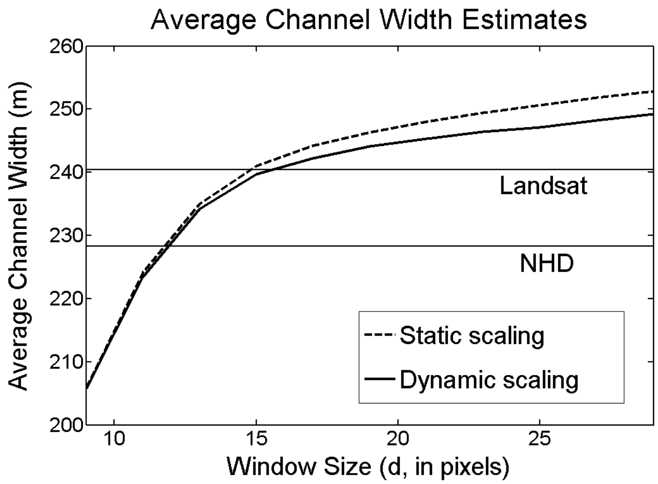


Figure 5. Average channel width estimates for different window sizes, comparing static and dynamic scaling. Average Landsat and NHD channel widths are indicated with horizontal lines.

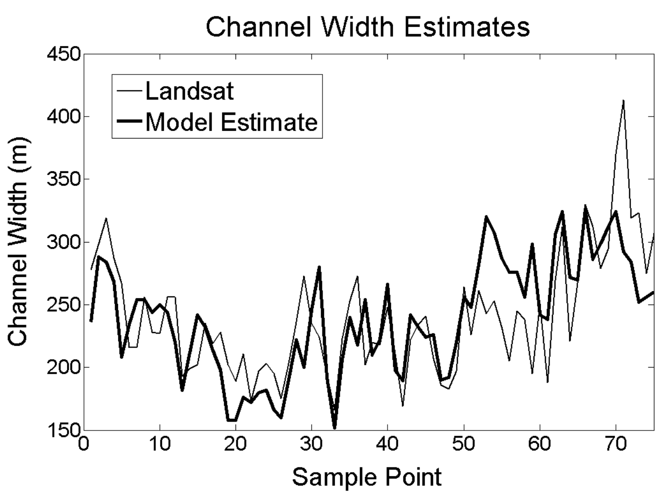


Figure 6. Two series of estimates for a series of Kansas river channel widths are shown. The “Landsat” series was determined using visual inspection and measurement. The “Model Estimate” series is described in the text.

Table 1. Channel width comparisons

	NHD	Landsat	Model 1	Model 2
Mean width	228.28	240.47	241.07	239.68
Std. dev. of width	45.25	47.75	45.08	45.03
RMSE (NHD)		28.71	39.22	38.22
RMSE (Landsat)	28.71		37.69	36.75
MAPE (NHD)		10.34	14.15	13.89
MAPE (Landsat)	9.43		12.02	11.71
MAE (NHD)		22.69	30.6	30.07
MAE (Landsat)	22.69		28.89	28.18
CORR (NHD)		0.843	0.659	0.669
CORR (Landsat)	0.843		0.667	0.684

Model 1 (static scaling) uses $s = d = 15$. Model 2 (dynamic scaling) uses $d = 15$ and s = (number of stream pixels in window). [RMSE = root mean squared error, MAPE = mean absolute percent error, MAE = mean absolute error, and CORR = correlation coefficient]

Appendix 2 - Wetland Evaluation Form.

Wetlands Evaluation Form

Site Name/Contact Information

Site Name: (if any)	Site ID Code:	State/County:	Date (dd-mm-yyyy):

Crew Initials:

Property Owner's Names & Address: Phone #:

GPS Coordinates of center of vegetative transect plot:
(report in decimal degrees)

circle one: WG589 NAD 83

Lat:

Long:

Comments:

Direction to Site/Access Issues (sketch maps on back):

Stressor Checklist

Immediate Landuse (within 50m)

%* Type

_______ Primary natural Cover (mature forest, prairie, wetlands)

_______Secondary natural Cover (second growth, restored land, CRP)

_______Low-intensity human-altered (pasture, residential unmowed, silviculture)

_______High-intensity human-altered (row crops, urban/industrial, mining, roads)

_______TOTAL (should roughly equal 100%)

* estimated to nearest 10%

Mean width of natural buffer (m): ________

Minimum width (m): _________

Maximum width (m): _________ *(up to 500m)*

Habitat Alteration (within wetland & 50m buffer)

Wetland	Buffer	
_____	_____	Mowing
_____	_____	Grazing
_____	_____	Removal of woody plants
_____	_____	Removal of emerg. veg.
_____	_____	Vehicle use
_____	_____	Cultivation
_____		Microtopography altered
	_____	Tree plantation

_______ + _______ = ______**TOTAL**
(subtotal) (subtotal)

Hydrologic Modification

_____ Ditching *inlet outlet both*

_____ Tile drains, #_____ (if multiple)

_____ Dredging

_____ Damming Type_____________

_____ Grading or filling (in or near wetland)

_____ Stormwater input/culvert, #_____

_____ Dike, berm, or levee ___________% *of wetland edge*

_____ Road or RR bed ___________% *of wetland edge*

_______**TOTAL**

Sedimentation

_____Sediment deposits/plumes

_____Eroding banks/slopes

_____Turbid water column

_____Soil disturbance in immediate upland (e.g. construction, cultivation)

_________**TOTAL**

Other Factors (check all that apply)

_____ 1. Evidence of fish present

_____ 2. Evidence of beaver activity

_____ 3. Excessive density of algae

_____ 4. Evidence of recent restoration (e.g. planting, landscaping)

_____ 5. Evidence that site is recently created wetland (e.g. absence of hydric soils)

_____ 6. Major extent (>25%) of wetland community is composed of exotic/invasive plants

_____ 7. Site has bog-like characteristics (e.g. sphagnum, floating mat, etc)

_____ 8. Site has lake-like characteristics (e.g. no substantial emergent fringe)

Site Elimination

If a site has checks for other factors #4, 5, 6, 7, or 8, it should be considered for possible elimination from the pool of potential study sites. If so, fill out the information below.
Based on the field observations, is there enough evidence to warrant dropping this site as a reference site? _________
Explain the rationale for this decision:

Comments

Appendix 3 - Wetlands Water Chemistry Data Sheet.

Water Chemistry Data Sheet
Missouri River Wetlands Project

FIELD CREW__________________________________ Page_____of _____

Wetland name			
Sample code			
Dup. (X), spike (S)			
Date (dd/mm/yyyy)[1]			
Time (24 hr.)			
Latitude & Longitude* (decimal degrees) * If different from center of vegetative plot location			
Location and instructions to the wetland			
Land use within 500m[2]			
Transect depths[3] (m) 1			
2			
3			
Maximum depth[4] (m)			
Livestock damage[5]			
Dwelling/ livestock density[6]			
Comments and observations			

Transect measures	1	2	3	1	2	3	1	2	3
Secchi depth (m)									
pH									
Conductivity (mS/cm)									
Turbidity (NTU)									
Dissolved oxygen (mg/L)									
H_2O temp. (^{o}C)									
Air temp. (^{o}C)									

[1] Use letter abbreviation foru month
[2] Indicate dominate or co-dominate land use within 500 m of the wetland (cultivated crop, pasture or hay meadow, wooded, urban, industrial, natural area)
[3] Average depth should be calculated from a minimum of three equally spaced transects perpendicular to the long axis of the wetland and consisting of no less than five measurements including edge of measurements at one meter from shoreline.
[4] Deepest observed portion of the wetland
[5] No damage or fecal matter (0), near waterbody fecal matter (1), fecal matter & trailing in and into water (2), extensive fecal matter, trailing and/or erosion. Estimated effects are relative to majority of wetland. Subjective evaluation of conditions that contribute to potential animal waste and/or sediment loading
[6] Less than 1 dwelling/ acre (0), 1-3 dwellings/acre or low livestock density (1), 4 or more dwellings/acre and/or high livestock density (2). Low livestock density is 4-5 animals/acre near the wetland; high livestock density is greater than 5 animals/acre

QA Signature__________________________________ Date_______________________PP

Appendix 4 – Palustrine and Lacustrine Wetland Plant Checklists

Missouri River Palustrine Plant Checklist

Site Name: ______________________________ **Observer(s):** ______________________ **Date:** ______________

T. _____ **R.** _____ **Section** _________ **Lat:** ______________________° **N; Long:** ______________________° **W**

_____ Acer negundo
_____ Acer saccharinum
_____ Acorus calamus
_____ Aesculus glabra
_____ Agalinis tenuifolia
_____ Ageratina altissima
_____ Agrimonia gryposepala
_____ Agrimonia parviflora
_____ Agrostis gigantea
_____ Agrostis stolonifera
_____ Alisma subcordatum
_____ Alisma triviale
_____ Alliaria petiolata
_____ Alopecurus aequalis
_____ Alopecurus pratensis
_____ Amaranthus tuberculatus
_____ Ambrosia trifida
_____ Ammannia coccinea
_____ Ammannia robusta
_____ Amorpha fruticosa
_____ Amphicarpaea bracteata
_____ Anemone canadensis
_____ Apios americana
_____ Apocynum cannabinum
_____ Asclepias hirtella
_____ Asclepias incarnata
_____ Asclepias speciosa
_____ Aster hesperius
_____ Aster lanceolatus
_____ Aster novae-angliae
_____ Aster praealtus
_____ Aster subulatus
_____ Athyrium filix-femina
_____ Bacopa rotundifolia
_____ Barbarea vulgaris
_____ Beckmannia syzigachne
_____ Bergia texana
_____ Berula erecta
_____ Bidens cernuus
_____ Bidens frondosus
_____ Bidens polylepis
_____ Bidens tripartitus
_____ Bidens vulgatus
_____ Boehmeria cylindrica
_____ Bolboschoenus fluviatilis
_____ Bolboschoenus maritimus
_____ Boltonia asteroides
_____ Brasenia schreberi
_____ Butomus umbellatus
_____ Cabomba caroliniana
_____ Calamagrostis canadensis
_____ Calamagrostis stricta
_____ Callitriche heterophylla
_____ Calystegia sepium
_____ Camelina sativa
_____ Campanula americana
_____ Campsis radicans
_____ Cardamine bulbosa
_____ Cardamine parviflora
_____ Cardamine pensylvanica
_____ Carex arkansana
_____ Carex aureolensis
_____ Carex blanda
_____ Carex brachyglossa
_____ Carex brevior
_____ Carex bushii
_____ Carex buxbaumii
_____ Carex conjuncta
_____ Carex corrugata
_____ Carex crawei
_____ Carex cristatella
_____ Carex crus-corvi
_____ Carex emoryi
_____ Carex festucacea
_____ Carex flaccosperma
_____ Carex frankii
_____ Carex granularis
_____ Carex gravida
_____ Carex grayi
_____ Carex grisea
_____ Carex hirsutella
_____ Carex hyalinolepis
_____ Carex hystericina
_____ Carex interior
_____ Carex laeviconica
_____ Carex lupulina
_____ Carex meadii
_____ Carex microdonta
_____ Carex missouriensis
_____ Carex molesta
_____ Carex muskingumensis
_____ Carex nebrascensis
_____ Carex normalis
_____ Carex opaca
_____ Carex pellita
_____ Carex praegracilis
_____ Carex scoparia
_____ Carex shinnersii
_____ Carex shortiana
_____ Carex sparganioides
_____ Carex stipata
_____ Carex tribuloides
_____ Carex vulpinoidea
_____ Carex ×subimpressa
_____ Celtis laevigata
_____ Cephalanthus occidentalis
_____ Ceratophyllum demersum
_____ Ceratophyllum echinatum
_____ Chaerophyllum procumbens
_____ Chasmanthium latifolium
_____ Chenopodium glaucum
_____ Cicuta maculata
_____ Cinna arundinacea
_____ Commelina communis
_____ Commelina diffusa
_____ Commelina virginica
_____ Conium maculatum
_____ Coreopsis tinctoria
_____ Cornus amomum
_____ Cornus drummondii
_____ Cynanchum laeve
_____ Cyperus acuminatus
_____ Cyperus bipartitus
_____ Cyperus diandrus
_____ Cyperus echinatus
_____ Cyperus erythrorhizos
_____ Cyperus esculentus
_____ Cyperus fuscus
_____ Cyperus odoratus
_____ Cyperus pseudovegetus
_____ Cyperus setigerus
_____ Cyperus squarrosus
_____ Cyperus strigosus
_____ Cyperus surinamensis
_____ Dalea leporina
_____ Daucus carota
_____ Dicliptera brachiata
_____ Didiplis diandra
_____ Dipsacus fullonum
_____ Dipsacus laciniatus
_____ Echinochloa crusgalli
_____ Echinochloa muricata
_____ Echinocystis lobata
_____ Echinodorus berteroi
_____ Echinodorus cordifolius
_____ Echinodorus tenellus
_____ Eclipta prostrata
_____ Egeria densa
_____ Elaeagnus angustifolia
_____ Eleocharis acicularis
_____ Eleocharis atropurpurea
_____ Eleocharis coloradoensis
_____ Eleocharis compressa
_____ Eleocharis engelmannii
_____ Eleocharis erythropoda
_____ Eleocharis geniculata
_____ Eleocharis lanceolata
_____ Eleocharis macrostachya
_____ Eleocharis montevidensis
_____ Eleocharis obtusa
_____ Eleocharis palustris
_____ Eleocharis verrucosa
_____ Eleocharis wolfii
_____ Ellisia nyctelea
_____ Elodea bifoliata
_____ Elodea nuttallii
_____ Elymus glabriflorus
_____ Elymus macgregorii
_____ Elymus repens
_____ Elymus submuticus
_____ Elymus virginicus
_____ Epilobium ciliatum
_____ Epilobium coloratum
_____ Epilobium leptophyllum
_____ Equisetum ×ferrissii
_____ Equisetum hyemale
_____ Equisetum laevigatum
_____ Eragrostis frankii
_____ Eragrostis hypnoides
_____ Eragrostis pectinacea
_____ Erechtites hieracifolius
_____ Erigeron philadelphicus
_____ Euonymus atropurpureus
_____ Eupatorium perfoliatum
_____ Eupatorium serotinum
_____ Euthamia gymnospermoides
_____ Eutrochium maculatum
_____ Eutrochium purpureum
_____ Festuca subverticillata
_____ Fimbristylis annua
_____ Fimbristylis autumnalis
_____ Fimbristylis puberula
_____ Fimbristylis vahlii
_____ Fraxinus pennsylvanica
_____ Fuirena simplex
_____ Galium boreale
_____ Galium obtusum
_____ Gleditsia triacanthos
_____ Glyceria striata
_____ Gratiola neglecta
_____ Gratiola virginiana
_____ Helenium autumnale
_____ Helianthus grosseserratus
_____ Helianthus tuberosus
_____ Heracleum sphondylium
_____ Heteranthera dubia
_____ Heteranthera limosa
_____ Heteranthera multiflora
_____ Heteranthera rotundifolia
_____ Hibiscus laevis
_____ Hibiscus moscheutos
_____ Hordeum jubatum
_____ Hordeum pusillum
_____ Hydrophyllum virginianum
_____ Hypericum ascyron
_____ Hypericum majus
_____ Hypericum mutilum
_____ Hypericum perforatum
_____ Hypoxis hirsuta
_____ Impatiens capensis
_____ Impatiens pallida
_____ Ipomoea lacunosa
_____ Iris brevicaulis
_____ Iris pseudacorus
_____ Iris virginica
_____ Iva annua
_____ Juncus acuminatus
_____ Juncus anthelatus
_____ Juncus arcticus
_____ Juncus brachycarpus
_____ Juncus brachyphyllus
_____ Juncus bufonius
_____ Juncus diffusissimus
_____ Juncus dudleyi
_____ Juncus effusus
_____ Juncus gerardii
_____ Juncus interior
_____ Juncus marginatus
_____ Juncus nodatus
_____ Juncus scirpoides
_____ Juncus tenuis
_____ Juncus torreyi
_____ Juncus validus

______	Justicia americana
______	Leersia oryzoides
______	Leersia virginica
______	Lemna aequinoctialis
______	Lemna minor
______	Lemna minuta
______	Lemna obscura
______	Lemna perpusilla
______	Lemna trisulca
______	Lemna turionifera
______	Lemna valdiviana
______	Leptochloa fusca
______	Leptochloa panicea
______	Lespedeza violacea
______	Leucospora multifida
______	Liatris pycnostachya
______	Lindernia dubia
______	Lipocarpha aristulata
______	Lipocarpha drummondii
______	Lipocarpha micrantha
______	Lithospermum arvense
______	Lobelia cardinalis
______	Lobelia siphilitica
______	Lobelia spicata
______	Ludwigia alternifolia
______	Ludwigia glandulosa
______	Ludwigia palustris
______	Ludwigia peploides
______	Ludwigia polycarpa
______	Ludwigia repens
______	Lycopus americanus
______	Lycopus asper
______	Lycopus rubellus
______	Lycopus uniflorus
______	Lycopus virginicus
______	Lysimachia ciliata
______	Lysimachia hybrida
______	Lysimachia nummularia
______	Lysimachia thyrsiflora
______	Lythrum alatum
______	Lythrum salicaria
______	Maianthemum racemosum
______	Maianthemum stellatum
______	Marrubium vulgare
______	Marsilea vestita
______	Mentha arvensis
______	Mimulus alatus
______	Mimulus glabratus
______	Mimulus ringens
______	Morus alba
______	Muhlenbergia frondosa
______	Muhlenbergia mexicana
______	Muhlenbergia racemosa
______	Myosotis verna
______	Myosoton aquaticum
______	Myosurus minimus
______	Myriophyllum aquaticum
______	Myriophyllum heterophyllum
______	Myriophyllum pinnatum
______	Myriophyllum sibiricum
______	Myriophyllum spicatum
______	Najas guadalupensis
______	Nasturtium officinale
______	Neeragrostis reptans
______	Nelumbo lutea
______	Nuphar advena
______	Nymphaea odorata
______	Oenothera villosa
______	Onoclea sensibilis
______	Osmorhiza longistylis
______	Packera glabella
______	Panicum anceps
______	Panicum capillare
______	Panicum dichotomiflorum
______	Panicum flexile
______	Panicum philadelphicum
______	Panicum rigidulum
______	Panicum virgatum
______	Parietaria pensylvanica
______	Parthenocissus quinquefolia
______	Parthenocissus vitacea
______	Paspalum floridanum
______	Paspalum laeve
______	Paspalum pubiflorum
______	Paspalum repens
______	Paspalum setaceum
______	Pastinaca sativa
______	Penthorum sedoides
______	Perilla frutescens
______	Persicaria amphibia
______	Persicaria bicornis
______	Persicaria hydropiper
______	Persicaria hydropiperoides
______	Persicaria lapathifolia
______	Persicaria longiseta
______	Persicaria maculosa
______	Persicaria orientalis
______	Persicaria pensylvanica
______	Persicaria punctata
______	Persicaria sagittata
______	Phalaris arundinacea
______	Phalaris caroliniana
______	Phlox pilosa
______	Phragmites australis
______	Phyla cuneifolia
______	Phyla lanceolata
______	Physalis pubescens
______	Physostegia virginiana
______	Phytolacca americana
______	Pilea pumila
______	Plantago lanceolata
______	Plantago major
______	Plantago rugelii
______	Platanus occidentalis
______	Pluchea camphorata
______	Pluchea odorata
______	Poa chapmaniana
______	Poa sylvestris
______	Poa trivialis
______	Polygala sanguinea
______	Polygala verticillata
______	Polygonum achoreum
______	Polygonum aviculare
______	Polygonum erectum
______	Polygonum ramosissimum
______	Polypogon monspeliensis
______	Pontederia cordata
______	Populus deltoides
______	Portulaca oleracea
______	Potamogeton amplifolius
______	Potamogeton crispus
______	Potamogeton diversifolius
______	Potamogeton foliosus
______	Potamogeton gramineus
______	Potamogeton illinoensis
______	Potamogeton natans
______	Potamogeton nodosus
______	Potamogeton pusillus
______	Potamogeton zosteriformis
______	Potentilla norvegica
______	Potentilla paradoxa
______	Potentilla rivalis
______	Prunella vulgaris
______	Pycnanthemum tenuifolium
______	Quercus bicolor
______	Quercus palustris
______	Quercus shumardii
______	Ranunculus abortivus
______	Ranunculus aquatilis
______	Ranunculus cymbalaria
______	Ranunculus flabellaris
______	Ranunculus hispidus
______	Ranunculus repens
______	Ranunculus sceleratus
______	Rorippa curvipes
______	Rorippa palustris
______	Rorippa sessiliflora
______	Rorippa sinuata
______	Rorippa sylvestris
______	Rotala ramosior
______	Rudbeckia laciniata
______	Rudbeckia subtomentosa
______	Rumex altissimus
______	Rumex crispus
______	Rumex fueginus
______	Rumex stenophyllus
______	Rumex verticillatus
______	Sagittaria ambigua
______	Sagittaria brevirostra
______	Sagittaria cuneata
______	Sagittaria graminea
______	Sagittaria latifolia
______	Sagittaria longiloba
______	Sagittaria montevidensis
______	Sagittaria platyphylla
______	Sagittaria rigida
______	Salix amygdaloides
______	Salix babylonica
______	Salix caroliniana
______	Salix eriocephala
______	Salix exigua
______	Salix nigra
______	Sambucus canadensis
______	Sanicula odorata
______	Schedonorus pratensis
______	Schoenoplectus acutus
______	Schoenoplectus americanus
______	Schoenoplectus hallii
______	Schoenoplectus heterochaetus
______	Schoenoplectus pungens
______	Schoenoplectus saximontanus
______	Schoenoplectus tabernaemontani
______	Scirpus atrovirens
______	Scirpus cyperinus
______	Scirpus georgianus
______	Scirpus pallidus
______	Scirpus pendulus
______	Scleria triglomerata
______	Scolochloa festucacea
______	Scrophularia lanceolata
______	Scutellaria galericulata
______	Scutellaria lateriflora
______	Setaria parviflora
______	Setaria pumila
______	Setaria verticillata
______	Sicyos angulatus
______	Silphium perfoliatum
______	Sisyrinchium angustifolium
______	Sium suave
______	Smilax herbacea
______	Smilax tamnoides
______	Solanum interius
______	Solidago gigantea
______	Sonchus asper
______	Sorghum bicolor
______	Sparganium americanum
______	Sparganium eurycarpum
______	Spartina pectinata
______	Sphenopholis obtusata
______	Spirodela polyrrhiza
______	Stachys pilosa
______	Stachys tenuifolia
______	Strophostyles leiosperma
______	Stuckenia pectinata
______	Symphoricarpos occidentalis
______	Tamarix ramosissima
______	Teucrium canadense
______	Thalictrum dasycarpum
______	Thelypteris palustris
______	Trifolium fragiferum
______	Triodanis perfoliata
______	Triosteum perfoliatum
______	Tripsacum dactyloides
______	Typha angustifolia
______	Typha domingensis
______	Typha latifolia
______	Typha ×glauca
______	Ulmus americana
______	Ulmus rubra
______	Urtica dioica
______	Utricularia gibba
______	Utricularia macrorhiza
______	Verbena hastata
______	Vernonia baldwinii
______	Vernonia fasciculata
______	Veronica anagallis-aquatica
______	Veronica catenata
______	Veronica peregrina
______	Viola bicolor
______	Viola pubescens
______	Viola sagittata
______	Viola sororia
______	Vitis cinerea
______	Vitis riparia
______	Vitis vulpina
______	Wolffia borealis
______	Wolffia brasiliensis
______	Wolffia columbiana
______	Xanthium strumarium
______	Zannichellia palustris
______	Zizia aurea

Missouri River Lacustrine Plant Checklist

Site Name: ____ **Observer(s):** ____________________________ **Date:** _________________

T. ____ **R.** ______ **Section** _________ **Lat:** _______________________° N; **Long:** _______________________° W

_____ Acorus calamus
_____ Alisma subcordatum
_____ Alisma triviale
_____ Bacopa rotundifolia
_____ Berula erecta
_____ Bolboschoenus fluviatilis
_____ Bolboschoenus maritimus
_____ Brasenia schreberi
_____ Butomus umbellatus
_____ Cabomba caroliniana
_____ Callitriche heterophylla
_____ Carex cristatella
_____ Carex crus-corvi
_____ Carex emoryi
_____ Carex frankii
_____ Carex grayi
_____ Carex hyalinolepis
_____ Carex hystericina
_____ Carex laeviconica
_____ Carex lupulina
_____ Carex muskingumensis
_____ Carex nebrascensis
_____ Carex pellita
_____ Carex praegracilis
_____ Carex scoparia
_____ Carex shortiana
_____ Carex stipata
_____ Carex tribuloides
_____ Carex vulpinoidea
_____ Carex ×subimpressa
_____ Ceratophyllum demersum
_____ Ceratophyllum echinatum
_____ Didiplis diandra
_____ Echinodorus cordifolius
_____ Egeria densa
_____ Eleocharis acicularis
_____ Eleocharis engelmannii
_____ Eleocharis erythropoda
_____ Eleocharis obtusa
_____ Eleocharis palustris
_____ Elodea bifoliata
_____ Elodea nuttallii
_____ Glyceria striata
_____ Heteranthera dubia
_____ Heteranthera limosa
_____ Heteranthera multiflora
_____ Heteranthera rotundifolia
_____ Hibiscus laevis
_____ Hibiscus moscheutos
_____ Iris brevicaulis
_____ Iris pseudacorus
_____ Iris virginica
_____ Juncus acuminatus
_____ Juncus effusus
_____ Juncus gerardii
_____ Juncus nodatus
_____ Justicia americana
_____ Leersia oryzoides
_____ Lemna aequinoctialis
_____ Lemna minor
_____ Lemna minuta
_____ Lemna obscura
_____ Lemna perpusilla
_____ Lemna trisulca
_____ Lemna turionifera
_____ Lemna valdiviana
_____ Marsilea vestita
_____ Myriophyllum aquaticum
_____ Myriophyllum heterophyllum
_____ Myriophyllum pinnatum
_____ Myriophyllum sibiricum
_____ Myriophyllum spicatum
_____ Najas guadalupensis
_____ Nasturtium officinale
_____ Nelumbo lutea
_____ Nuphar advena
_____ Nymphaea odorata
_____ Persicaria amphibia
_____ Persicaria hydropiper
_____ Persicaria hydropiperoides
_____ Persicaria lapathifolia
_____ Persicaria maculosa
_____ Persicaria punctata
_____ Persicaria sagittata
_____ Pontederia cordata
_____ Potamogeton amplifolius
_____ Potamogeton crispus
_____ Potamogeton diversifolius
_____ Potamogeton foliosus
_____ Potamogeton gramineus
_____ Potamogeton illinoensis
_____ Potamogeton natans
_____ Potamogeton nodosus
_____ Potamogeton pusillus
_____ Potamogeton zosteriformis
_____ Ranunculus aquatilis
_____ Ranunculus cymbalaria
_____ Ranunculus flabellaris
_____ Ranunculus sceleratus
_____ Rumex verticillatus
_____ Sagittaria ambigua
_____ Sagittaria brevirostra
_____ Sagittaria cuneata
_____ Sagittaria graminea
_____ Sagittaria latifolia
_____ Sagittaria longiloba
_____ Sagittaria montevidensis
_____ Sagittaria platyphylla
_____ Sagittaria rigida
_____ Schoenoplectus acutus
_____ Schoenoplectus americanus
_____ Schoenoplectus hallii
_____ Schoenoplectus heterochaetus
_____ Schoenoplectus pungens
_____ Schoenoplectus saximontanus
_____ Schoenoplectus tabernaemontani
_____ Scirpus atrovirens
_____ Scirpus cyperinus
_____ Scirpus georgianus
_____ Scirpus pallidus
_____ Scirpus pendulus
_____ Sparganium americanum
_____ Sparganium eurycarpum
_____ Spirodela polyrrhiza
_____ Stuckenia pectinata
_____ Typha ×glauca
_____ Typha angustifolia
_____ Typha domingensis
_____ Typha latifolia
_____ Utricularia gibba
_____ Utricularia macrorhiza
_____ Veronica anagallis-aquatica
_____ Veronica catenata
_____ Wolffia borealis
_____ Wolffia brasiliensis
_____ Wolffia columbiana
_____ Zanichellia palusris
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Appendix 5 – Raw Water Chemistry Data.

Table 1. Raw chemistry data for selected species of nitrogen, phosphorous, and carbon. The sites labeled with a (*) indicate the sites that were sampled and then determined to be non-reference in the analysis.

Site ID	Sampling Date	NO_3+NO_2	NO_2	NH_3	TOTAL N	ORGANIC N	PO_4	TOTAL P	ORGANIC P	Chlorophyll *a*	Pheophytin *a*	TOC	DOC
		mg-N/L	mg-N/L	µg-N/L	mg-N/L	mg-N/L	µg-P/L	µg-P/L	µg-P/L	µg/L	µg/L	mg/L	mg/L
MP1494	7/11/2005	0.05	0.00	164.00	3.79	3.58	614	1185	571.0	71.0	44.5	20.9	19.3
ML1276	7/12/2005	0.04	0.00	36.60	3.71	3.64	82.5	2030	1947.5	156.9	31.3	15.5	14.4
ML1709	7/12/2005	0.00	0.00	26.80	1.61	1.58	29.2	271	241.8	43.6	11.0	15.4	6.6
MP276	7/14/2005	0.02	0.00	23.50	1.97	1.92	12.2	238	225.8	61.3	< 1.0	19.9	16.6
MP1005	7/14/2005	0.01	0.00	47.80	1.18	1.13	9.2	186	176.8	47.1	8.0	8.6	8.0
ML1715	7/14/2005	0.03	0.02	72.30	1.67	1.57	8.6	496	487.4	61.0	27.2	8.9	8.4
UL1402	7/21/2005	0.11	0.01	71.20	1.53	1.35	27.7	130	102.3	47.1	10.2	10.4	7.8
UL962b	7/21/2005	0.10	0.00	160.00	1.50	1.24	19.8	156	136.2	31.4	11.2	10.9	8.2
UL1413*	7/21/2005	0.59	0.00	195.00	3.66	2.88	75.0	435	360.0	291.4	14.0	13.7	13.6
UP701	7/27/2005	0.07	0.00	37.50	1.44	1.33	18.8	123	104.2	53.8	13.3	9.3	6.1
UP1583	7/28/2005	0.13	0.02	49.10	0.96	0.78	36.1	83.1	47.0	16.4	8.4	5.1	3.8
UP962a	7/26/2005	0.04	0.00	193.00	2.01	1.78	428	672	244.0	29.9	6.4	20.3	20.2
UL1608	8/16/2005	0.10	0.00	425.00	1.48	0.96	13.5	127	113.5	37.4	22.1	7.3	6.0
UL1658	7/27/2005	0.03	0.00	68.60	1.66	1.56	16.4	114	97.6	36.6	7.6	7.1	6.3
UP1302	7/26/2005	0.03	0.00	77.20	0.96	0.85	154	242	88.0	14.0	4.0	9.7	4.5
UP868*	7/27/2005	0.09	0.02	67.50	1.61	1.45	33.9	98.6	64.7	82.2	3.3	8.1	6.9
UP1081*	8/4/2005	0.03	0.00	40.00	2.19	2.12	30.2	132	101.8	63.5	12.8	19.4	12.9
ML1677	8/26/2005	0.04	0.00	44.20	2.69	2.61	51.6	554	502.4	74.7	53.5	9.5	7.3

Table 2. Raw water chemistry data for herbicides and selected metabolites. The sites labeled with a (*) indicate the sites that were sampled and then determined to be non-reference in the analysis.

Site ID	Desisoprophylatrazine	Desethylatrazine	Simazine	Atrazine	Metributzin	Alachlor	Metolachlor	Cyanazine
MP1494	< 0.05	3.38	< 0.05	2.93	< 0.05	< 0.05	< 0.02	< 0.1
ML1276	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	< 0.02	< 0.1
ML1709	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	< 0.02	< 0.1
MP276	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	< 0.02	< 0.1
MP1005	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	0.23	< 0.1
ML1715	< 0.05	< 0.05	< 0.05	6.11	< 0.05	< 0.05	0.08	< 0.1
UL1402	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	0.50	< 0.1
UL962b	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	0.45	< 0.1
UL1413*	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	< 0.02	< 0.1
UP701	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	< 0.02	< 0.1
UP1583	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	< 0.02	< 0.1
UP962a	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	< 0.02	< 0.1
UL1608	< 0.05	< 0.05	< 0.05	0.29	< 0.05	< 0.05	< 0.02	< 0.1
UL1658	< 0.05	< 0.05	< 0.05	1.35	< 0.05	< 0.05	0.02	< 0.1
UP1302	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	< 0.02	< 0.1
UP868*	< 0.05	< 0.05	< 0.05	0.82	< 0.05	< 0.05	0.04	< 0.1
UP1081*	< 0.05	< 0.05	< 0.05	< 0.02	< 0.05	< 0.05	< 0.02	< 0.1
ML1677	< 0.05	< 0.05	< 0.05	0.66	< 0.05	< 0.05	< 0.02	< 0.1

Appendix 6 – Selected Box Plots of Water Chemistry Data and Likelihood of Reference for PRWs.

Figure 1. NH_3 plotted against likelihood of reference, grouped into potential reference and non-reference wetlands.

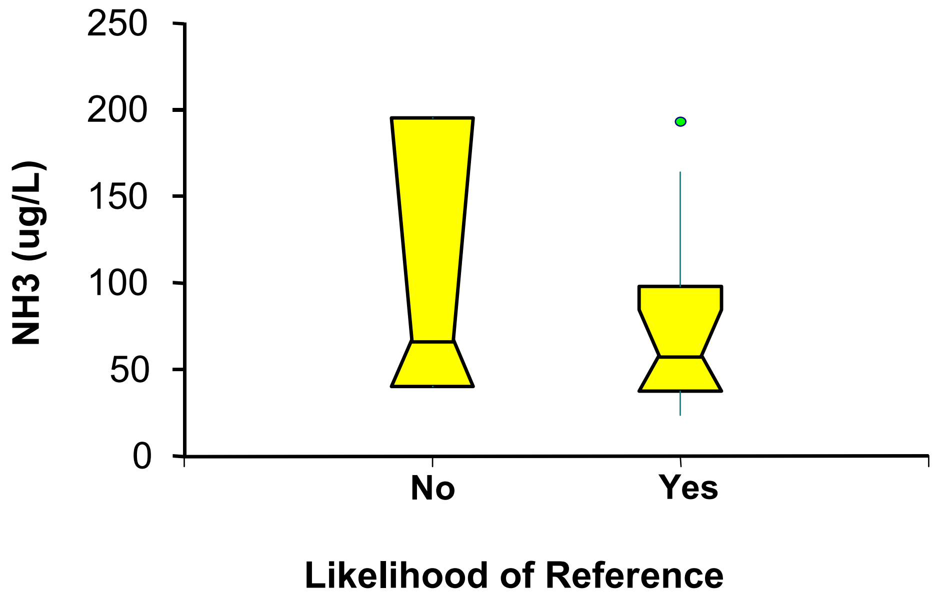


Figure 2. Total nitorgen (N) plotted against likelihood of reference, grouped into potential reference and non-reference wetlands.

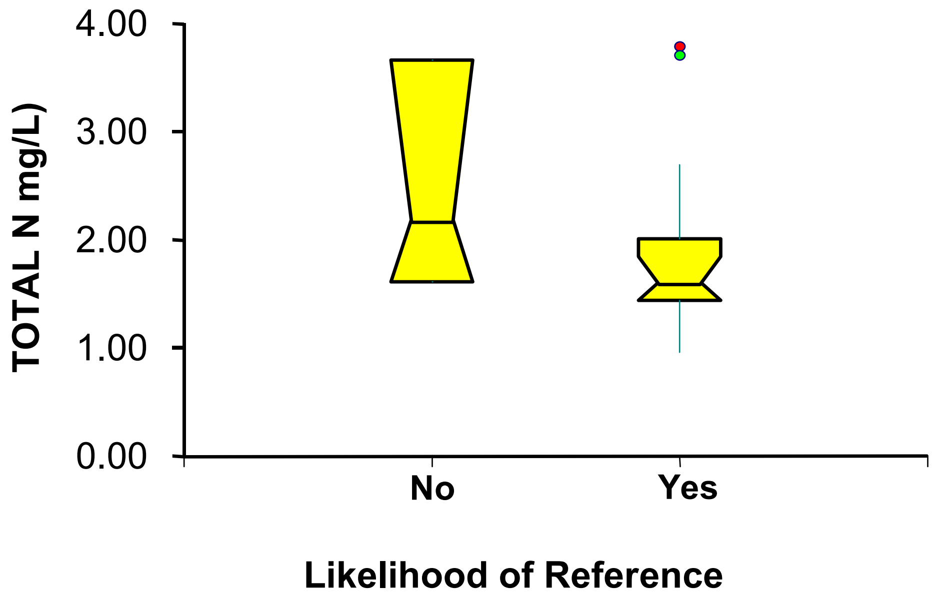


Figure 3. Total phosphorus (P) plotted against likelihood of reference, grouped into potential reference and non-reference wetlands.

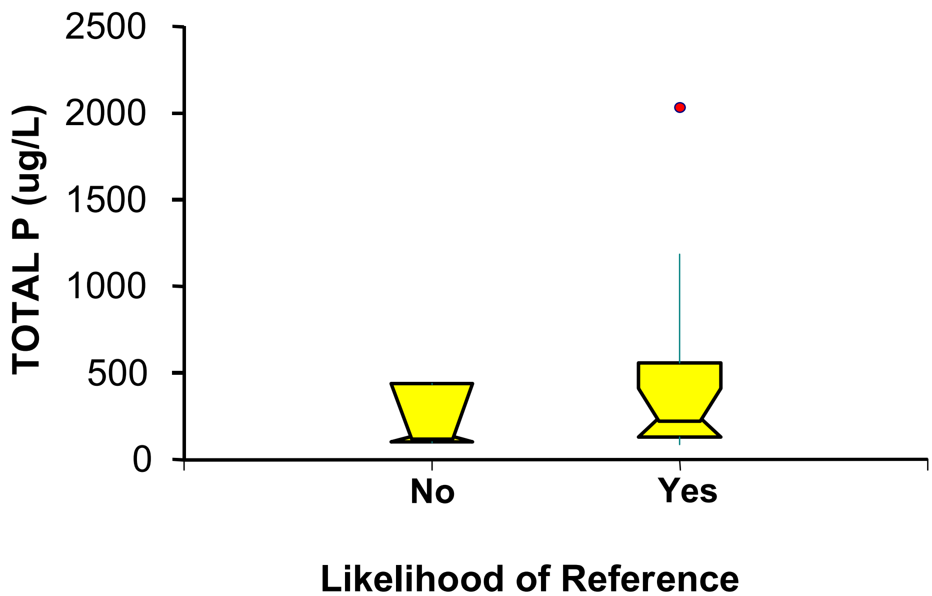


Figure 4. Chlorophyll-a plotted against likelihood of reference, grouped into potential reference and non-reference wetlands.

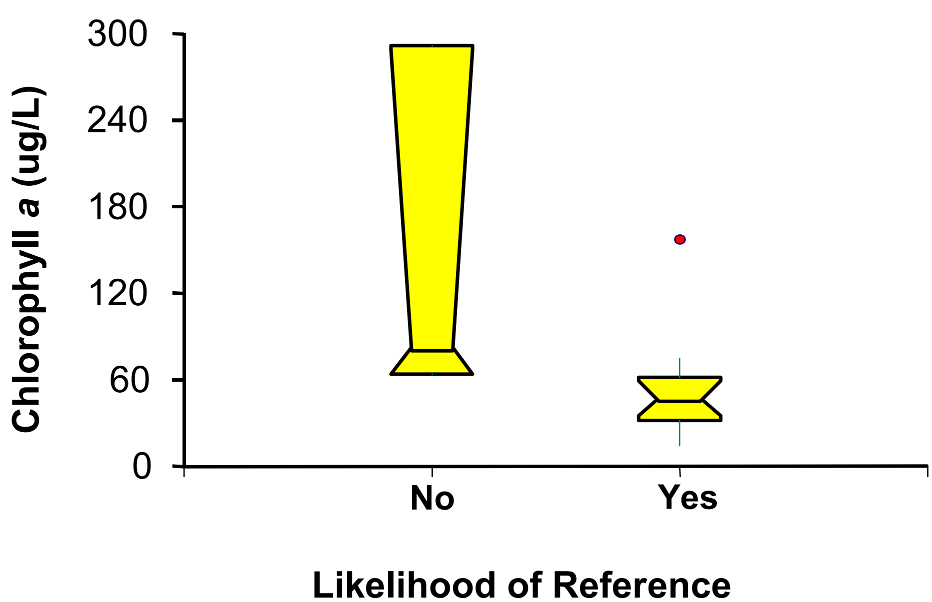
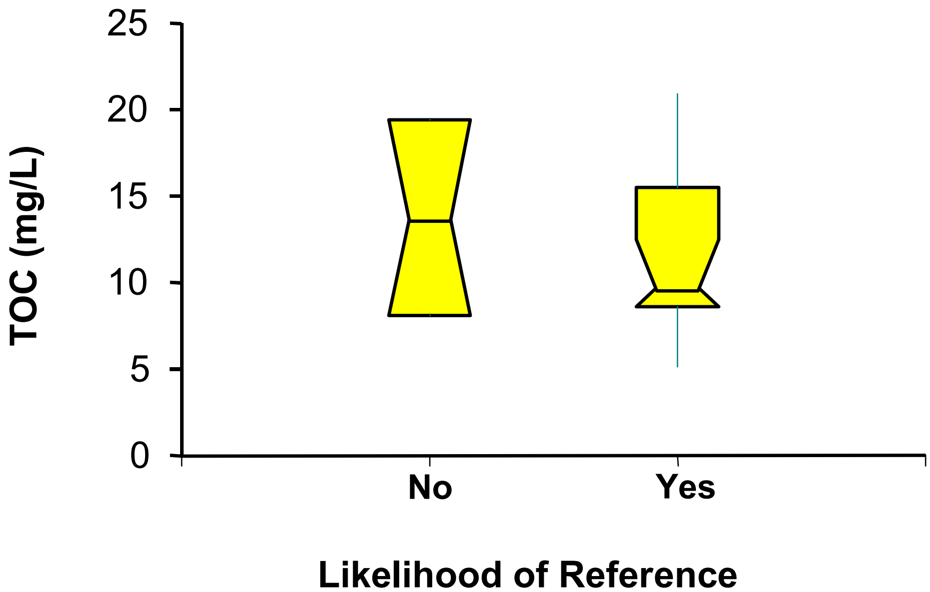


Figure 5. Total organic carbon (TOC) plotted against likelihood of reference, grouped into potential reference and non-reference wetlands.



Appendix 7 – Raw Floristic Quality Data.

Table 1. Raw Floristic Quality Data. Data are divided by state because conservatism values for a species may vary from state to state. The sites labeled with a (*) indicate the sites that were sampled and then determined to be non-reference in the analysis.

Site Name	Richness (all)	Richness (native)	Percent Non-native	Mean Conservatism (all)	FQI (all)	Mean Conservatism (native)	FQI (native)
IOWA							
UL1662	46	41	10.87	2.50	16.96	2.80	17.96
UL1238	28	24	14.29	1.93	10.21	2.25	11.02
UL1402	46	44	4.35	3.26	22.12	3.41	22.61
UL1413*	36	30	16.67	2.56	15.33	3.07	16.80
UL1608	55	49	10.91	2.56	19.01	2.88	20.14
UL1658	49	42	14.29	2.59	18.14	3.02	19.60
UL962b	42	37	11.90	3.26	21.14	3.70	22.52
UP701	29	25	13.79	3.17	17.08	3.68	18.40
UP868*	66	54	18.18	1.85	15.02	2.26	16.60
UP962a	33	28	15.15	2.88	16.54	3.39	17.95
UP1081*	42	35	16.67	2.48	16.05	2.97	17.58
UP1302	63	53	15.87	2.49	19.78	2.96	21.57
UP1398	40	32	20.00	1.90	12.02	2.38	13.44
UP1583	67	60	10.45	3.39	27.73	3.78	29.31
MISSOURI							
ML1276	28	24	14.29	3.36	17.76	3.92	19.19
ML1677	43	39	9.30	3.28	21.50	3.62	22.58
ML1709	11	11	0.00	5.09	16.88	5.09	16.88
MP276	45	40	11.11	3.42	22.96	3.85	24.35
MP1005	42	39	7.14	3.79	24.53	4.08	25.46
MP1449	38	36	5.26	3.66	22.55	3.86	23.17
MP1494	21	20	4.76	3.76	17.24	3.95	17.66
ML1715	28	25	10.71	3.89	20.60	4.36	21.80

Appendix 8 - Selected Box Plots of Floristic Quality Data and Likelihood of Reference for PRWs.

Figure 1. Richness for all species plotted against likelihood of reference, grouped into potential reference and non-reference wetlands.

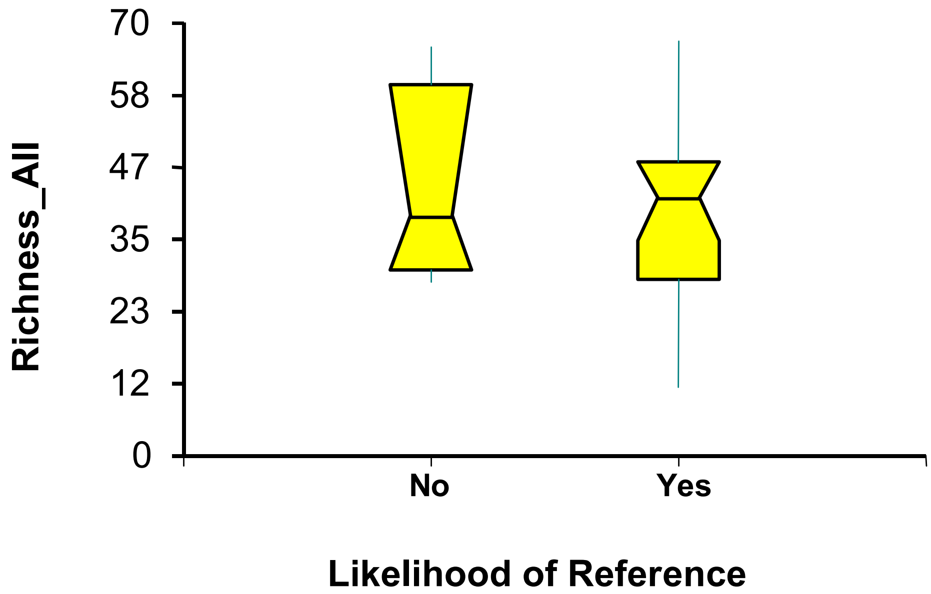


Figure 2. Percent non-native species plotted against likelihood of reference, grouped into potential reference and non-reference wetlands.

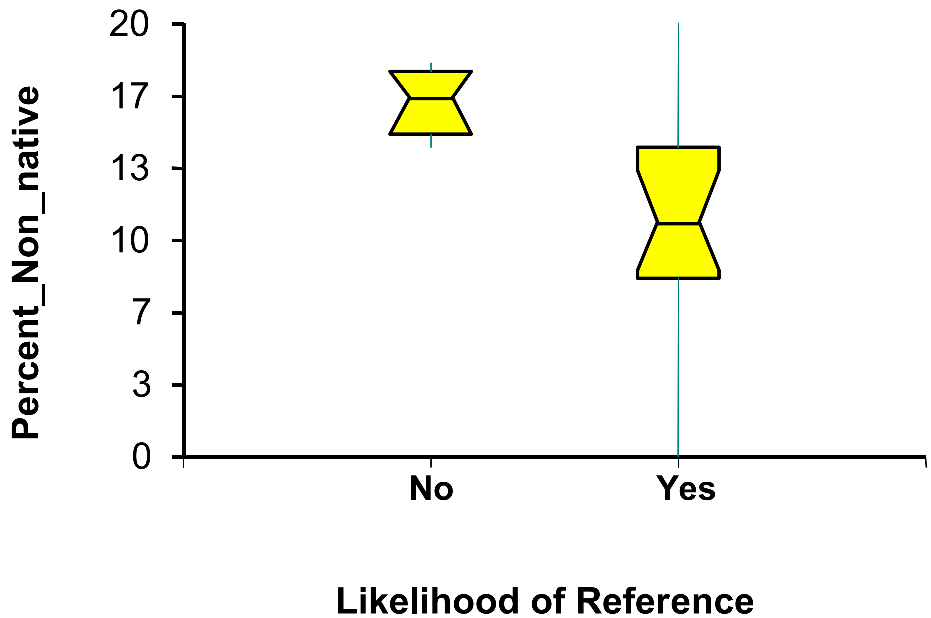


Figure 3. Mean conservatism for all species plotted against likelihood of reference, grouped into potential reference and non-reference wetlands.

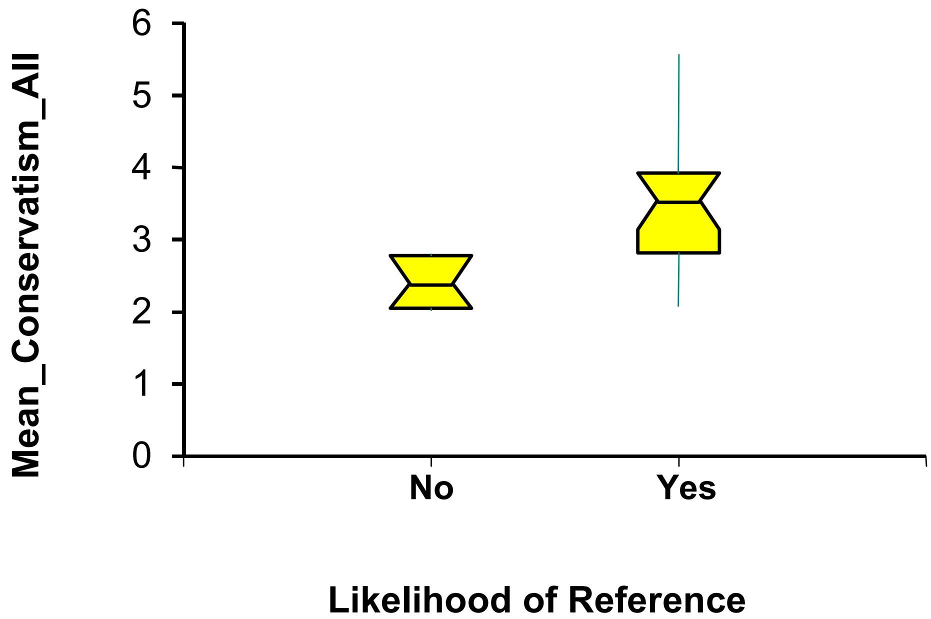
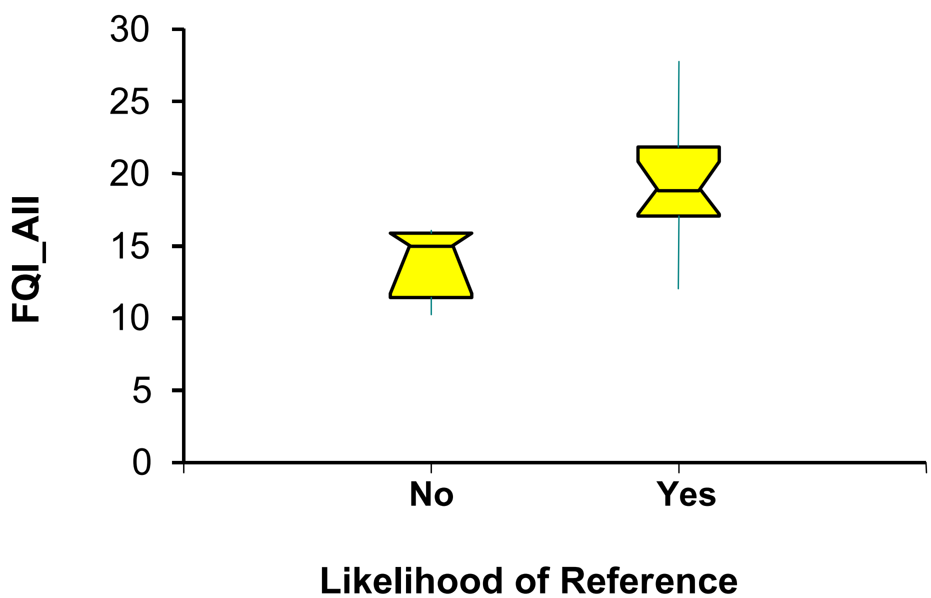
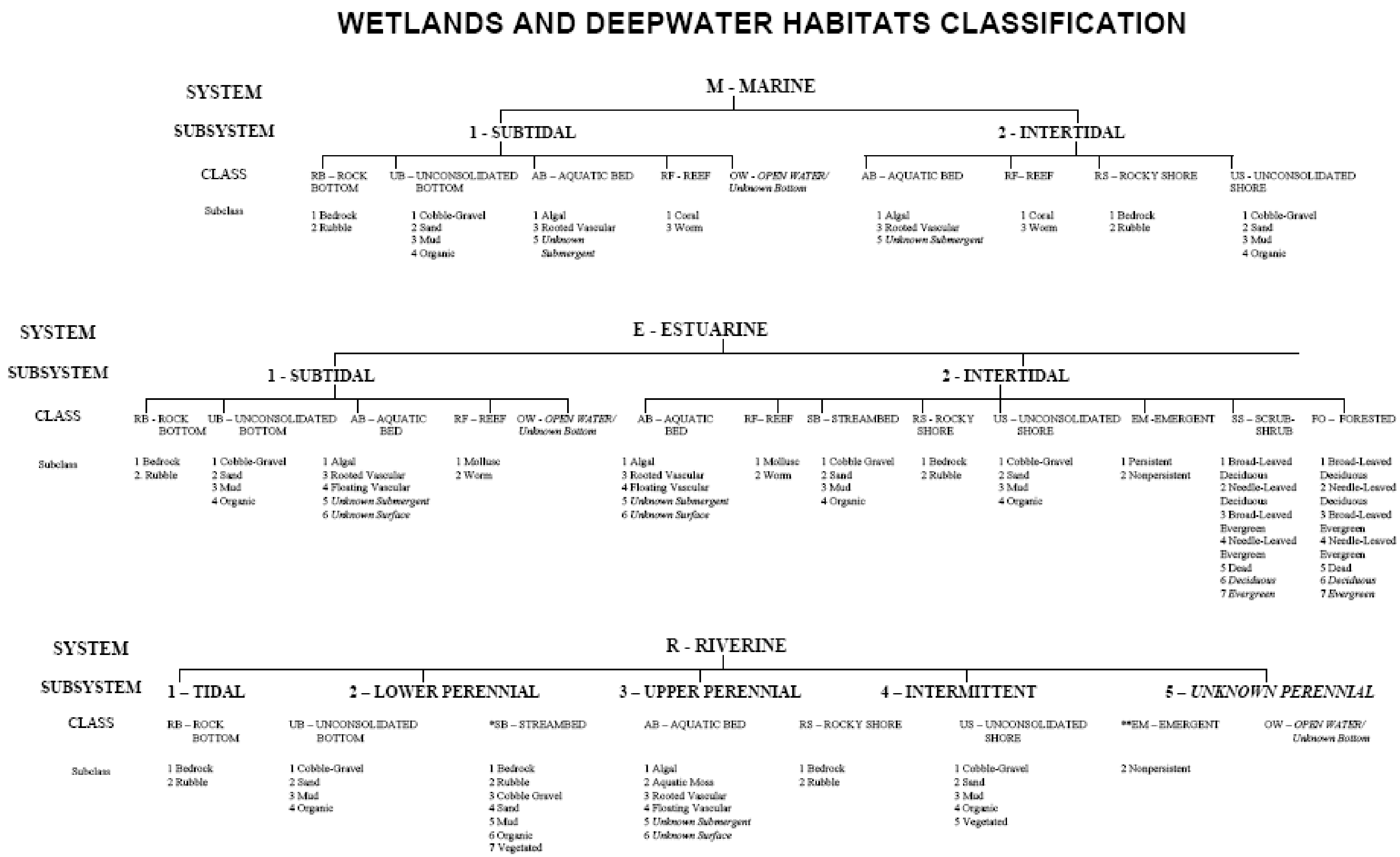


Figure 4. Floristic quality index (FQI) for all species plotted against likelihood of reference, grouped into potential reference and non-reference wetlands.



Appendix 9 – National wetlands inventory wetland habitat classification scheme.



* STREAMBED is limited to TIDAL and INTERMITTENT SUBSYSTEMS, and comprises the only CLASS in the INTERMITTENT SUBSYSTEM.
** EMERGENT is limited to TIDAL and LOWER PERENNIAL SUBSYSTEMS.

Classification of Wetlands and Deepwater Habitats of the United States
Cowardin ET AL. 1979 as modified for National Wetland Inventory Mapping Convention