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COMPARISON OF THE WISCONSIN AND NATIONAL WETLANDS INVENTORIES

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Abstract: The Wisconsin Wetlands Inventory (WWI) was conducted by the State of Wisconsin, USA using a classification system and methods that are similar but not identical to those of the National Wetlands Inventory (NWI). Dissimilarities between the two inventories present problems for applications that cross state boundaries, such as inter-state comparisons or compilation of regional wetland statistics. The methods and classification systems of the two wetland inventories were compared, and GIS coverages were analyzed where the two inventories overlap near the cities of Superior and Baraboo. The NWI mapped both wetland and deepwater habitats and included Lacustrine and Riverine deepwater habitats that were intentionally not mapped by the WWI. Of the 178 km^2 Superior study area, 52% was mapped as upland by both, 22% was mapped as wetland by both, 10% was mapped as Palustrine wetland by NWI but not WWI, and 6% was mapped as wetland by WWI but not NWI. Of the 281 km^2 Baraboo study area, 91% was mapped as upland by both, 2% was mapped as wetland by both, 1% was mapped as Palustrine wetland by NWI but not WWI, and 1% was mapped as wetland by WWI but not NWI. Errors of omission were found for both inventories, but errors of commission (i.e., areas incorrectly mapped as wetland) were found only for the NWI maps in the Superior study area, which were prepared using 1:80,000 black and white panchromatic aerial photos. In theory and in practice, the two inventories were nearly equivalent with regard to Palustrine wetland class and subclass. The WWI ''hydrologic modifier'' has fewer categories than the NWI ''water regime,'' but a preliminary conversion table was developed to recode the WWI digital maps to their equivalent NWI categories based on the modal NWI water regime associated with each NWI class. Methods were developed for converting the WWI digital databases to make the two inventories more compatible; recommendations for future updates of the WWI include use of leaf-off color infrared aerial photography and merging of the digital WWI with a digital database of deepwater habitats.

Key Words: wetland mapping, classification, aerial photograph, digital, GIS, National Wetlands Inventory, Wisconsin

INTRODUCTION

The state of Wisconsin appears as a gaping hole in the National Wetlands Inventory (NWI) status map (http://wetlands.fws.gov/webstat.gif) because Wisconsin conducted its own wetlands inventory that is similar but not identical to the NWI. Wisconsin has more than 2.1 million ha of wetlands (WDNR 1998), making it a significant omission from the NWI. The lack of correspondence between the two inventories also presents problems for applications that cross state boundaries, such as inter-state comparisons or compilation of regional wetland statistics.

Contemporary geographic information systems (GISs) could facilitate the conversion of the Wisconsin Wetlands Inventory (WWI) into a format comparable to that of the NWI (Johnston 1998). Unfortunately, the GIS metadata that exist for the WWI (http://wisclinc.state.wi.us/metadata/dnr/dnrwet01.html) and the NWI (http://www.fgdc.gov/metadata/metadata.html) describe the methods used to produce the digital products, rather than the hard copy maps. Comparison of the classification systems used by the two inventories is relatively straightforward, but classification categories are related more to the description of vegetation *within* wetlands than the methods used to distinguish wetland from non-wetland. Therefore, conversion of information between inventories requires an understanding of the mapping conventions underlying both systems.

This paper compares the WWI and the NWI by contrasting the mapping conventions used by both inventories and by illustrating differences within areas where both inventories were conducted independently. Author Johnston directed the WWI from its inception to 1983, which provides her with unique insight (but also potential bias) with regard to the WWI. Specific goals of the paper are to provide background about the

WWI, to identify mapping differences between the WWI and the NWI, and to recommend methods for converting digital WWI maps into a format comparable to the NWI.

COMPARISON OF MAPPING CONVENTIONS

The Wisconsin Legislature mandated in 1978 that a statewide inventory of wetlands be conducted and completed by 1984 (§23.32 Wisconsin Statutes). The act creating the WWI charged the Wisconsin Department of Natural Resources (WDNR) with preparing by July 1, 1983 ''maps that, at a minimum, identify as accurately as is practicable the individual wetlands in the state which have an area of 5 acres or more . . . utilizing the best methods practicable with the funds available for that purpose.'' The ''funds available for that purpose'' were $175,000 per year (Chapter 374, Laws of 1977). The GIS version of the inventory was conceived early in the mapping process (Johnston et al. 1988), but funds were not initially allocated for that purpose.

At the time, methods for the NWI were still being developed. The NWI classification system was still an ''Operational Draft'' (Cowardin et al. 1977), having evolved from a national workshop held two years earlier (Sather 1976). A delegation from the Wisconsin Department of Natural Resources (WDNR), the agency charged with conducting the WWI, visited the Fish and Wildlife Service's NWI office in St. Petersburg, Florida in 1978 to discuss wetland mapping and classification procedures. It was known that the NWI would be conducted by aerial photo interpretation and that it would eventually be digital, but mapping methods were still being developed and Geographic Information Systems were in their infancy.

Because of their parallel development and a desire to minimize duplication of effort, the two inventories are very similar. However, the WWI was faced with its statutorily mandated deadline, which was made more urgent by the formal adoption of the WWI maps into Shoreland Zoning regulations (Chapter 330, Laws of 1981). The WWI was completed within its mandated timeframe (Johnston 1984) and has been updated in many parts of the state with more recent photography. The NWI faced budget cutbacks and is still not complete after 23 years (http://wetlands.fws.gov/webstat.gif).

Differences in Aerial Photography

Film type, photo scale, and date of photo acquisition have important implications for the final map product (Johnston 1977, Tiner 1990,1996). ''Leaf-off'' photography, taken in spring before deciduous leaves emerge or in autumn after leaf fall, is preferred for detecting wet soils under deciduous forest canopies, particularly where the tree or shrub species present are not clearly hydrophytic or where soils are seasonally flooded. ''Leaf-on'' photography, taken in summer when deciduous trees and shrubs have leaves, is preferred for identifying non-persistent emergent and aquatic vegetation. A combination of both photo dates is best for wetland mapping, combining the merits of each.

Both the NWI and the WWI used stereoscopic aerial photo interpretation as the basis for wetland identification, and wetland boundaries were delineated on contact prints or transparencies (Johnston 1984, NWI 1990). For the NWI, interpretation was conducted using high altitude aerial photography transparencies taken during leaf-off conditions, but in the late 1970s, the only such photography that was available for Wisconsin was black and white panchromatic imagery with a scale of 1:80,000. At this scale, a 0.13 mm line drawn on the aerial photo (the width of a 6x0 pen point) represents 10.4 m on the ground. Black and white photography with a scale of 1:80,000 or 1:120,000 was used for wetland mapping in 34 states by the NWI (Table 13.4 in Tiner 1996), but the photography currently preferred is 1:58,000 or 1:40,000 color infrared aerial photographs taken by the National High Altitude Photography and Aerial Photography Programs, photography with more suitable scale and film type for wetland discrimination and delineation.

The initial WWI used 1:20,000 black and white infrared leaf-on aerial photos taken during the summers of 1978 and 1979. These photos were acquired primarily for the state forest inventory conducted by the WDNR Bureau of Forestry. Although the Bureau of Forestry conceded to the 1:20,000 scale (1:15,840 scale photos had typically been used), it would not agree to the acquisition of color infrared photography. Each 1:20,000 photo was centered over four sections of the U.S. Public Land Survey, an area of 10.4 km^2.

Differences in Delineation of Lakes and Rivers

The NWI is an inventory of wetlands *and* deepwater habitats: NWI maps delineate all lakes, rivers, and streams visible on the source aerial photography used (NWI 1990). In contrast, the WWI hard copy maps depict *only* wetlands (including shallow lakes), with the rationale that other sources of information are adequate or superior for non-wetland surface-water resources. To distinguish wetland lakes from non-wetland lakes, the WWI used the publication ''Wisconsin Lakes'' (WDNR 1978), which provides the maximum depth of all named lakes of all sizes and of unnamed

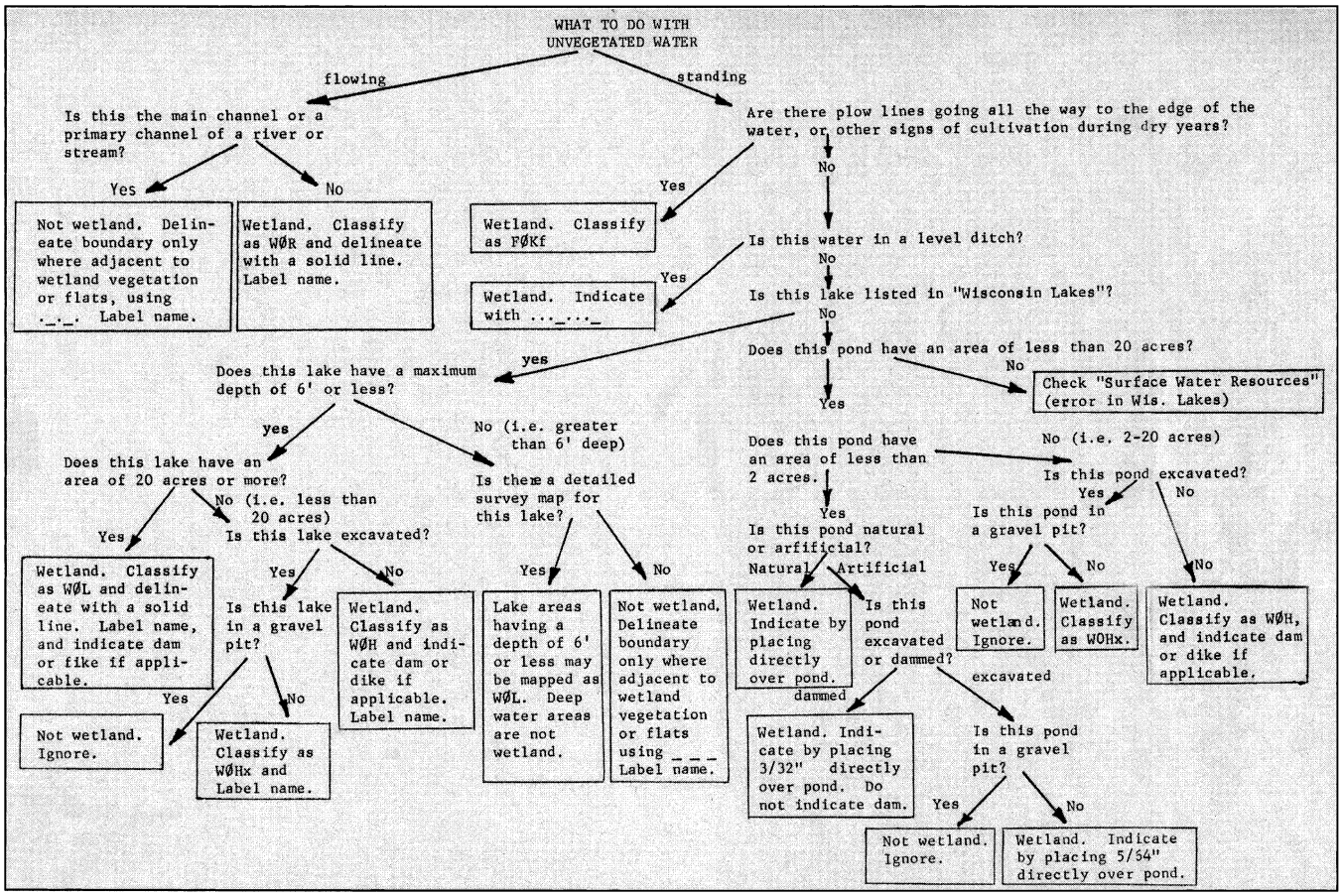

Figure 1. Flow chart illustrating treatment of water bodies by the Wisconsin Wetlands Inventory, scanned from the original document used by WWI.

lakes greater than 8 ha. The WWI Operational Definition of Wetland (Johnston 1982a) specifically included:

5. All lakes listed in ''Wisconsin Lakes'' or ''Surface Water Resources'' as having a maximum depth of six feet or less, whether vegetated or not.

6. All lakes, flowages, and natural and artificial ponds for which there is no available depth information, except those specifically excluded in #5 and #6 of the following section.

The WWI Operational Definition of Wetland specifically excluded:

1. Areas of open water or submerged aquatic vegetation in lakes deeper than six feet.

5. All sewage lagoons, manure storage pits, mine waste settling ponds, and other man-made waste disposal pits, whether or not they support wetland vegetation.

6. All ponds created by mining of gravel or other mineral resources which are unvegetated, or which support only aquatic bed vegetation (e.g, surface algae).

Lakes larger than 8 ha that met the WWI Operational Definition of Wetland were assigned the WWI hydrologic modifer ''standing water, lake'' (L), and lakes 8 ha or smaller were mapped using the WWI hydrologic modifier ''standing water, palustrine'' (H) to be consistent with the corresponding System designations in the NWI (Lacustrine and Palustrine, respectively). Any area of floating aquatic or non-persistent emergent vegetation within a lake boundary was mapped as wetland, regardless of the maximum depth of the lake (Figure 1). On digital versions of the WWI maps, non-wetland lakes that are completely surrounded by wetland are indicated by the code ''DWL'' (deepwater lake) in the WETCODE attribute field to distinguish them from upland islands, but deepwater lakes that are not completely surrounded by wetlands are included under ''U.'' This is confusing because ''U'' indicates upland on NWI maps. On WWI maps, ''U'' means ''non-wetland,'' including deepwater habitats as well as uplands.

With regard to rivers, the WWI Operational Definition of Wetland specifically included as wetland ''ar-

eas of standing water or emergent wetland vegetation in sloughs, oxbows, the abandoned and secondary channels of rivers and streams, and the associated mud flats and sand bars'' and specifically excluded ''areas of flowing open water or submerged aquatic vegetation in the main and primary channels of rivers and streams'' (Johnston 1982a). As with lakes, any area of floating aquatic or non-persistent emergent vegetation within a riverbed was mapped as wetland (Figure 1). On digital versions of the WWI maps, a primary channel of flowing water that has wetland on both sides is indicated by the code ''RIVER'' in the WETCODE attribute field; otherwise, rivers are included under ''U.''

Non-persistent emergents and aquatic beds were rarely visible on the leaf-off aerial photography used by the NWI. Spring photos were taken before these plants had begun to emerge above the water surface, and fall photos were usually taken after their senescence. These two vegetation types *were* present on the summer photography used by the WWI and were more commonly mapped than would have been the case using leaf-off photography. Areas mapped by the WWI as non-persistent emergents or floating aquatic bed would likely have been mapped by the NWI as open water. Submergent aquatics were virtually undetectable on the black and white infrared photos used by the WWI due to the poor water penetration of infrared light and were therefore rarely mapped by WWI.

Although non-wetland lakes and rivers were not delineated as polygons on WWI maps, their presence relative to wetlands was indicated on the hard copy maps by the use of special linear features. Streams flowing through wetlands and river banks bordering wetlands were delineated as dot-dash lines, and boundaries between lakes and wetlands were delineated as dashed lines (Figure 1). These special linear features do not appear on digital versions of the WWI maps.

Differences in Classification and Coding

The WWI used the same ''classes'' and ''subclasses'' as the Operational Draft of the NWI (Cowardin et al. 1977), so there is virtually a one-to-one correspondence between the two inventories (Table 1). Four emergent subclasses (narrow-leaved persistent, broad-leaved persistent, narrow-leaved nonpersistent, broad-leaved nonpersistent) were dropped by the NWI by the time its final classification went to press (Cowardin et al. 1979). These emergent subclasses continued to be a part of the WWI classification system, but the more general ''persistent'' and ''non-persistent'' subclasses were used most often. The WWI added a subclass for indeterminate needle-leaved trees (T8) because the persistence of conifer needles could not be distinguished on its summer leaf-on photography (i.e., it was impossible to distinguish the deciduous conifer *Larix laricina* (Du Roi) K. Koch from evergreen conifers). Similarly, the WWI added categories for needle-leaved shrubs (S8) and broad-leaved shrubs (S9) of indeterminate persistence (Table 1). The WWI lacked subclasses comparable to the algal and aquatic moss aquatic beds in the NWI classification, but these subclasses are almost never used on NWI maps in freshwater regions. The WWI also lacked subclasses comparable to the NWI lichen subclass because that subclass does not exist in Wisconsin.

At a minimum, each WWI code consists of an uppercase alphabetical character indicating ''class,'' a numerical character indicating ''subclass,'' and an uppercase alphabetical character indicating ''hydrologic modifier'' (Tables 1, 2). Similar to the NWI, mixed classes are indicated in the WWI by a slash separating taller from shorter (e.g., T3/S3K). Mixed subclasses are also allowed in the WWI, such as mixed broad-leaved deciduous and needle-leaved evergreen forest (T3/5K).

The WWI ''hydrologic modifier'' performs two functions: (1) it distinguishes among wetlands in NWI Lacustrine, Riverine, and Palustrine systems, and (2) within the Palustrine system, it distinguishes wetlands with standing water from those with wet soils (Table 2). Because deepwater was not mapped by the WWI, the ''Standing Water, Lake'' and ''Flowing Water, River'' hydrologic modifiers were *only* applied to wetlands. The NWI has many more ''water regimes'' than the WWI has ''hydrologic modifiers,'' so a WWI hydrologic modifier corresponds to several possible NWI codes. In particular, the WWI ''wet soils'' hydrologic modifier corresponds to any of several NWI water regimes.

The ''ROAD'' and ''$'' codes are used to indicate special upland types on digital versions of the WWI. ''ROAD'' refers to an area of road that has wetland on both sides; such areas are mapped as upland in NWI. The ''$'' symbol is placed before a wetland classification code to denote that it no longer exists due to filling or drainage.

Lowercase alphabetical characters at the end of a WWI code sequence indicate optional ''human influence modifiers'' and ''special wetland characteristics.'' The six ''human influence modifiers'' are abandoned farmland (a), cranberry bog (b), cultivated cropland (f), grazed (g), vegetation recently removed (v), and excavated (x). The WWI ''special wetland characteristics'' included several categories of wetland complexes, areas in which upland and wetland were intricately interwoven (Table 3). The use of wetland complexes was deemed necessary because of unique geomorphic features in the recently glaciated Wiscon-

Table 1. Correspondence between NWI and WWI classes and subclasses. Codes in parentheses indicate no direct equivalent. Lichen subclass (NWI subclass ML2) does not occur in Wisconsin.

Class	Subclass	NWI Code	WWI Code
Open water/unknown bottom*	none	OW	W0
Rock bottom†	Bedrock, Rubble	RB1, RB2	(W0)
Unconsolidated bottom†	Cobble-Gravel	UB1	W1
	Sand	UB2	W2
	Mud	UB3	W3
	Organic	UB4	W4
Aquatic bed	Algal	AB1	(W0 or A2)
	Aquatic Moss	AB2	(W0)
	Rooted Vascular	AB3	A3
	Floating Vascular	AB4	A4
	Unknown Submergent	AB5	A1
	Unknown Surface	AB6	A2
Unconsolidated Shore	Cobble-Gravel	US1	F1
	Sand	US2	F2
	Mud	US3	F3
	Organic	US4	F4
	Vegetated	US5	F5
Moss-Lichen	Moss	ML1	M0
Emergent	Persistent	EM1	E1
	Narrow-Leaved Persistent	(EM1)	E2
	Broad-Leaved Persistent	(EM1)	E3
	Nonpersistent	EM2	E4
	Narrow-Leaved Nonpersistent	(EM2)	E5
	Broad-Leaved Nonpersistent	(EM2)	E6
Scrub-Shrub	Broad-Leaved Deciduous	SS1	S3
	Needle-Leaved Deciduous	SS2	S2
	Broad-Leaved Evergreen	SS3	S6
	Needle-Leaved Evergreen	SS4	S5
	Dead	SS5	S7
	Indeterminate Deciduous	SS6	S1
	Indeterminate Evergreen	SS7	S4
	Needle-Leaved	(SS2 or SS4)	S8
	Broad-Leaved	(SS1 or SS3)	S9
Forested	Broad-Leaved Deciduous	FO1	T3
	Needle-Leaved Deciduous	FO2	T2
	Broad-Leaved Evergreen	FO3	T6
	Needle-Leaved Evergreen	FO4	T5
	Dead	FO5	T7
	Indeterminate Deciduous	FO6	T1
	Indeterminate Evergreen	FO7	T4
	Needle-Leaved	(FO2 or FO4)	T8

* Used on older NWI maps.
† Used on newer NWI maps.

sin terrain, in which wetlands and uplands are interspersed in nearly level terrain (Johnston 1982b). Wetland complexes included areas in which it was difficult to distinguish wetland from upland, such as Lake Superior glaciolacustrine plain, as well as areas in which the distinction between wetland and upland was possible but impractical, such as the ridge and swale complexes adjacent to Lake Michigan. This approach is comparable in concept to soil associations mapped by the National Cooperative Soil Survey. Although ''special modifiers'' were also devised for the NWI, they are infrequently used.

Table 2. Correspondence between WWI Hydrologic Modifiers and NWI System and Water Regime classes.

WWI code	WWI Hydrologic Modifier	NWI System	NWI code	Equivalent NWI Water Regime
L	Standing Water, Lake	Lacustrine	H	Permanently Flooded
R	Flowing Water, River	Riverine	F	Semipermanently Flooded
			G	Intermittently Exposed
			H	Permanently Flooded
H	Standing Water, Palustrine	Palustrine	E	Seasonally Flooded/Saturated
			F	Semipermanently Flooded
			H	Permanently Flooded
			K	Artificially Flooded
			Z	Intermittently Exposed/Permanent
K	Wet Soil	Palustrine	A	Temporarily Flooded
			B	Saturated
			C	Seasonally Flooded
			Y	Saturated/Semipermanent/Seasonal

Differences in Minimum Mapping Unit and Cartographic Methods

Both inventories define a minimum mapping unit, using a point or linear symbol to indicate wetlands visible on the aerial photos that are smaller than the minimum area. For the Wisconsin Wetland Inventory, the minimum mapping unit was 0.8 or 2 ha, depending on the county. For the National Wetlands Inventory, the ''target mapping unit'' was 1.2–2 ha for 1:80,000 aerial photos used to map wetlands in the forested northeastern U.S. A target mapping unit is an estimate of the minimum sized wetland that the NWI is attempting to map consistently (Tiner 1997).

Both the WWI and the NWI manually transferred wetland boundaries and classification codes from the interpreted aerial photos to a base cartographic medium. The NWI used black and white 1:24,000 U.S.G.S. topographic maps printed onto frosted mylar as its base medium. The WWI used two types of photographic media printed onto frosted mylar: (1) U.S.G.S. analog orthophotoquads were used for the two areas of central Wisconsin where they were available, about 15% of the state; and (2) nominally rectified and ratioed enlargements of township-centered photographs were used for the remainder of the state. A Bausch and Lomb Zoom Transferscope™ was used by both inventories to transfer boundaries from interpreted photos to the base medium, but the WWI used this instrument only when wetland boundaries were not readily apparent on the base photographs.

Table 3. Special wetland characteristic codes for the Wisconsin Wetlands Inventory.

Code	Description
e	complex of exposed flats and secondary river channels, used primarily in the Wisconsin and Mississippi Rivers
j	shallow marsh/wet meadow/sand ridge complex, used primarily in the Glacial Lake Wisconsin region of central Wisconsin
m	floating peat mat
s	ridge and swale complex, used primarily along Lake Michigan
w	flood plain complex composed of seasonally flooded wetland, meander scars, and oxbow lakes, with some inclusions of upland
z	evidence of muskrat activity

METHODS

In contrast to the previous section, which compares procedural standards, the following section compares actual maps prepared by the Wisconsin and National wetland inventories. This is important because it reveals aspects of mapping implementation that may be unrecognized by formal specifications. Rather than provide anecdotal comparison of theoretical differences, this section is a quantitative GIS analysis of the two sets of maps where they co-occur in Wisconsin.

Study Areas

Superior Study Area. The quantitative analysis required comparison of digital wetland maps. Although NWI hardcopy maps were prepared for the four states bordering Wisconsin, a search using NWI's on-line Wetlands Interactive Mapper Tool (http://wetlands.fws.gov/mapper_tool.htm) showed that the only border region for which standard NWI hardcopy maps were digitized within Wisconsin was in the vicinity of Superior, Wisconsin. Therefore, the primary study site consists of the Wisconsin portion of the adjacent Superior and West Duluth 1:24,000 quadrangles (NWI

maps 46092-F1 and 46092-F2; WWI maps T49N R15W, T49N R14W, T49N R13W, T48N R15W, T48N R14W, T48N R13W). This study site is desirable for comparing wetland classification systems because (1) it contains an abundance of wetlands, (2) all three freshwater NWI systems (lacustrine, riverine, palustrine) are present, and (3) the source photographs for the WWI and NWI maps were acquired within nine months of each other, so the two inventories represent wetland conditions as they existed at approximately the same time. The source photography for the NWI maps was 1:80,000 black and white transparencies taken in November 1978, whereas the source photography for the WWI maps was 1:20,000 black and white infrared contact prints taken in summer 1979. The original aerial photointerpretation for both inventories was conducted in the early 1980s.

Despite the many positive reasons for selecting the Superior study area, the glacial geomorphology, soils, and disturbance history of the area make the delineation of upland–wetland boundaries challenging. The entire region was submerged by Glacial Lake Duluth about 10,500 B.P., and its red clay soils are derived from lacustrine bottom sediments (Clayton 1984). Forested and shrub wetlands are common in the nearly level glaciolacustrine plain, lying at elevations between 198–207 m, but are generally absent in the stream corridors that deeply dissect the glaciolacustrine plain. Thus, wetlands occur on table-tops separated by ''upland'' stream corridors, the inverse of wetland placement in most landscapes. The distinction between wetland and non-wetland is often obscure because of the level topography, clay soils, and an abundance of facultative woody covertypes. Many of the wetlands within the City of Superior have been subjected to human disturbances such as clearing and partial filling, which promotes weedy vegetation that is poorly indicative of wetland conditions.

Baraboo Study Area. Updated NWI methods involve digitization directly from aerial photographs through the use of a digital transferscope, thereby eliminating the need to prepare hardcopy maps. In most cases, existing digital data can be edited through this process. Furthermore, the NWI now uses larger scale aerial photos than were used for the Superior study site. In order to evaluate this contemporary methodology, a secondary study site (Baraboo) was chosen to compare WWI maps with NWI maps prepared for the adjacent Sauk City and Baraboo 1:24,000 quadrangles (NWI maps 43089-C6 and 43089-D6; WWI maps T12N R6E, T12N R7E, T11N R6E, T11N R7E, T10N R6E, T10N R7E, T9N R6E, T9N R7E). These two quadrangles were prepared as a special project by NWI and are the only examples of this updated NWI methodology in Wisconsin. The WWI digital data were used as a starting point for the updated NWI maps, so much agreement between the two databases would be expected.

The Baraboo study area extends from the cities of Baraboo at its northern edge to Prairie du Sac and Sauk City at its southern edge, within Sauk County and northeastern Dane County. It straddles the terminal moraine of the Wisconsin glaciation, which separates the hilly ''Driftless Area'' of western Wisconsin from the glaciated eastern portions of the state. The area is geomorphologically diverse, encompassing the resistant quartzite Baraboo Hills at its northwestern edge, the sandy floodplain of the Wisconsin River, and rolling glacial end moraine at its southeastern edge. Agriculture is the predominant land use. The former Badger Army Ammunition Plant also lies within the study area.

Comparison of the two wetland inventories is complicated by the temporal displacement between photo dates at the Baraboo site. The NWI quadrangles were interpreted from black and white 1:40,000 photographs taken in 1998 and 1999. The WWI maps were interpreted from 1986 aerial photos in Dane County (T9N R7E and portions of T9N R6E) and 1978 aerial photos in Sauk County. Thus, differences between the two wetland inventories could be due to changes that have taken place in the 13 to 21 years intervening between the photo dates of the two inventories.

Data Sources and Analysis

Digital versions of Wisconsin Wetland Inventory maps were procured by the U.S. Environmental Protection Agency Region V in Arc/Info coverage format and reprojected by the authors from Wisconsin Transverse Mercator NAD 83 into UTM Zone 15 NAD 83 for overlay with other digital data sources. Digital versions of the Baraboo and Sauk City NWI maps were downloaded in Arc Export format from the NWI website (http://wetlands.fws.gov/downloads.htm). Digital versions of the Superior study area NWI maps were procured in ArcView shapefile format from the Minnesota Department of Natural Resources (MDNR 1997). The Minnesota-Wisconsin border was digitized on-screen from the U.S.G.S. digital raster graphics (DRGs) for the West Duluth and Superior 1:24,000 topographic maps and used to clip out the Wisconsin portions of the corresponding NWI maps.

Digital versions of the NWI and WWI maps were combined and converted to ''shapefiles'' for analysis in ArcView Geographic Information System, Version 3.2. The ''identity'' function in ArcView was used to intersect the two maps, creating new polygons as combinations of the two sets of classes. The area and num-

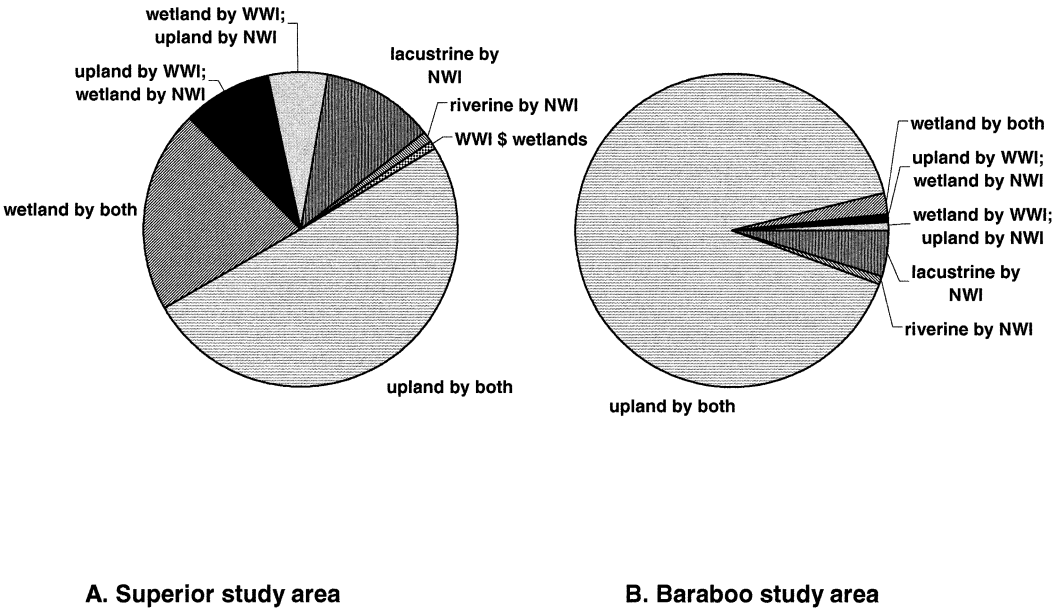

Figure 2. General categories of correspondence between the two inventories, as a proportion of the total map area within Wisconsin. A. Superior study area. B. Baraboo study area.

ber of polygons in each new combination were summarized using the ''frequency'' function to generate a .dbf file that was imported into a spreadsheet program for further analysis.

Ancillary data sources used in evaluation of the study area included U.S.G.S. topographic maps, field studies previously conducted by the authors (Johnston et al. 1996, 1999, 2001), descriptions of Lake Superior coastal wetlands by the Wisconsin Department of Natural Resources (Epstein et al. 1997), the hardcopy navigational chart of the Duluth-Superior harbor (NOAA 1997), and on-line, non-geofererenced images of the navigational chart of the Duluth-Superior harbor (http://mfproducts.nos.noaa.gov/images/charts/14975_1.gif) and Upper St. Louis River (http://mfproducts.nos.noaa.gov/images/charts/14975_2.gif). Digital data sources used as a backdrop for displaying the digital wetland data included DRGs, which are georeferenced images of U.S.G.S. topographic maps and Digital Orthophotoquads (georeferenced, spatially-corrected aerial photo images).

RESULTS

NWI Map Classifications

Superior Study Area. Nearly half of the 17,780-ha Superior study area was mapped as wetland or deepwater habitat by the NWI (Figure 2a). The Lacustrine system covered 2,078 ha of Lake Superior and its extension into Superior Bay and the St. Louis River. As per NWI mapping conventions, the St. Louis River estuary was classified as Lacustrine at its broad mouth near the Superior harbor and Riverine as it became more constricted upstream. The bridge linking Oliver, WI and New Duluth, MN was chosen as the boundary between the Lacustrine and Riverine portions of the St. Louis River.

The only areas mapped by NWI as lacustrine littoral open water (L2OW) were a 59-ha area of the Superior harbor surrounding Barker's Island, a 9-ha area on the Superior harbor side of Connors Point, a 35-ha area surrounding Interstate Island State Wildlife Management Area in the Superior harbor, and a 12-ha strip of shallow water on the Lake Superior side of Wisconsin Point. The remaining 1,961 ha of lacustrine area in Wisconsin, consisting of the open water of Lake Superior, most of the Superior harbor, and all of the St. Louis River estuary, was mapped as lacustrine limnetic open water (L1OW).

Comparison of the NWI maps with bathymetric data published for the Superior harbor and St. Louis River estuary showed poor correspondence. Only part of the area mapped as L2OW around Barker's Island was actually < 2 m deep; the Barker's Island marina was deeper than 2 m and should have been mapped as L1OW. Similarly, portions of the 35-ha area mapped as L2OW around the Interstate Island State Wildlife Management Area were much deeper than 2 m. Conversely, Allouez Bay and most of the St. Louis River estuary is shallower than 2 m and should have been mapped as L2OW instead of L1OW.

The NWI mapped 170 ha of Riverine system habitats. The Nemadji and upper St. Louis River were classified as R2OWH (135 ha). The Pokegama River (9

ha) was incorrectly classified as ''intermittently exposed'' (R2OWG); the Pokegama River is extremely turbid, but the riverbed is never exposed (Johnston et al. 2001). A 26-ha area of nonpersistent Riverine emergents was correctly mapped along the Pokegama River (R2EMF); species present included *Sagittaria cristata* Engelm. and *Sparganium eurycarpum* Engelm. ex Gray. Although linear symbols were used to map ''Upper Perennial Riverine'' streams (R3OWH) on the hard copy NWI maps, linear features were digitized by NWI in a separate file that was not used in this analysis.

The remaining 50 wetland types used by NWI were Palustrine. They consisted of various combinations of five classes (AB, EM, OW, SS, FO) and nine water regimes (A, B, C, E, F, G, H, Y, Z) (Tables 1, 2). Subclasses were occasionally used with the FO vegetation class (FO1, FO5, FO6) but were rarely or never used with the other vegetation classes in the Superior study area. The only special modifiers used by NWI were ''beaver'' and ''excavated.''

Different NWI water regimes were used to distinguish wet deciduous forests in two distinctive geomorphic situations: the NWI PFO1C and PFO1E classes were applied to deciduous floodplain forests along the Nemadji and Red rivers, whereas the PFO1A class was applied to wet deciduous forests on the poorly drained, red clay flats. The floodplain forests lie at elevations ranging from 184 m (just above the level of Lake Superior) to 195 m, whereas the other wet deciduous forests are perched at elevations above 198 m. The Y and Z water regimes were applied only to wetlands contiguous with Lake Superior and the St. Louis River.

Baraboo Study Area. More than 90% of the Baraboo study area is upland (Figure 2b). The 1,300 ha of Lacustrine system mapped by NWI within the Baraboo study area include several natural lakes (Devils Lake, Fish Lake, Crystal Lake, Gallus Slough) and part of Lake Wisconsin, an impoundment of the Wisconsin River upstream from the Prairie du Sac dam. The natural lakes were classified as L1UBH, whereas Lake Wisconsin was classified with an ''impounded'' modifier (L1UBHh). The 247 ha of Riverine system was mapped primarily as Lower Perennial Unconsolidated Bottom Permanent (R2UBH), with a few small areas of Unconsolidated Shore (R2USA and R2USC) in the Baraboo River and the Wisconsin River downstream of the Prairie du Sac dam.

Even though total Palustrine wetland area was less in the Baraboo study site (855 ha) than in the Superior study site (5,351 ha), there were more unique Palustrine wetland classification combinations used (66 combinations in the Baraboo study area vs. 50 combinations in the Superior study area). This is partly due to a procedural change between the two sets of maps in the application of mixed classifications. Mixed classes on the Superior NWI maps always listed the taller life form first (e.g., PFO/SS, PSS/EM), and reciprocals were not used. In contrast, mixed classes on the Baraboo NWI maps listed classes in order of their areal coverage, so that reciprocal pairs such as PEM1/SS1 and PSS1/EM1 were treated as different class combinations.

The classes used in the Baraboo study area, either individually or in combination, were AB, EM, SS, FO, UB, and US. The Unconsolidated Bottom class (UB) was substituted for the Open Water (OW) class that had been used on earlier maps. Subclass numbers were applied to all vegetated wetland classes, but all woody vegetation was mapped as ''Broad-Leaved Deciduous,'' and all emergent vegetation was mapped as ''Permanent.'' Special modifiers were commonly used, including the ''Pf'' designation to indicate unclassified farmed wetlands.

Six water regimes were used in the Baraboo study area: A, C, E, F, H, and K. The ''Saturated'' (B) water regime, which was commonly applied to shrub/scrub wetlands in the Superior study area, was used only for a single 0.2-ha polygon of EM1B in the Baraboo study area. The ''Semipermanently Flooded'' (F) and ''Permanently Flooded'' (H) water regimes were applied almost exclusively to Palustrine ponds (PUB); the latter water regime was most common. Most of the wetlands mapped as ''Seasonally Flooded/Saturated'' (E) were adjacent to Manley Creek in T11N R7E, although the E water regime was also applied to marshes fringing Alder Pond and Lake Wisconsin. In contrast to the Superior study site, where the E water regime was applied to 50 ha of deciduous floodplain forest, the E water regime was not applied to any forested wetlands in the Baraboo study area. Two-thirds of PFO1 wetlands in the Baraboo study area were mapped as ''Temporarily Flooded'' (A); the remainder were mapped as ''Seasonally Flooded'' (C). Mixed woody/emergent wetlands (e.g., PFO1/EM1, PSS1/EM1) were nearly always mapped with a C water regime. Water regimes applied to Palustrine emergent, and mixed emergent/shrub wetlands (PEM1/SS1) were about 40% Seasonally Flooded/Saturated, 40% Seasonally Flooded, and 15% Temporarily Flooded. The ''Artificially Flooded'' (K) water regime was applied to some excavated ponds (e.g., PUBKx, PUBKrx), but it was not clear how these excavated ponds differed from excavated ponds mapped as PUBHx.

WWI Map Classifications

Superior Study Area. A total of 67 classes were used on the WWI maps. Of these, nine were non-wetland

classes: U, ROAD, and seven classes of eliminated wetlands (preceded by $). A total of fourteen covertypes were used: A1, A2, E1, E2, E4, F3, S3, S6, S9, T3, T5, T7, T8, and W0 (see Table 1 for description). The ''L'' hydrologic modifer was used for 123 ha of aquatic bed vegetation, and the ''R'' hydrologic modifier was used for 15 ha of non-persistent emergents mixed with aquatic bed vegetation (E4/A2R), but all other wetlands were mapped using the ''H'' or ''K'' hydrologic modifier (see Table 2 for description). Three special wetland characteristics were used: m, r, and w (Table 3). All of the human-influence modifiers except cranberry bogs were used (a, f, g, v, x).

The ''red clay complex'' (r) was commonly used within the study region. Field surveys conducted by Epstein and collegues (1997) later described such areas:

> The extensive, poorly drained, red clay flats in the headwaters of the Pokegama and Little Pokegama rivers support a large wetland mosaic of shrub swamp, sedge meadow, emergent marsh, and small ponds. Tiny, upland ''islets'' of white spruce (*Picea glauca* (Moench) Voss; FACU), white pine (*Pinus strobus* L.; FACU), red pine (*Pinus resinosa* Aiton; FACU), balsam poplar (*Populus balsamifera* L.; FACW) and trembling aspen (*Populus tremuloides* Michx.; FAC) puntuate the flats. The shrub wetlands are composed mostly of speckled alder (*Alnus incana* L. Moench; OBL) and willows (*Salix petiolaris* Sm.; FACW+, *S. discolor* Muhl.; FACW, *S. pyrifolia* Anderss.; FACW+, others).

The WWI maps included 172 ha of eliminated wetlands (classification preceded by ''$''). Most of these wetlands were associated with human development, such as wetlands filled to construct a large shopping mall, expand the Bong airport and adjacent Douglas County fairground, reroute U.S. Route 2, construct new railroad yards and radio towers at Pokegama WI, place fill in dock areas in Superior, create new housing developments, and build a warehouse in South Itasca. These development pressures were usually obvious upon examination of current U.S.G.S. quadrangle maps, which were updated from 1991 aerial photos to show altered cultural features. The eliminated wetlands may also have been marginal to begin with because about half (by area) were never mapped as wetland by NWI. The largest of these was a 25-ha area of $S3Kr north of Bong Airport that was not mapped as wetland by NWI. It was impossible to tell from the digitized WWI maps whether the development pressures affecting the eliminated wetlands actually caused their demise or merely increased the level of scrutiny of the maps in response to a zoning application. However, the Wisconsin Department of Natural Resources keeps records of the reasons for map alterations, which could provide this information.

Baraboo Study Area. A total of 41 classes were used on the WWI maps for the Baraboo study area. Of these, four were non-wetland classes: U, ROAD, DWL, and RIVER. The DWL (deepwater lake) designation was applied to Alder Pond, a 1.7-ha kettlehole lake deeper than 2 m that is surrounded by emergent marsh; NWI mapped this feature as PUBH. Only seven covertypes were used (A2, E1, E2, F2, S3, T3,W0), fewer than the number mapped in the Superior study area due to the predominance of broad-leaved deciduous shrubs and trees in this region of Wisconsin. Nearly all wetlands were mapped using the ''H'' or ''K'' hydrologic modifier. The ''L'' hydrologic modifer was used for 13 ha of aquatic bed vegetation along the north edge of Gallus Slough (mapped as L1UBH by NWI). The ''R'' hydrologic modifier was not used at all in this study site, but sand flats in the Wisconsin River were mapped as F2K and F2Ke. Three special wetland characteristic codes (e, m, w: Table 3) and all of the human influence modifiers except cranberry bogs (a, f, g, v, x) were used. Of the 820 ha of wetlands mapped by WWI, 12% were grazed.

Correspondence between Classification Systems

Superior Study Area. There was substantial agreement between the two inventories. Of the 17,780 ha analyzed in the Superior study area, 51% of the area was classified as upland by both, and 21% was classified as wetland by both (Figure 2a). The two inventories are similar in the placement and extent of wetlands at the Pokegama/Carnegie Wetlands, Nemadji River Marshes, Hill Avenue Wetlands, Oliver Marsh, Wisconsin Point Marshes, and numerous unnamed wetland sites.

The two inventories differed by design in their mapping of deepwater habitats. Of the 2,078 ha classified as Lacustrine system habitats on the NWI maps, nearly all was classified as non-wetland (U) on the WWI maps, consistent with their respective mapping conventions. Similarly, the WWI classified as non-wetland most of the 170 ha of NWI Riverine habitats.

Of the Palustrine wetlands mapped by both inventories, there was substantial agreement in classification. Although the total number of possible combinations from the intersection of the two maps is 3,752 (56 NWI classes $\times$ 66 WWI classes), only 444 unique combinations actually occurred, indicating that the relationship between the two inventories is not random. The 39 combinations with an area of 10 ha or more (Table 4) represent 89% of all wetland area in common

Table 4. Comparison matrix showing area (ha) of correspondence between major NWI Palustrine system wetland types (columns) and WWI wetland types (rows) for the Superior study area.

	PEME	PFO1A	PFO1C	PFO1E	PFO/ SSA	PFO/ SSB	PFO6/ SSA	PFO6/ SS3A	PSSA	PSSB	PSS3A	PSS/ EMB	PSS/ EME	U	Proportion Mapped as Wetland by NWI
E2/W0H	10		2											5	87%*
E2H	80			2									21	13	90%*
S3/E1Kr					1		11		6	30		61		31	78%
S3/E2H	27			4									22	7	92%*
S3K	2	5		1	32	1	96		81		72	1	6	60	84%
S3Ka									15			1		7	71%
S3Kr		9			151	3	193	4	384	21		58		209	80%
S6/E2Hm	16			3										1	94%
T3K	4	4	19	24			1							38	61%
T3Kw			11	1										2	86%
T3/S3K	1	42	2		79	1	111		42	1				89	77%
T3/S3Kr		26		1	481	12	492	31	239	24		24	3	414	77%
T5/S3Kr					94				5					4	96%
T7/W0H	1		12	7										3	88%
T8/S3K					118				22					0	100%
Wetlands					21		17		33	2		15		79	54%
U	40	49	192	53	483	10	310	13	150	14	14	20	17	8922	
Proportion Mapped as Wetland by WWI	81%	65%	28%	49%	68%	62%	74%	73%	81%	84%	84%	81%	81%		

* Includes areas mapped by NWI as Lacustrine or Riverine.

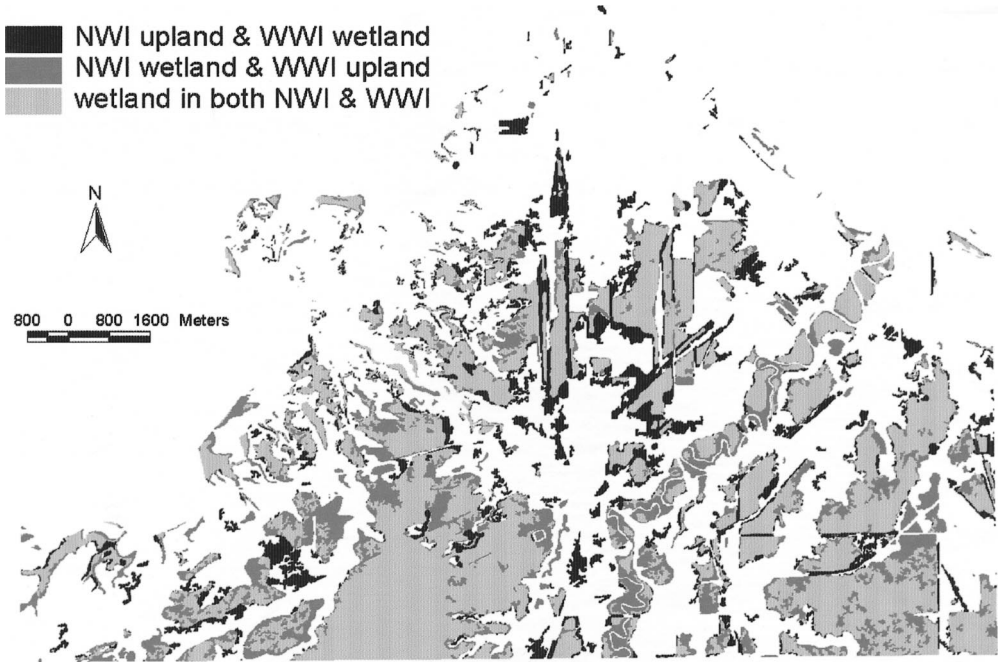

Figure 3. Map of Superior study area, showing correspondence of Palustrine wetland between the two inventories. The ''NWI upland & WWI wetland'' includes 79 ha of wetlands eliminated ($) on the WWI maps that were not mapped as wetland by NWI.

between the two maps, and the corresponding wetland types generally make sense in terms of their class descriptions (Table 1).

Approximately half of the area mapped as Palustrine wetland by NWI in the Superior study area was classified as PFO/SSA or PFO6/SSA (Table 4). There was little apparent distinction between these two classes within the NWI map, and they corresponded to approximately the same WWI classes: T3/S3Kr, S3Kr, and T3/S3K. It was reassuring that coniferous forest covertypes distinguished by the WWI (e.g., T8/S3K, T5/S3Kr, T8/S3Kr, T3/5K) all corresponded to the PFO/SSA (forested/shrub) class and *not* to the PFO6/SSA (deciduous forest/shrub) class. The NWI shrub class PSS3A corresponded exclusively to WWI shrub class S3K. The NWI shrub classes PSSA and PSSB corresponded primarily to WWI types S3Kr, T3/S3Kr, and S3K. The mixed shrub/emergent class PSS/EMB corresponded primarily to S3/E1Kr and S3K, whereas the wetter PSS/EME corresponded to S3/E2H and E2H. The wetter emergent classes in the two inventories (i.e., NWI PEME vs. WWI E2H and E2/W0H) corresponded well with each other (Table 4).

Although the NWI distinguished floodplain forests through the use of the PFO1C and PFO1E classes, there was no single WWI equivalent (Table 4). Areas mapped by WWI as pure deciduous forest without an ''r'' complex modifier (i.e., T3K, T3Kw, T3H, T3Hw) occurred almost exclusively on areas mapped by NWI as PFO1C, PFOE, and PFO1E. The WWI class T7/W0H, usually representing dead trees flooded by beaver impoundments, also occurred primarily within areas mapped by NWI as PFO1C or PFO1E.

Palustrine wetlands having the NWI ''Seasonally Flooded/Saturated'' water regime (E) generally corresponded to the WWI wetlands with the ''Standing Water'' hydrologic modifier (H). This was true for emergent wetlands (PEME) and mixed shrub/emergent wetlands (PSS/EME) (Table 4). Floodplain forests mapped as PFO1E by NWI were most often designated T3K by WWI, and half (by area) were not mapped as wetland at all by WWI.

Only 22 ha of Palustrine open water was mapped by NWI (POWH, POWZ). Corresponding areas in WWI were primarily W0H or a vegetated covertype mixed with W0H (i.e., E2/W0H, T7/W0H).

The most abundant WWI classes were T3/S3Kr, S3Kr, S3K, and T3/S3K (Table 4). Pairs of WWI classes with or without the ''r'' modifier (i.e., T3/S3K vs. T3/S3Kr) corresponded to approximately the same set of NWI classes. Coniferous forest covertypes distinguished by WWI (e.g., T8/S3K, T5/S3Kr) were not distinguished as such by NWI. A single large (141 ha) polygon of T8/S3K mapped by WWI in the core of the Pokegama/Carnegie Wetlands was mapped as PFO/SSA and PSSA by NWI.

There were 1,636 ha mapped as Palustrine wetland by NWI by not by WWI within the Superior study area (Figure 3), about half of which was PFO/SSA or PFO6/SSA (Table 4). There were 779 polygons

mapped as wetland by NWI by not by WWI, with an average area of 2.1 ha per polygon.

The WWI was more conservative about mapping forested wetland than was the NWI and, in many cases, was clearly too conservative. Several large areas of PFO6/SSA and PFO1A in the southeast corner of the Superior study area near Peyton (T48N R13W, sections 8 & 17) appear to have been correctly mapped as wetland by the NWI because they are corroborated by wetland symbols on the U.S.G.S. quadrangle. An 18-ha area of PSSA mapped by the NWI but not the WWI near Ambridge (T48N, R14W, section 13) is corroborated by wetland symbols on the U.S.G.S. quadrangle, as are 74-ha area of PFO/SSA (sections 7 & 18) and a 29-ha area of PEMB (section 8) in the same township.

The NWI and WWI differed substantially in the mapping of floodplain forest, most of which was along the Nemadji River. Of the areas mapped as PFO1C and PFO1E by NWI, only 28% and 49%, respectively, were mapped as wetland by WWI (Table 4). If an area of floodplain forest was shown as upland on U.S.G.S. quadrangles, the WWI tended to map it as upland. The NWI also mapped the Red River floodplain forest as extending further upstream than did the WWI. The Nemadji River Bottoms is dominated by black ash (*Fraxinus nigra* Marsh.; FACW+), and includes green ash (*F. pennsylvanica* Marsh.; FACW), basswood (*Tilia americana* L.; FACU), red maple (*Acer rubrum* L.; FAC), silver maple (*A. saccharinum* L.; FACW) balsam poplar (*Populus balsamifera* L.; FACW) and burr oak (*Quercus macrocarpa* Michx.; FAC-), species that are mostly facultative wetland hydrophytes. However, topographic contours show the Nemadji River to be much lower than its floodplain in its upper reaches, so it is difficult to determine which inventory is correct without water-table data or field delineation.

The two inventories were most consistent when covertypes were shrubby or emergent wetlands (Table 4). A 6-ha area of emergent marsh along the Pokegama River at the boundary between T48N R14W and T49N R14W was erroneously omitted by the WWI, but this may have been a digitizing error because the adjacent WWI maps do not match across this boundary; an area of emergent marsh on the WWI map for T49N, R14W stops abruptly at the township border.

There are several examples of areas mapped as wetland by NWI but not the WWI in which the NWI is clearly incorrect: an area mapped as PFO/SSA on a 5% slope and several forested areas in Superior township (T48N, R15W) that cross 9 m deep ravines. The most noticeable error is the mapping of wetland on Barker's Island, a completely artificial island created by dredge spoil placement that was a hotel resort and marina as of the date of aerial photography.

There were 1,086 ha mapped as wetland by the WWI by not by the NWI in the Superior study area (Figure 3). The top four classes in this category were T3/S3Kr, S3Kr, T3/S3K, and S3K, consistent with the relative abundance of these four classes in areas mapped as wetland by both inventories (Table 4). There were 658 polygons mapped as wetland by WWI by not by NWI, with an average area of 1.7 ha per polygon. One of the largest contiguous areas mapped by the WWI but not by NWI is a 47-ha area of T3/S3K and T3/S3Kr southeast of Oliver (T48N, R14W, sec. 18 and T48N, R15W, sec. 13), which is corroborated by wetland symbols on the topographic map.

Many of the areas mapped by WWI but not by NWI were associated with some type of disturbance, either past or present. The WWI correctly included a 12.5-ha area of S3/E1Kr south of Superior, which is part of the Superior Airport/Hill Avenue Wetlands/South Superior Triangle Priority Site (T49N, R14W, sec. 26), described by Epstein et al. (1997) as follows:

> These three sites, now separated by roads, railroad tracks, and other urban developments, are the largest remnants of a formerly contiguous wetland within the City of Superior. The wetlands are mosaics of shrub swamp and open meadow, with a few small patches of emergent marsh. Trembling aspen (*Populus tremuloides*) often occupies drier portions of the sites. Despite the severe disturbances which have altered the composition, structure, function, size, and configuration of these wetlands, they harbor significant populations of rare plants.

Other urban areas mapped as wetland by WWI but not NWI include a 42-ha area of S3Kr east of South Superior, a 18-ha area of S3/E2Kr and E2Kr near the East End of Superior (T49N, R14W, sec. 25), a 11-ha area of T3/S3K near Allouez, and a triangular area of mixed covertypes (T3/S3K, S3K/E2K, E2K, S3K) sandwiched between railroad tracks east of the Billings Park neighborhood in Superior.

Several areas mapped as wetland by WWI but not NWI were associated with farmland, such as a 13-ha area of second growth shrubs and wet meadow in an abandoned farm field (S3/E1Ka) near Peyton (T48N, R13W, sec. 17) and a 10-ha area of S3K and adjacent wet pasture (E1Kg) south of Saunders (T48N, R14W, sec. 22). None of the area mapped as E1Ka, E1Kf, or E1Kv by WWI was mapped as wetland by NWI, although most of the area mapped as S3Ka was.

Differences in cartographic convention with regard to transportation corridors also explain some of the areas mapped as wetland by WWI but not by NWI. Where a road or railroad crossed a wetland, the WWI drafted the wetland as continuous and indicated the

road or railroad on the hard copy map with linear symbols superimposed on the wetland. During digitization of the WWI maps, road symbols were digitized as separate polygons, but railroad symbols were not. Because of the abundance of railroads within the study area, there are numerous linear corridors corresponding to railroad lines that were distinguished by NWI but not by the digital versions of the WWI maps.

Baraboo Study Area. There was substantial agreement between the two inventories in the mapping of ungrazed wet meadows. Wetlands mapped as S3/E2K or E2K by WWI were almost always mapped as wetland by NWI (Table 5). Conversely, wetlands mapped as PSS1/EM1C, PEM1Cd, or PEM1E by NWI were almost always mapped as wetland by WWI. Most of the area mapped as S3/E2K consisted primarily of a single 116-ha polygon along Manley Creek on the WWI map for T11N R7E; the same area was subdivided by NWI into smaller polygons of PEM1/SS1C, PEM1C, PEM1E, PSS1A, PSS1/EM1C, and PSS1E.

There was slightly less agreement between the two inventories in the mapping of grazed wet meadows. Of 97 ha mapped as E2Kg by WWI, 81 ha (70%) were also mapped as wetland by NWI (Table 5). Grazed wet meadows tend to be some of the driest wetlands, so discrepancies between the two inventories in the mapping of these areas may be due to differences in interpretation or climatic conditions between the two sets of photo dates. A two-ha area that was mapped as E2Kg by WWI using 1978 aerial photos was later dug out to create a pond and mapped as PUBHx by NWI using contemporary aerial photos.

Of the 48 ha of emergent marsh (E2H) mapped by the WWI, only 34 ha were mapped as wetland by NWI (Table 5). Most of the E2H area mapped as upland by the NWI was in old oxbows of the Baraboo River in T11N R7E and T12N R7E, which were mapped in more detail by WWI than NWI. There were also 4 ha of E2H mapped by WWI adjacent to Mud and Fish Lakes that were mapped as upland by NWI. A 10-ha area of E2H was mapped as PEM1Ad by NWI, but examination of aerial photos for this area indicated that the area should have been classified by NWI as a ''Seasonally Flooded/Saturated'' (E) water regime.

Of the 42 ha of ponds mapped by NWI as PUBHx, only 40% were mapped by WWI (Table 5). The WWI used a minimum mapping area of 2 ha in Sauk County and 0.8 ha in Dane County, so natural and excavated ponds smaller than these limits do not appear in the digital data (although they were marked with point symbols on the hard copy WWI maps). The two wetland inventories also differed by design in their mapping of waste disposal ponds (see section on ''Differences in Delineation of Lakes and Rivers''). The NWI mapped as PUBHx groups of sewage disposal ponds for the communities of Merrimac and Prairie du Sac, even though they are marked as such on U.S.G.S. topographic maps; the WWI specifically excluded waste disposal ponds from its definition of wetland. Thus, the discrepancy between the two inventories in the mapping of PUBHx ponds was due to differences in mapping conventions rather than mapping error.

As in the Superior study area, there were substantial differences between the two inventories in the mapping of floodplain forest. The WWI mapped 44 ha of T3Kw within the study area, almost none of which was mapped as wetland by NWI (Table 5). The area mapped as T3Kw is contiguous with the Mazomanie Bottoms, a Wisconsin State Natural Area consisting of southern wet-mesic forest (WDNR 1999):

> Mazomanie Bottoms encompasses a large area of Wisconsin River floodplain forest dissected by old river channels that are dry except during periodic floods. Silver maple (*Acer saccharinum* L.; FACW), elm (*Ulmus* spp.), basswood (*Tilia americana* L.; FACU), and ash (*Fraxinus pennsylvanica* Marsh.; FACW) dominate the forest; other trees include swamp white oak (*Quercus bicolor* Willd.; FACW+), cottonwood (*Populus deltoides* Bartr. ex Marsh.; FAC+, willow (*Salix* spp.), river birch (*Betula nigra* L.; FACW), and hackberry (*Celtis occidentalis* L.; FAC-).

Only 58% and 65% of areas mapped by WWI as T3/S3K and T3K were mapped as wetland by NWI, and most of the discrepancies also occurred in the Mazomanie Bottoms area (T9N R6E). Nearly all of the area mapped by NWI as PFO1C was also mapped as wetland by WWI, but only half of the 49 ha mapped by NWI as PFO1A were mapped as wetland by WWI. Areas of PFO1A not mapped as wetland by WWI included a 10-ha area of deciduous floodplain forest in the Baraboo River floodplain and a 8-ha area of conifer plantation near a ditched drainageway, in sections 5 and 18, respectively, of T11N R7E.

Map Complexity and Distortion

Differences in air photo scale caused differences in mapping complexity between the two inventories in the Superior study area because the coarse scale of the source photography used for the NWI maps (1:80,000) prevented detailed delineation. There were 1050 polygons in the WWI map, as opposed to only 639 in the NWI map. There was 87 m of perimeter drawn on the 1:24,000 WWI maps, representing 2,087 km on the ground; 70 m of perimeter was drawn on the NWI maps, representing 1669 km on the ground. Average area per polygon (excluding ROAD polygons) was

Table 5. Comparison matrix showing area (ha) of correspondence between major NWI Palustrine system wetland types (columns) and WWI wetland types (rows) for the Baraboo study area.

	PEM1/ SS1C	PEM1/ SS1Cd	PEM1/ SS1E	PEM1Ad	PEM1C	PEM1Cd	PEM1E	PFO1/ EM1C	PFO1A	PFO1C	PSS1/ EM1C	PSS1E	PUBHx	U	Proportion mapped as Wetland by NWI
E1Kv			14											0	99%
E2H	1		1	10	1					5	1		1	14	71%*
E2K	2	9	9	5	18	31	2	5	5		3			9	93%*
E2Ka			2		2		16					2		1	97%
E2Kg		2	5	4	16	11	9		1		1	11	2	29	70%
S3/E1K			8				2				11			5	79%
S3/E2K	9		3		7		85		3		4	11		7	95%*
S3K			12		2	4				10				12	74%
T3/S3K		11				3			9	2				20	58%
T3K					1	5	2	10	4	5				18	65%
T3Kw														41	7%*
W0H	1						1						10	3	84%
U	8	16	9	6	12	9	7	1	25	2	2	7	25	25500	
Proportion Mapped as Wetland by WWI	62%	59%	85%	78%	79%	87%	95%	96%	50%	93%	93%	79%	40%		

* Includes areas mapped by NWI as Lacustrine or Riverine.

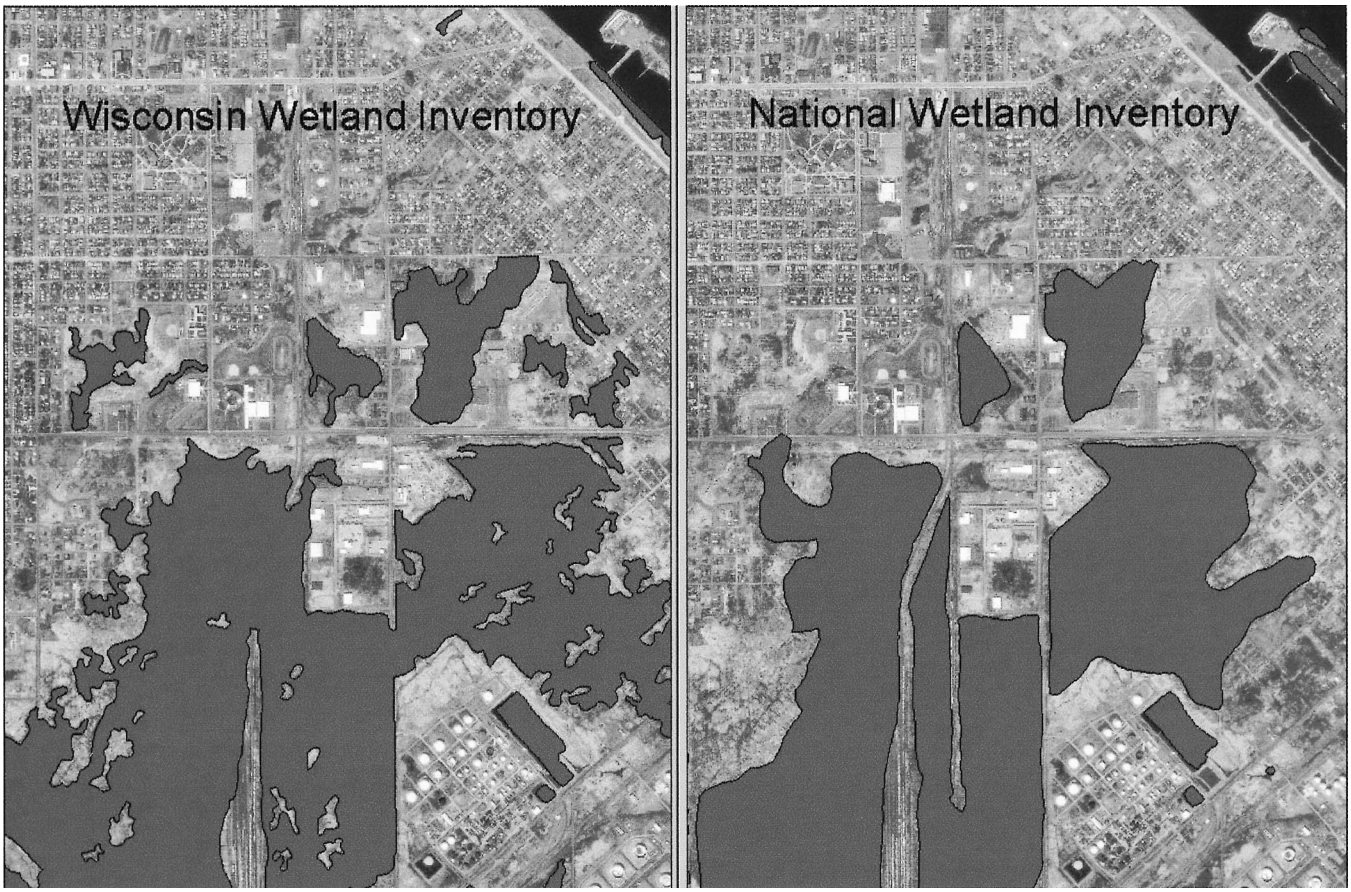

Figure 4. Comparison of boundary complexity between the two inventories in a portion of the Superior study area (sections 23–26, T49N, R14W). Grey shading masks all Palustrine wetlands (wet forests, shrub swamps, wet meadows, and excavated ponds) mapped by the Wisconsin Wetlands Inventory (left side) and the National Wetlands Inventory (right side). The U.S.G.S. digital orthophoto backdrop is identical on both sides, and was not an information source for either inventory.

18.5 ha for the WWI as opposed to 26.7 ha for the NWI. Even though the WWI had a stated minimum mapping unit of 0.8 ha, the WWI map contained 265 non-road polygons < 0.8 ha; the NWI map contained 215 polygons < 0.8 ha. The WWI has no stated minimum area for upland, and upland islands as small as 0.006 ha were mapped; the smallest upland island mapped by NWI was 0.09 ha. The influence of the different scales of aerial photos used by the two inventories is evident from a comparison of the boundary complexity of the two maps (Figure 4).

In contrast, the NWI maps were *more* complex than WWI maps in the Baraboo study area, where the use of a digital transferscope and 1:40,000 source photography permitted fine delineation of boundaries and very small wetlands. This difference was especially evident in Sauk County, where WWI used a minimum mapping unit of 2 ha.

Distortion in the photographic enlargements used by WWI as the base for delineation of its hard copy maps caused some displacement of the areas depicted as wetland. There was a 70-m offset in boundaries of a wetland on the border between T48N R13W and T49N R13W in the Superior study area north of Itasca, and a 40-m offset in the location of the Pokegama River, located at the boundary between T48N R14W and T49N R14W.

DISCUSSION

How Comparable are the WWI and the NWI?

The NWI and the WWI are both complex, and the comparison of two complex maps can make their differences seem overwhelming. There is no question that there are differences between the NWI and the WWI, but the differences are generally explainable with a knowledge of the classification and mapping methods used.

There was substantial agreement between the two inventories, with a high percentage of correspondence in areas mapped as Palustrine wetland. Within areas mapped by both as wetland, there was very good correspondence between covertypes. This was expected

based on definitional similarities between classes and subclasses in the two classification systems (Table 1), but the degree of similarity was greater than expected between the WWI hydrologic modifier and the NWI water regime. The two inventories differed by design in their treatment of deepwater habitats, but that difference could be remedied through the use of GIS techniques (see below).

Despite generally good agreement, areas mapped as Palustrine wetland were not identical between the two inventories. In the Superior study area, 1,636 ha were mapped as Palustrine wetland by NWI but not WWI, and 1,086 ha were mapped as wetland by WWI but not NWI. In the Baraboo study area, 270 ha were mapped as Palustrine wetland by NWI but not WWI, and 235 ha were mapped as wetland by WWI but not NWI. Some boundary mismatch would be expected, even if all air photointerpreters were working with the same aerial photos and mapping conventions (Gong and Cheng 1992). However, these numbers are unacceptably high and reveal problems with both inventories.

Forested wetlands were the most common source of discrepancy between the two inventories. The two inventories differed in their treatment of floodplain forest, but the differences were inconsistent. The NWI was more conservative than the WWI in mapping of floodplain forest on sandy soils along the Wisconsin River but less conservative than the WWI in the mapping of floodplain forest on finer textured soils along the Baraboo and Nemadji Rivers. It is difficult to say which is correct with the evidence at hand. In its report on wetland delineation, the National Research Council (1995) noted that ''riparian zones often contain substantial amounts of land that cannot be classified as wetland according to present regulatory definitions of wetland'' and recommended that regulation be achieved through legislation that recognizes the special attributes of these landscape features rather than by attempting to define them as wetlands.

Temporarily flooded, forested wetland is one of the most difficult types to map from aerial photography (Tiner 1991, 1996, National Research Council 1995). The leaf-on photography used by the WWI is suboptimal for mapping forested wetland because the foliage obscures ground conditions. The WWI was too conservative in its mapping of forested wetland in the Superior study area, and there were numerous errors of omission. Given that the identification of wetland on U.S.G.S. topographic maps is based on leaf-off photography, the WWI should have placed more faith in this ancillary data source in the Superior study area.

The NWI was conservative in its mapping of disturbed wetlands (e.g., wet abandoned farmland, degraded urban wetlands) in the Superior study area but not in the Baraboo study area. Although such wetlands might rank poorly in terms of their quality and functions, they should nonetheless be mapped if they have wetland hydrology, soils, and vegetation. In the case of the Superior Airport/Hill Avenue Wetlands/South Superior Triangle Priority Site, wetland remnants that have been subjected to numerous urban disturbances still harbor significant populations of rare plants. An evaluation of NWI maps by Moorhead and Cook (1992) also indicated that NWI was conservative about mapping wetlands on hydric mineral soils.

The NWI ''Seasonally Flooded/Saturated'' (E) water regime was usually applied to wetlands adjacent to rivers and streams and seemed to relate more to perceived water source than flooding duration. Water-depth measurements made in wetlands adjacent to the Pokegama and St. Louis Rivers (Johnston et al. 2001) showed that emergent wetlands mapped as PEME had overlying surface water for most of the growing season, whereas the water table of forested wetlands mapped as PFO1E was usually below the surface. Thus, the NWI Seasonally Flooded/Saturated water regime seems to represent different hydrologic conditions, depending on the vegetation class.

There were several errors of commission (i.e., areas incorrectly mapped as wetland) by the NWI in the Superior study area, but none were detected in the Baraboo study area. The incorrect mapping of upland forest as wetland by the NWI illustrates the need to consult topographic maps as an ancillary data source during air photo interpretation and drafting. The incorrect mapping of portions of Barkers Island as wetland is an understandable error given its lack of topography and adjacency to Lake Superior, but it infers that the NWI may have been pushing the limits of aerial photo detection by trying to map very small wetlands with 1:80,000 photography. This problem seems to have diminished with the use of a digital transferscope with 1:40,000 aerial photos, as was done in the Baraboo study area.

Additional field investigation of areas of discrepancy between the WWI and NWI maps is needed to resolve their differences in wetland identification. Comparison of the Baraboo study area wetland maps with digital detailed soil surveys would also aid in the identification of candidate field check sites (detailed soil surveys do not yet exist for the Superior site, either in published or digital form).

The use of aerial photo enlargements as a mapping base by the WWI has been a source of concern nearly since the inventory's inception. These photo bases incorporated positional errors due to camera tilt and relief displacement of as much as 45–60 m, and wetland features along township boundaries are often noticeably displaced (Niemann 2001). There was some ob-

vious displacement of wetland boundaries along WWI map borders within the Superior study area and edge matching errors along WWI map borders within the Baraboo study area. There were no displacement problems observed on the NWI maps.

Other possible sources of positional error are drafting error and digitizing error. Potential drafting errors include incorrect coding and the displacement or omission of wetlands delineated on the aerial photos when the information is transferred to the map base by a cartographer. Potential digitizing errors include the same types of errors (incorrect coding, displacement or omission of wetlands) occurring when the information is digitized from the drafted map base into computer format, as well as positional errors that can occur during georeferencing of the base maps. Although these sources of error undoubtedly affect the accuracy of both digital datasets, drafting and digitizing errors were not analyzed in this comparison.

Table 6. Preliminary conversion table from common WWI classifications to NWI classifications.

WWI Code	Corresonding NWI Code
A2L	L2AB6H*
E1K or E2K	PEM1C
E1H or E2H	PEM1E
E1/W0H or E2/W0H	PEM1F
F2K or F2Ke	R2USA
S3/E1K or S3/E2K	PSS1/EM1C
S3/E1H or S3/E2H	PEM1/SS1E
S3K	PSS1A or PSS1E†
S6/E2Hm	PSS3/EM1E‡
T3K	PFO1C
T3/S3K	PFO1/SS1A
T5/S3K or T8/S3K	PFO4/SS1A
W0H	PUBH
W0L	L2UBH*

* Areas actually mapped by NWI as L1OWH (Superior) and L1UBH (Baraboo).
† Water regime differed between study areas, requires further research.
‡ Areas actually mapped by NWI as EM1E but should have been mapped as PSS3/EM1E.

Increasing the Compatibility of Existing WWI and NWI Products

Given that the WWI is the only detailed wetland inventory currently available for Wisconsin, what can be done to make existing WWI and NWI maps more compatible for applications that require information from both, such as compilation of regional wetland statistics? Some of the differences between the WWI and the NWI are fairly easily remedied. If information is desired about Palustrine wetland classes only, areas mapped as deepwater by NWI (ie., Lacustrine and Riverine) could be excluded from the digital NWI maps. If information about deepwaters is required, a digital hydrography database such as the recently completed National Hydrography Dataset (http://nhd.usgs.gov) could be unioned with the WWI digital dataset, retaining deepwater polygons in preference to WWI wetland polygons where they intersect. This solution would yield reasonable statistics, but additional editing would be required to create attractive maps in areas where wetland boundaries mapped by WWI adjoin deepwaters because of probable linework mismatch. Fortunately, the hardcopy maps produced by the WWI identify wetland-deepwater boundaries with special linework symbols (Figure 1), which would facilitate identification of the areas requiring editing.

In theory and in practice, the two inventories are nearly equivalent with regard to covertype class and subclass. A GIS lookup table could easily be developed to recode the WWI digital maps to their equivalent NWI class and subclass.

Development of a lookup table between the WWI hydrologic modifier and the NWI water regime is more difficult, because a single WWI hydrologic modifier corresponds to multiple possible NWI water regimes (Table 2). However, evidence from the map comparison indicates that many NWI classes in Wisconsin are associated with a modal water regime. For example, PUB is usually associated with an ''H'' water regime. The NWI PEM class is associated with several water regimes, but the WWI hydrologic modifier codes ''K'' and ''H'' can be used to discriminate PEM1C from PEM1E (Table 6). The application of water regimes to PSS wetlands differed between the Superior study site, where PSSA was most common, and the Baraboo study site, where PSSE was most common. Additional research would be needed to determine whether this difference is due to an unstated procedural change (NWI maps for the Baraboo study area were prepared nearly 20 years after maps for the Superior study area) or due to actual differences in field conditions. In general, however, the class code in combination with the hydrologic modifier can yield a fairly reliable equivalency (Table 6).

Although there is no NWI equivalent, the WWI protocol of using the $ to indicate eliminated wetlands provides important information that could potentially be used to evaluate the type and mode of wetland loss, and the retention of this information with the digital data should be continued. However, the $ symbol is also used to correct errors of commission (i.e., areas incorrectly mapped as wetland), which decreases its utility for assessing sources of wetland loss. A data field existed in the digital WWI database for a code to indicate the reason for the change, but it contained no entries. Either that data field should be implemented,

or a different symbol should be used to distinguish error corrections from actual wetland change.

Recommendations for Updating the WWI

The Wisconsin Land Information Program (WLIP) of the state Department of Administration is currently considering ways to modernize the WWI (Niemann 2001). Concerns raised by the WLIP relate mainly to cartographic quality and data accessibility. There is no question that positional errors induced by the use of photographic enlargements as a map base media seriously degrade the quality of the WWI digital database. This paper has focused on the classification integrity of the WWI maps, however, and the following recommendations relate primarily to ways of improving the content and accuracy of wetlands data contained in the WWI.

(1) Future updates of the WWI should be made with leaf-off color infrared (CIR) photography. The leaf-on, black and white infrared photography that was used for the initial WWI and subsequent updates is suboptimal for mapping forested wetlands because ground conditions are obscured by foliage and the tree species present in questionable areas are usually facultative. Alternate sources of CIR photography now exist that were not available when the WWI was initiated.

(2) Future updates of the WWI should allow for errors of omission to be corrected. The $ symbol is currently applied when an error of commission is detected (i.e., non-wetland mapped as wetland), but there is no update protocol for adding wetlands that were erroneously omitted from the original maps.

(3) The current digital version of WWI should be merged with a digital database of deepwater habitats. This would not only make the WWI more compatible with the NWI but would also provide information about wetland/deepwater boundaries that was shown on the hard copy WWI maps but not digitized.

(4) Additional studies should be conducted to evaluate mapping of floodplain forests. Available stream gauge data should be compared with surface elevation data for forested floodplains to estimate flooding frequency and duration. Satellite remote sensing imagery taken during a seasonal flooding period could also be analyzed to determine the extent of flooding.

(5) Future digitizing should be done using a digital transferscope or on-screen using digital orthophotography without an intermediate paper map.

(6) The State of Wisconsin and the U.S. Fish and Wildlife Service should work together so that the next comprehensive mapping of Wisconsin wetlands provides products that meet both their needs.

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