Methods for estimating wetland loss: The Rainbasin region of Nebraska, 1927-1981

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ABSTRACT: Measurement of wetland loss is important to those who manage the resource. Because technology and data limitations do not yet allow for accurate reconstruction of "pre-agricultural-development landscapes," researchers must resort to an assortment of methods and data for analyzing the spatial variability of wetlands. We demonstrate the measurement and quantification of historic changes in the areal extent of wetlands in the Rainbasin region of Nebraska with and without digital geographic overlay procedures. Results are compared to earlier estimates based on traditional approaches. Although wetlands have inherent indeterminate boundaries, the use of digital geographic overlay procedures is a logical approach to estimating wetland loss. Errors in the estimation of wetland loss can be attributed to field mapping discrepancies, mistakes in the original or final map product, and errors in the digitization of map data.

THE basin of the Big Blue River is a loess-mantled plain encompassing all or parts of 19 counties in south central Nebraska. Portions of that area are characterized by surficial depressions that are wetlands during the wet periods of the year and dry basins at other times. The soils in these depressions have a subsoil that is silty clay in texture with a very low rate of hydraulic conductivity. This subsoil causes water to perch above it and pond at the surface. The ponding of rainwater in the depressions has led to the area being called the "Rainwater Basin," or, more succinctly, the "Rainbasin" (Figure 1).

Relatively little documentation and some misconceptions surround the numerous wetlands and depressions of the Rainbasin. The first written evidence pertaining to the basins was provided by field surveyors in the 1850s who did not establish section corners at certain points along their traverses because of wetlands (*2*). At these locations, the surveyors simply placed "Xs" on the maps. However fragmentary, such evidence constitutes the first documentation of marshy conditions in the landscape of the Rainbasin.

The earliest scientific observer, George Condra, in discussing the topography of the loess plain of southeastern Nebraska in his 1906 publication, stated:

"In some places the surface contains shallow undrained basins filled by the rainfall at wet-weather times. Most of these small lakes dry up entirely during the summer. The lakes occur principally in York, Fillmore, Clay, and Phelps counties" (*5*).

Although a region in southeastern Nebraska characterized by seasonally wet and dry topographic depressions was at least noted in Condra's early reports, it was not until 1972 that the Rainbasin area received widespread public attention. That year, McMurtrey and associates (*16*) published their Nebraska Game and Parks Commission report, which served as the principal catalyst for subsequent interest in the Rainbasin region. To generate statistics on wetland loss in the region, they estimated the original extent of wetlands by interpreting the earliest soil survey maps available and then based their findings (Table 1) on "...a visual inspection of each wetland and interviews with persons having background knowledge of the area...", along with interpretation and planimeter-measurement from air photos. These statistics have been cited repeatedly in subsequent work by numerous authors (*7, 9, 10, 11*). In short, the Rainbasin is an area of considerable current ecological interest. It represents a classic case of environmental issues at odds with agricultural and economic considerations.

The relatively sparse scientific literature dealing with the Rainbasin includes the work of Starks (*20*), who developed a basic geography of the depressions in Clay County. In addition to a map of the basins, his cartographic and quantitative analysis recognized that some basins in the county, which range in size from 0.1 ha (0.25 acre) to nearly 1,175 ha (2,900 acres), are "breached"; in other words, they exhibit external drainage. In addition, Starks focused on the many "lunettes," crescent-shaped ridges found on the south and east sides of 51 of the 120 depressions he studied. He found that the pattern of lunettes extends diagonally from the northwest corner to the southeast corner of the county; the large depressions tend to be elliptical in shape, while the small ones have varied shapes, and the surface area and volume of the depressions and lunettes are linked statistically.

Krueger's work, which focused upon the origin of the depressions, was based on the stratigraphy of a basin located in central York County (*14*). Sediments collected from 16 test holes indicated that the basin was likely to have formed during the early Wisconsinan glacial period. In addition, Krueger concluded that the basin probably developed because of the strong prevailing winds and lake currents during a moist phase of the Wisconsinan.

Kuzila (*15*) addressed the issue of genesis and morphology of soils within and surrounding two breached Rainbasin depressions in Clay County. His results indicated that the soils within the basin and on uplands surrounding the basins had a similar morphology even though they were on different landscape positions. Subsurface investigations showed that the depression-forming processes predated the deposition of the loess parent material. The soils were found to be similar because they formed in the

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same parent material under similar soil-forming conditions.

Purpose and objective

Motivated not only by a concern for the reduction of wetlands in the Rainbasin but also by the availability of useful digital data sets and new technical and analytical tools, we defined our principal objective as follows: determine as accurately and objectively as possible the areal extent of wetland loss between 1927 and 1981 in our study area. For this, we decided to use various approaches and data sources. Secondarily, we were curious about how well pertinent digital data sets coincided spatially. The use of the 1927 soil survey as a baseline data set in our work can be viewed as replicative, but we believe it is different from that of McMurtrey and associates (*16*) for at least the following reasons: (1) we used modern geographic technologies to convert relevant secondary sources of information to computer-readable data sets tied to a common map scale and projection; (2) our focus was on only one 7-1/2 minute map quadrangle instead of entire counties; (3) we used two diverse data types in our research; and (4) the organizing framework for our study was the geographic information system (GIS).

Study area

The particular portion of the Nebraska Rainbasin selected for our study is in Clay County, which possesses a greater number of surficial depressions than any other county in the region (Table 1). Specifically, the study site we selected was the U.S. Geological Survey Edgar NW 7-1/2 minute quadrangle (Figure 1), which we considered representative of the Rainbasin. Soils within the study area are generally represented by the Hastings-Massie and Hastings-Crete-Butler

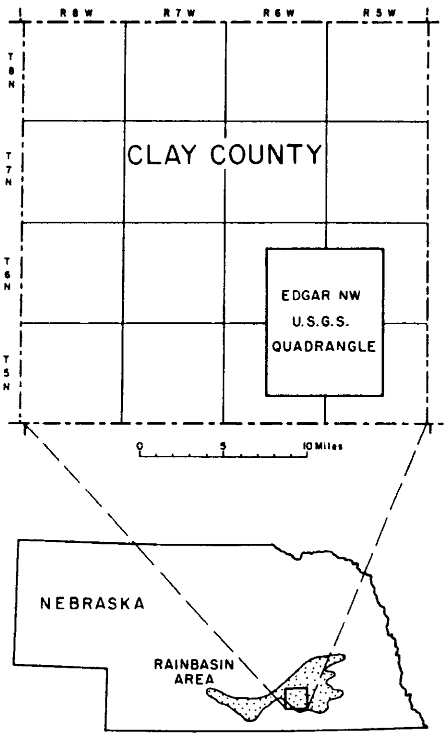

Figure 1. Location of USGS Edgar NW quadrangle within the Rainbasin region.

soil associations (*13*). We not only viewed our work as exploratory (i.e., a feasibility project) but we also felt that any conclusions reached from an analysis of the Edgar NW quadrangle could, to some extent, be extrapolated to other parts of the Rainbasin.

Data sources

Because the emphasis of our work was on landscape change over time and because no early wetland surveys were available, we had to use two different data types in our attempt to document terrain modification. What was actually needed, of course, was a reconstruction of the "pre-development landscape," but this cannot be done using current technologies and available data. Therefore, we could only make use of secondary sources in an attempt to make some inferences about wetland loss. The 1927 (*18*) and 1981 (*13*) soil surveys of Clay County, Nebraska, and data from the 1981 National Wetlands Inventory (*23*) were selected for this purpose (Figure 2).

Our first task was to define and identify wetlands on each of the three data sets. The Nebraska Game and Parks Commission wetland survey (*16*) inventoried only natural water-holding depressions, exclusive of streams and associated bottomlands. Thus, we interpreted the data sets, as discussed below, and defined only natural water-holding depressions as wetlands in this study.

Soil survey of Clay County, Nebraska, 1927. The first soil survey of Clay County, published in 1927 at a scale of 1:63,000, was our baseline data set (*18*). That survey showed many basin-like depressions in certain areas of the county. The soil survey stated that Fillmore and Scott soils occurred in these basins or depressions. In Clay County, 5,936 ha (14,656 acres) of Fillmore and 3,396 ha (8,384 acres) of Scott soils were mapped yielding a total of 9,332 ha (23,040 acres) of wetland soils in the county (Table 2). This figure is 1,470 ha (3,629 acres) greater than the 7,861 ha (19,411 acres) (Table 1) of original basins identified by McMurtrey and associates (*16*). Because of the discrepancy, an attempt was made to replicate the McMurtrey and associates' data (*16*) by adjusting the 1927 estimate using a land use factor. Roberts and Gemmel (*18*) stated that 40% of the Fillmore soils were cultivated and that 100% of the Scott soils occupied the most poorly drained depressions and were of little agricultural value. Using these percentages as a guide, we estimated that 60% of the Fillmore soils and 100% of the Scott soils were probably active wetlands in 1927, for a total of 6,958 ha (17,178 acres) (Table 2). While an improvement, this figure is 903 ha (2,233 acres) (Table 1) less than that estimated by McMurtrey and associates (*16*).

Within the Edgar NW quadrangle, 1,035 ha (2,555 acres) of Fillmore soils and 870 ha (2,148 acres) of Scott soils were mapped in 1927, totalling 1,905 ha (4,703 acres) of wetland soils (Table 2). Adjusting for land use (as described above), we estimated the existence of 1,491 ha (3,681 acres) of active wetlands within the Edgar NW quadrangle. Thus, our baseline assumption is that there were 1,491 ha (3,681 acres) of natural water-holding depressions when the 1927 soil survey was made.

Soil survey of Clay County, Nebraska,

Table 1. Number and extent of basins in south central Nebraska.

County	Number of Basins			Extent of Basins		
	Original	Lost	Existing	Original	Lost	Existing
				ha		
Adams	97	81	16	906	683	223
Butler	327	304	23	1,423	967	456
Clay	858	641	217	7,861	4,519	3,731
Fillmore	622	504	118	8,520	5,862	2,294
Franklin	105	91	14	1,089	379	710
Gosper	156	128	28	1,027	450	578
Hall	18	7	11	324	73	251
Hamilton	290	270	20	3,146	2,771	375
Harlan	36	31	5	428	254	151
Kearney	133	104	29	1,199	506	693
Nuckolls	44	38	6	396	264	131
Phelps	56	16	40	2,416	1,019	1,398
Polk	227	194	33	1,690	1,386	305
Saline	78	73	5	520	470	50
Seward	177	165	12	2,153	1,882	271
Thayer	11	9	2	331	305	26
York	672	566	106	4,655	3,124	1,532
Total	3,904	3,219	685	38,084	24,914	13,175

Adapted from McMurtrey and associates, tables 1 and 2 (*16*).

1981. We also made use of the modern soil survey for Clay County, published at a scale of 1:20,000 (*13*). Those soils designated as hydric (*22*) by the Soil Conservation Service were considered as wetlands for the purpose of this study. SCS defines a hydric soil as "a soil that in undrained condition is saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation." Soils designated as hydric in Clay County were Fillmore, Massie, and Scott (Fine, montmorillonitic, mesic, Typic Argialbolls). Fillmore soils were represented by two 1981 soil map units: Fillmore silt loam and Fillmore silt loam, drained. The latter was not designated as hydric by SCS, so we did not consider it as wetland.

In Clay County, 5,415 ha (13,370 acres) of Fillmore soils, 1,187 ha (2,930 acres) of Massie soils, and 1,904 ha (4,700 acres) of Scott soils were mapped in 1981, totalling 8,506 ha (21,000 acres) of wetlands (Table 2). Hammer and associates (*13*) estimated that 50% of the Fillmore soils were cultivated and 50% were in native grass. Nearly all the areas of Massie and Scott soils were described as being in wetland vegetation and native grass. Therefore, we designated 50% of the Fillmore soils and 100% of the Massie and Scott soils as active wetland. As a result, we estimated the existence of 5,799 ha (14,315 acres) of wetland soils in Clay County. This figure suggests a 1,159-ha (2,863-acre) loss of wetlands after 1927. Our estimate is 2,062 ha (5,093 acres) less than the 7,861 ha (19,411 acres) (Table 1) reported by McMurtrey and associates (*16*).

Within the Edgar NW quadrangle, 533 ha (1,315 acres) of Fillmore soils, 369 ha (912 acres) of Massie soils, and 333 ha (821 acres) of Scott soils were mapped in 1981, for a total of 1,235 ha (3,048 acres) of wetland soils. Adjusting for land use as described by Hammer and associates (*13*), we estimated the existence of 969 ha (2,391 acres) of wetlands (Table 2). A simple estimation of 522 ha (1,290 acres) of wetland loss in the study area was calculated by subtracting the 1981 adjusted wetland soils from the 1927 adjusted wetland soils. Thus, one can obtain a rough approximation of wetland reduction by merely referring to time-sequential soil surveys.

Table 2. Estimated and adjusted wetlands from soil surveys.

Soil Series	Soil Map Unit Area (ha): Clay County	Soil Map Unit Area (ha): Edgar Quadrangle	Estimated Wetlands (%)	Adjusted Wetlands (ha): Clay County	Adjusted Wetlands (ha): Edgar Quadrangle
1927 Soil Survey					
Fillmore	5,936	1,035	60	3,562	621
Scott	3,396	870	100	3,396	870
Total	9,332	1,905	-	6,958	1,491
1981 Soil Survey					
Fillmore	5,415	533	50	2,708	267
Massie	1,187	369	100	1,187	369
Scott	1,904	333	100	1,904	333
Total	8,506	1,235	-	5,799	969
Loss	826	670	-	1,159	522

National Wetlands Inventory, 1981. Mapping for the National Wetlands Inventory (NWI) was based on interpretation and stereoscopic analysis of high-altitude, color-infared aerial photography. In the case of the Edgar NW quadrangle, the study site for our research, the mapping was completed in 1987 from air photos flown on May 24, 1981, at a scale of 1:58,000 (*23*). The mapped information was digitized by the U.S. Fish and Wildlife Service (FWS) and stored on magnetic tape.

The FWS program for inventorying wetlands nationwide began in 1974. A new classification system for the wetlands and deep-water habitats of the United States was published in 1979, and that new system was used for the national survey (*6*). To keep our data sets consistent, only those wetlands considered natural water-holding depressions, exclusive of streams and associated bottomlands (as designated on the 1981 NWI), were used in this study. Thus, all wetlands designated as riverine system or modified by h (diked, impounded) or x (excavated) were not considered wetlands.

The 1981 NWI identified 946 ha (2,335 acres) within the Edgar NW quadrangle that met the wetlands criteria for our study. A simple estimation of wetland loss in the study area of 545 ha (1,346 acres) was calculated by subtracting the 1981 NWI wetland acreage from the 1927 wetland acreage. This figure of wetland loss was close to that estimated using the 1981 and 1927 soil surveys and showed we could obtain a "reasonable" result with no "hard" analysis.

Analytical procedures

Our focus was on the Fillmore and Scott soils as mapped in 1927; the Fillmore, Scott and Massie soils as mapped in 1981; and the extent to which the geographic position and size of the soil map units correspond with each other and with the wetlands identified by the 1981 NWI. We believed that such a comparison would provide us with a better

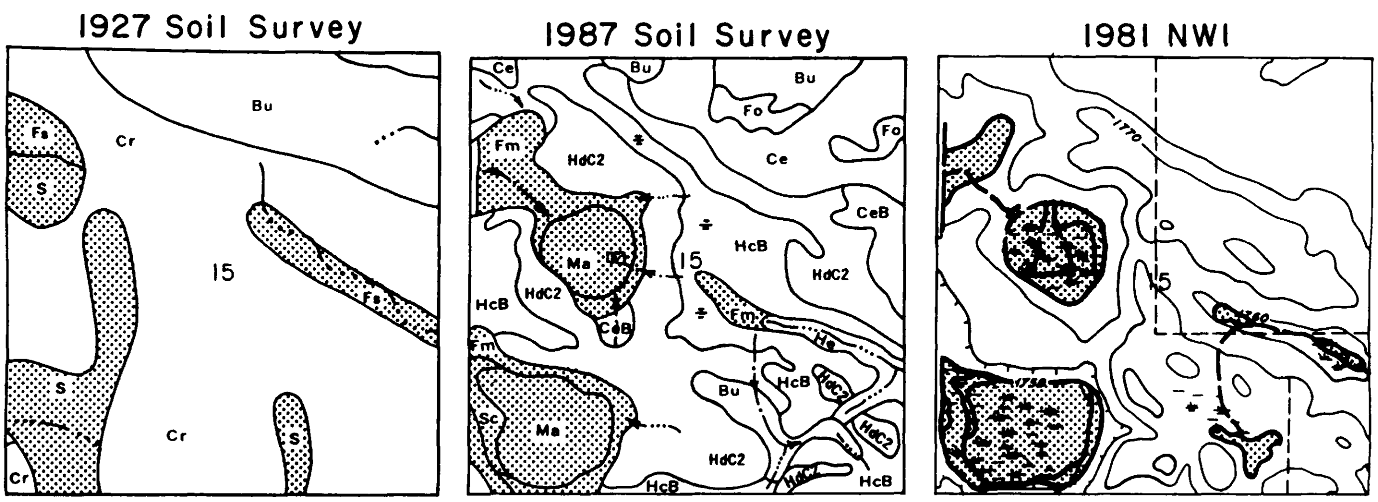

Figure 2. Examples of map data from Section 15, T. 6 N., R. 6 W., within the USGS Edgar NW quadrangle. Shaded areas indicate wetland soils/wetlands.

understanding of the wetlands-reduction information.

In an attempt to both examine the spatial element and to further refine the estimates of historic wetland loss, both the 1927 and 1981 soil surveys corresponding to the area of the Edgar NW quadrangle were digitized by means of standard, manually operated coordinate digitizing procedures. The digitizing process took about 16 hours of student labor. Once the survey maps and airphoto bases were converted into computer-readable form, the data sets were rasterized to cells ("pixels") 30 m by 30 m in size. Both digital data sets also were registered to the UTM (Universal Transverse Mercator) map projection, which took about 2 hours of student labor.

The NWI data were obtained in digital form from FWS. The data set consists of a series of coordinates that represent the polygonal, linear, and point wetlands. FWS codes the mapped wetlands according to Lambert Conic coordinates; to overlay them on or with soil survey data, we first transformed the NWI information from a Lambert Conic to a UTM projection, then rasterized the data so they matched the soils in both general form and cell size. Geometric registration was based on coordinates for the corners of the Edgar NW quadrangle. The NWI conversion process took about 2 hours of student labor.

The processing of overlays of the three data sets took about 4 hours of student labor. The total amount of time necessary to digitize, convert, and process the data was about 24 hours. At $5.00 per hour, the student labor cost was $120.00. Assuming that the Edgar NW quadrangle covers about 130 km² (50 square miles), the cost was about $0.92/km² ($2.40/square mile). Most of the expense was in digitizing the soil surveys. In the future, when soil surveys are available in digital form, the entire process will be less expensive.

Results

Testing the accuracy of the 1927 soil survey. Before proceeding to the soil survey-NWI comparison, we felt we needed to determine how well the 1927 and 1981 soil surveys of Clay County matched. The simple procedure for evaluation was a digital overlay of the two data sets, followed by a pixel-by-pixel comparison, in this case, how many pixels representing wetlands and nonwetlands, respectively, were classified the same in both 1927 and 1981.

The results of overlaying the 1981 soil survey on that done in 1927 indicated that, for the most part, the two data sets agreed (Table 3). On a pixel-by-pixel basis, there was 89.1% overall agreement on wetland and nonwetland designations. However, 1,147 ha (2,832 acres) were classified as wetland in 1927 but nonwetland in 1981. Conversely, 477 ha (1,178 acres) were classified nonwetland in 1927 but wetland in 1981. These data could be interpreted as indicating a net loss of 670 ha (1,654 acres) of wetlands in the Edgar NW quadrangle between 1927 and 1981, or the difference could be attributed to minor field-mapping, map production, or digitizing errors (*1*).

Overlay of 1927 soil survey and 1981 NWI. Our digital analysis of wetland change is based on a pixel-by-pixel comparison of 1927 wetland soils with natural water-holding depressions as designated on the 1981 NWI. The 1927 soil survey and the 1981 NWI agreed on 88.5% of the wetland and nonwetland designations (Table 3). However, 1,334 ha (3,296 acres) were classified as wetland soils in the 1927 soil survey but nonwetland in the 1981 NWI. Conversely, 375 ha (928 acres) were classified as nonwetland soils in the 1927 soil survey but wetland in the 1981 NWI. These data indicate a net loss of 959 ha (2,368 acres) of wetlands in the Edgar NW quadrangle between 1927 and 1981.

Overlay of 1981 soil survey and 1981 NWI. As a final check on the inference made earlier concerning the extent of wetland loss in the study area, we overlaid the 1981 soil survey and the 1981 NWI. The two data sets agreed in 94.2% of the wetland and nonwetland designations (Table 3). However, 575 ha (1,422 acres) were classified as wetland soils in the 1981 soil survey but nonwetland in the 1981 NWI. Conversely, 286 ha (708 acres) were classified as nonwetland soils in the 1981 soil survey but wetland in the 1981 NWI. We can offer no reason for such a discrepancy, aside from differences in basic agency definitions about what is a wetland and general mapping strategies.

Summary and conclusions

Our results are preliminary, but it reassured us to find that the data sets had, on average, about 90% agreement (Table 3). As one would hope, agreement between the 1981 soil survey and the 1981 NWI was the highest of all the comparisons.

We estimated the wetlands lost in the Edgar quadrangle between 1927 and 1981 in the following ways: (1) by using acreage tables in the 1927 and 1981 soil surveys, with no GIS technology; (2) comparing the 1927 soil survey with the 1981 NWI within the framework of an automated GIS; and (3) comparing the 1927 and 1981 soil surveys using GIS.

Estimated losses of wetland in the Edgar quadrangle varied according to the method by which they were determined and ranged from 1,334 ha (3,295 acres) to 522 ha (1,289 acres). Relating these losses to the 1,491 ha (3,681 acres) estimated earlier to be the extent of wetlands in 1927, the greatest loss was 90% as determined within the GIS by comparing the 1927 soil survey and the 1981 NWI. The least loss was 35% as determined outside the GIS by comparing the 1927 and 1981 soil surveys. Net losses also were estimated within the GIS by subtracting the gain in wetlands from the loss in wetlands (Table 3). The greatest estimated net loss, 959 ha (2,369 acres), and least estimated net loss, 670 ha (1,655 acres), were determined within the GIS by comparing the 1927 soil survey and the 1981 NWI and the 1927 and 1981 soil surveys, respectively. The greatest and least estimated net losses represented a 64% and 45% loss of wetlands, respectively. McMurtrey and associates (*16*) estimated that 58% (Table 1) of the original wetland acreage in Clay County had been lost.

As is shown by our data, we recorded small amounts of what could be interpreted as gains in wetland area between 1927 and 1981 (Table 3). Given the agricultural development in Clay County, it is, of course, un-

Table 3. Wetland and nonwetland classification.

1927 vs. 1981 Soil Surveys				*1927 Soil Survey vs. 1981 NWI*				*1981 Soil Survey vs. 1981 NWI*			
Classification		*Amount (ha)*		*Classification*		*Amount (ha)*		*Classification*		*Amount (ha)*	
1927 SS	*1981 SS*			*1927 SS*	*1981 NWI*			*1981 SS*	*1981 NWI*		
Wetland	Wetland	758		Wetland	Wetland	569		Wetland	Wetland	658	
Wetland	Nonwetland	1,147	(Loss)	Wetland	Nonwetland	1,334	(Loss)	Wetland	Nonwetland	575	
Nonwetland	Wetland	477	(Gain)	Nonwetland	Wetland	375	(Gain)	Nonwetland	Wetland	286	
Nonwetland	Nonwetland	12,502		Nonwetland	Nonwetland	12,593		Nonwetland	Nonwetland	13,352	
Total		14,884				14,871				14,871	
Agreement		13,260	(89.1%)			13,162	(88.5%)			14,010	(94.2%)
Net Loss		670				959					

likely that actual gains in natural water-holding depressions occurred. What is more plausible, we believe, is that such a discrepancy is symptomatic of the broader problem of trying to measure precisely changes in something as "fuzzy" as a "wetland," which has an inherently indeterminate boundary (*4*).

Our personal knowledge of the Rainbasin tells us that the wetlands vary considerably because of meteorologic and climatic fluctuations, a fact underscored by the earlier quote from Condra (*5*). Thus, in some ways, it seems rather futile to attempt to map and measure wetlands because, no matter who does the work and how it is accomplished, the result represents the areal extent of the wetland at only one instant in time.

If a decision is made to analyze landscape modification in an area like the Rainbasin, we believe that use of an automated GIS remains the logical and best approach to the problem. Such technology, of course, is not without problems of its own. Some error in our results could be attributed to field mapping discrepancies, mistakes in the original draft or the final soil map product, and errors in the digitization of map data. Our digital maps can be no better than the paper maps from which they were developed. Thus, it is possible that the same soil area may not be located in exactly the same geographic position on two different maps (Figure 3) because of differences in scales, base maps, and mapping techniques. It also is possible that in a digitized product linear data could be portrayed as polygonal data (Figure 4) as a result of mistakes in digitization due to software and/or operator error. Additional flaws in our results could be attributed to problems in the original airphoto interpretation of wetlands, errors made in the production of wetland maps, or other problems (*1, 4, 8, 12*). Nevertheless, we feel that the percentage loss figures we derived provide believable results that are at least as accurate as estimates made by others (*16*).

The issue of the precision of our digital data sets is a difficult, if not impossible, one to address, given the preliminary and exploratory nature of our research. In fact, the underlying problem of map-accuracy determination is by no means an exact science (*21*). Error assessment in GIS, an important area of research, must address problems including map scale, positional accuracy, the nature of class boundaries, and a host of other issues (*3*).

The registration/overlay of our data was based on the geographic corner coordinates of the Edgar NW USGS quadrangle at 1:24,000 scale, a map product with horizontal positional accuracy on the order of 12 m (40 feet) (*21*). Soils data were taken from the

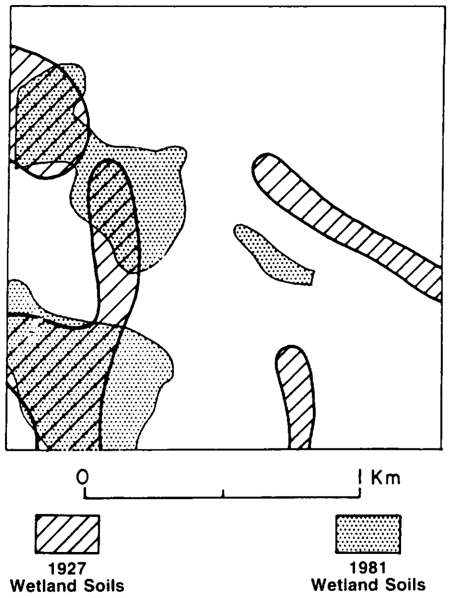

Figure 3. Location of wetland soils within Section 15, T. 6 N., R. 6 W., Clay County, Nebraska, as identified in the 1927 and 1981 soil surveys.

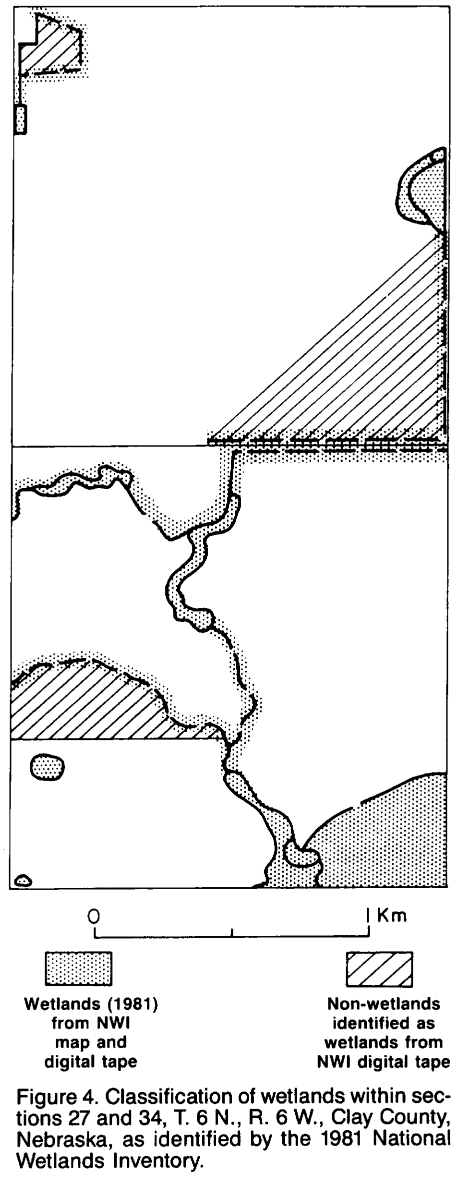

Figure 4. Classification of wetlands within sections 27 and 34, T. 6 N., R. 6 W., Clay County, Nebraska, as identified by the 1981 National Wetlands Inventory.

1927 and 1981 soil surveys with scales of 1:63,360 and 1:20,000, respectively. An estimation of the horizontal spatial integrity of those maps was not available. Soil mapping consists of a sequence of predictions and verifications (*19*). The ability of a soil scientist to predict and verify soil delineations depends upon experience, the scale and type of base map, and the natural variability of the soil and landscape. Consequently, the vagaries of the field soil mapping process are innumerable. The NWI is mapped on USGS orthophoto quads with a minimum mapping unit in the range of less than 0.5 ha up to 1.2 ha (about 1-3 acres) (*17*). Thus, it seems apparent that additional work is needed to evaluate, in a quantitative sense, the precision of our digital overlays.

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