Status and Trends of Wetlands in Minnesota: Wetland Quantity Baseline

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Abstract – The state of Minnesota has developed a monitoring program to collect scientifically sound data that can be used to assess status and trends of wetland quantity and quality for Minnesota. This paper summarizes the wetland quantity results for the first three-year cycle of the Minnesota Wetland Status and Trends Monitoring Program (WSTMP) to serve as a baseline for future trend analyses. The results for the WSTMP are compared to the National Wetland Inventory (NWI) data and the geographic distribution of wetlands is described. Based on the WSTMP data, the current total wetland area for Minnesota is 10.62 (±0.363) million acres. If deepwater habitats are included, the total area is 13.24 (±0.410) million acres. Remarkably, the statewide estimate of wetland area based on WSTMP (2006-2008) is the same as that from the National Wetland Inventory for Minnesota (1976-1984). However, there are differences in the geographic distribution as well as differences in the distribution of wetland types. These differences are likely a result of a combination of factors including differences in source data, methodology, mapping policies, climate, and ecological succession. Therefore, caution should be used in attempting to draw conclusions about wetland change between these two surveys. The Prairie Parkland and Paleozoic Plateau regions have considerably less wetland than the Eastern Broadleaf Forest and Laurentian Mixed Forest regions. Wetland and deepwater land cover for these regions are 6.90%, 5.35%, 19.9%, and 41.3%, respectively. Field validation efforts indicate that the WSTMP data correctly distinguish between wetland and upland 94% of the time and correctly classify wetland and upland cover types 89% of the time. Analysis of 250 annual plots shows little change in wetland area from year-to-year for the initial three-year sampling cycle.

Introduction

It has been estimated that Minnesota has lost approximately half of its original presettlement wetlands due to draining and filling for agriculture and development, with some regions of the State having lost more than 90 percent of their original wetlands (Anderson and Craig 1984). In response to concern over the loss of wetlands, Minnesota passed one of the most comprehensive wetland protection laws in the nation, the Minnesota Wetland Conservation Act of 1991 (WCA). This law set forth a goal of no net loss of wetlands and requires anyone proposing to drain, fill, or excavate a wetland to first avoid disturbing the wetland whenever possible; second, to minimize impacts to the wetland; and finally to replace any lost wetland area or functions.

While wetland gains and losses under WCA are compiled and reported, various exemptions and unreported violations make it nearly impossible to reliably assess whether the State is achieving its no-net-loss goal. Consequently, the State has developed a monitoring program to collect scientifically sound data that can be used to assess status and trends in wetland quantity and quality for Minnesota. This paper summarizes the wetland quantity results for the first three-year cycle of the Minnesota Wetland Status and Trends Monitoring Program (WSTMP). These data will serve as the baseline for future trend analyses. In addition, this paper compares the results for the WSTMP to the National Wetland Inventory (NWI) data and other sources of wetland data and characterizes the geographic distribution of these wetlands.

Methods

Measurements of wetland area were made by mapping wetlands for 4,990 randomly selected, permanent 1-mi^2 plots, known as primary sampling units (PSUs). Survey plots were selected using the Generalized Random Tessellation Stratified design to ensure that random samples are spatially distributed across the state (Stevens and Olsen 2004). The PSUs are arranged in a cyclical, interpenetrating panel structure. The program design consists of three panels of 1,580 PSUs that are mapped in successive years, so that each panel is mapped every third year. In addition, 250 PSUs are mapped every year to allow assessment of annual variability. The mapping protocol calls for mapping all wetlands within the sampled plots that are at least 0.5 acres in size. Additional details regarding the classification system and methods used are provided in the technical procedures document (Kloiber et al. 2010). The overall design of the program is patterned after the national wetland status and trends program described by Dahl and Bergeson (2009).

Mapping was performed by the Minnesota Department of Natural Resources (DNR) using photo-interpretation of high-resolution color stereo-imagery. Imagery was collected during leaf-off (spring) periods at a typical altitude of 6,700 feet on medium-format film (41 x 56 mm frame size), which is subsequently scanned at 2400 dots per inch and georeferenced to create a digital image with a ground sampling resolution of approximately two feet. Hard copy prints are made at a print scale of 1:12,000 for stereo photo-interpretation. Land cover for each PSU was delineated and classified into 12 land cover classes; six wetland classes, one deepwater class, and five upland classes (Table 1).

A field verification process is used to ensure consistency and accuracy of the wetland interpretation. Roadway accessible wetlands were randomly selected throughout the state, with a goal of field checking at least 30 polygons of each wetland type. Error rates for omission, commission, and overall error rates were calculated using an error matrix following procedures described in Congalton and Green (1999).

Table 1: Land cover codes for the Minnesota WSTMP and the equivalent NWI class codes for wetland cover types.

WSTMP Code	Description	NWI Wetland Codes
AB	Aquatic Bed	L2AB, PAB
CW	Cultivated Wetland	Any code with “f” modifier
DW	Deep Water	L1UB
EM	Emergent	L2EM, PEM, R2EM
FO	Forested Wetland	PFO
SS	Scrub-Shrub	PSS
UB	Unconsolidated Bottom	L2RS, L2UB, L2US, PUB, PUS, R2UB, R2US, R3UB, R3US, R4SB
A	Agricultural	Upland
N	Natural Upland	Upland
R	Rural Development	Upland
S	Silviculture	Upland
U	Urban Development	Upland

Spatial patterns in wetland distribution were also examined. An analysis of wetland occurrence by ecological region was used to assess the geographic patterns in wetland distribution. These regions were modified from the ecological provinces described by Bailey (1995) by extracting the Paleozoic Plateau Section from the Eastern Broadleaf Forest Province and then combining the Tallgrass Aspen Parkland Province with the remainder of the Eastern Broadleaf Forest Province (Figure 1). These regions were selected because the type and abundance of wetland resources in each of them is fairly distinct. The area for each of these regions was determined using the “calculate geometry” function in ArcGIS. The statewide area (84,382 square-miles) was determined as the sum of these regions.

The NWI was geographically intersected with the PSU boundaries to create a dataset that could be compared to the WSTMP data. Nine PSUs were excluded from this analysis due to missing or partly missing NWI data. A classification conversion system was developed to allow comparison of these datasets (Table 1).

Special modifiers were added to the WSTMP data to indicate which wetlands are artificially flooded (af) or man-made (m). Water regimes were also added for emergent wetlands to indicate whether the wetland water regime was seasonal, saturated, or inundated.

Geographic information processing for this report was performed using ArcGIS, version 9.3. Statistical analysis and graphing was done using Microsoft Excel 2000 and JMP, version 8 (SAS Institute, Cary, NC, 2010).

Results

Field Verification

Based on field verification of cover class features the WSTMP results have an overall accuracy of 94% for distinguishing wetland vs. non-wetland and of 89% for classifying cover class (Tables 2 and 3). Omission errors for wetlands are quite low at only 3%. The corresponding producer’s accuracy is 97% for mapping wetlands. These accuracy rates are based on feature counts and not feature area. The area-weighted accuracy is probably better than this because errors are more likely

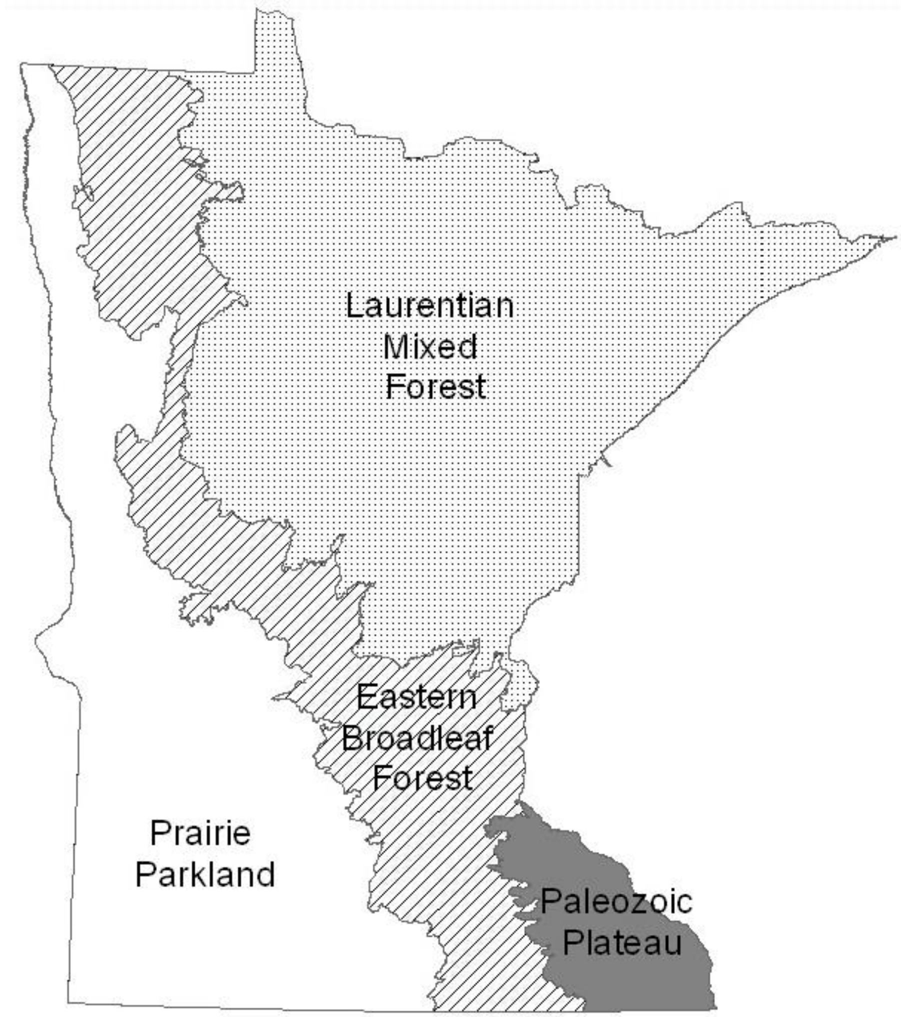

Figure 1: Analysis regions for the Minnesota Wetland Status and Trends Monitoring Program.

Table 2: Wetland vs. non-wetland error matrix for feature counts in the 2006-2008 WSTMP. The overall accuracy is 94% and the kappa coefficient (κ) is 89%. Shaded entries along the diagonal are correctly classified.

		Ground Reference Class			
		Wetland	Non-Wetland	Total	Commission
Photo-Interpreted Class	Wetland	856	67	923	7%
	Non-Wetland	24	707	731	3%
	Total	880	774	1654	
	Omission	3%	9%		

Table 3: Cover class error matrix for feature counts in the 2006-2008 WSTMP. The overall accuracy is 89% and the kappa coefficient (κ) is 87%. Shaded entries along the diagonal are correctly classified.

Photo-interpreted Cover Class	Ground Reference Cover Class: DW	UB	AB	EM	SS	FO	CW	N	S	A	R	U	Totals	Commission
DW	100	1		2									103	3%
UB	5	134	4	2									145	8%
AB		7	93	5									105	11%
EM		4	2	315	11		1	17		6	1	2	359	12%
SS				9	100	8		7		2			126	21%
FO				1	4	98		12					115	15%
CW				11			47			15			73	36%
N				2	7	8		135	1	3	3	2	161	16%
S								3	103				106	3%
A				2	1		1	6	1	135	2	2	150	10%
R											122	2	124	2%
U											1	86	87	1%
Totals	105	146	99	349	123	114	49	180	105	161	129	94	1654	
Omission	5%	8%	6%	10%	19%	14%	4%	25%	2%	16%	5%	9%		

associated with smaller features (features with lower weight); however, the validation sample was not selected according to feature size, so an analysis of the area-weighted accuracy is not possible.

The individual cover classes generally have errors of commission and omission that are less than 15%. Notable exceptions include cultivated wetlands which have a relatively high commission error rate of 36% and the natural upland class which has an omission error rate of 25%. The classes most commonly confused with the cultivated wetland class are emergent wetlands and agricultural land. The scrub-shrub wetland class also has moderately high rates of commission error (21%) and omission error (19%) and is most frequently confused with emergent wetlands, forested wetland, or natural upland. All other classes have relatively modest error rates ranging approximately from 5% to 15%.

Wetland Quantity

The total area assessed through the 2006-2008 cycle of the wetland status and trends monitoring program was 4,965 square miles. This area is slightly less than the number of PSUs because some PSUs fall on the state border and the portion that lies outside of the state was not measured. Wetlands occupy 19.7% of the sampled area and deepwater habitats cover 4.86% (Table 4). Total wetland and deepwater habitat cover 24.6% of the area. The most prevalent type of wetland identified through this monitoring program was forested wetlands, which occupy 8.14% of the assessed area. The next most prevalent wetland types are emergent wetlands (5.89%) and scrub-shrub wetlands (4.36%).

Extrapolating from the data in Table 4 and given a total area for the state of Minnesota of 84,382 square-miles, the total area of wetland for Minnesota is 10.62 million acres, not including deepwater habitat. The margin of error for wetland area in Minnesota is ±0.363 million acres (two-tailed, 95% confidence limit). If deepwater habitat is included, the total area is 13.24 million acres with a margin of error of ±0.410 million acres. These error estimates are extrapolated from the standard error of the mean for all PSUs and include the effect of both sampling uncertainty and measurement error.

Water Regime

Water regimes for emergent wetland were also classified for this program. The three water regime classes are seasonally flooded, saturated, and inundated (either permanently or semi-permanently). The inundated water regime comprises 20% to 25% of all emergent wetlands across the four assessment regions (Table 5). Saturated water regimes predominate in the Eastern Broadleaf Forest and Laurentian Mixed Forest regions with 64% and 70% occurrence, respectively. The occurrence of the saturated water regime is somewhat lower in the Paleozoic Plateau and the Prairie Parkland regions at just below 50% and seasonal water regimes tend to be more common in these regions than in other regions.

Accuracy for water regime classification is generally lower than the accuracy of wetland identification or type classification (Table 6). The overall accuracy for water regime classification is estimated to be 80% with a kappa coefficient of 70%.

Special Modifiers

Special modifiers were added to the wetland classification data to indicate wetlands that were found to have water levels that are artificially manipulated (modifier = af) and wetlands that are man-made or modified (modifier = m). Only four cover classes have cases where these modifiers were applied, including aquatic bed, emergent, unconsolidated bottom, and deepwater classes. Of these classes, the modifiers were most frequently applied to

Table 4: Statewide summary statistics of wetland area for the 2006 to 2008 WSTMP.

Wetland Type	Sum of Measured Area (acres)	Mean of Measured Area (%)	Extrapolated Statewide Area (acres)
Aquatic Bed	14,500	0.456%	246,400
Cultivated Wetland	8,093	0.255%	138,000
Emergent	187,100	5.89%	3,183,000
Forested	258,500	8.14%	4,388,000
Scrub-Shrub	138,400	4.36%	2,350,000
Unconsolidated Bottom	18,450	0.581%	314,000
Sub-Total Wetland	625,000	19.7%	10,620,000
Deepwater	154,400	4.86%	2,623,000
Total Wetland and Deepwater	779,400	24.6%	13,240,000

Table 5: Water regime distribution for emergent wetlands by ecological region in the 2006-2008 WSTMP.

Ecological Region	Extrapolated Emergent Wetland (acres)	Inundated (%)	Saturated (%)	Seasonal (%)
Eastern Broadleaf Forest	1,021,000	21%	64%	15%
Laurentian Mixed Forest	1,569,000	20%	70%	10%
Paleozoic Plateau	50,700	23%	47%	30%
Prairie Parkland	541,800	25%	48%	27%

Table 6: Water regime error matrix for feature counts in the 2006-2008 WSTMP. The overall accuracy is 80% and the kappa coefficient (κ) is 70%. Shaded entries along the diagonal are correctly classified.

		Ground Reference Class				
		Seasonal	Saturated	Inundated	Total	Commission
Photo-Interpreted Class	Seasonal	72	9	8	89	19%
	Saturated	21	90	19	130	31%
	Inundated	4	2	88	94	6%
	Total	97	101	115	313	
	Omission	26%	11%	23%		

emergent or unconsolidated bottom wetlands. The man-made modifier (m) was applied to 14.2% of unconsolidated bottom wetlands and 2.3% of emergent wetlands (Table 7). The artificially flooded modifier (af) was applied to 3.6% of unconsolidated bottom wetlands and 1.0% of emergent wetlands. The man-made modifier was also applied to 1.4% of aquatic bed wetlands. Modifiers were applied to 0.5% or less of deepwater habitats.

Annual Variability

Of the 250 annually-sampled PSUs, only five exhibited changes between 2006 and 2007 that triggered boundary updates between upland and wetland land cover types. One PSU showed a net decrease in wetland area of 0.08 acres. All of the net increases in wetland area were less than 0.33 acres, with the exception of one relatively large change of +15.9 acres that resulted from a wetland constructed for mitigation purposes. The vast majority of the annual PSUs (245) showed no net change in wetland area from 2006 to 2007.

Looking at the change from 2007 to 2008 in these same annual PSUs, there were nine PSUs with net decreases in wetland area and four PSUs with net increases in wetland area. The net decreases ranged from -0.1 to -1.2 acres. The net increases ranged from +0.3 to +1.6 acres. Again, the vast majority of PSUs (237) showed no change in net wetland area.

Geographic Distribution

Wetland occurrence varies considerably across the state, with a general pattern of increasing wetland occurrence from south to north. The distribution of wetland types also varies across the state (Table 8). Further breakdown of the wetland data is provided in the appendix.

The Paleozoic Plateau ecological region has the lowest frequency of occurrence of total wetland area at 4.05% while the Laurentian Mixed Forest has the highest frequency of wetland area at 33.2% (Table 8). If deepwater habitat is included, the values for these two ecological regions increase to 5.35% and 41.3%, respectively.

Table 7: Area of artificially flooded and man-made wetlands by wetland type in the 2006-2008 WSTMP.

	Extrapolated Statewide Area (acres)		
Wetland Type	Total Area	Artificially Flooded	Man-Made
Aquatic Bed	246,400	443	3,448
Deepwater	2,623,000	64	13,790
Emergent	3,183,000	32,560	73,360
Unconsolidated Bottom	314,000	11,330	44,410

Aquatic bed, cultivated, and unconsolidated bottom wetlands comprise less than 1% of the area of each of the four regions and show relatively little variability across these provinces. The Paleozoic Plateau has the lowest frequency of occurrence for all wetlands except forested, which is lowest in the Prairie Parkland region. The Laurentian Mixed Forest region has a far higher frequency of deepwater habitat, forested wetlands, and scrub-shrub wetlands than any other region. It has more than twice the frequency of deepwater and scrub-shrub wetlands than the next highest region and seven times more forested wetlands. The Eastern Broadleaf Forest region has the highest frequency of aquatic bed and emergent wetlands (Table 8).

Comparison to National Wetland Inventory

Comparing the percent wetland area for the WSTMP and the NWI on a plot-by-plot basis shows a strong correlation with an r-squared value of 0.89 and a fitted line with a slope that is nearly 1:1 (Figure 2a). However, while the majority of data fall close to the line, there are many deviations. Comparing the deepwater habitat for these two datasets also yields a very strong relationship with an r-squared value of 0.95 (Figure 2b) and the slope almost matches the expected 1:1 line. The relationship for forested wetlands exhibits more scatter about the prediction line, and the r-squared value is slightly weaker at 0.81 (Figure 2c). For emergent wetland, there is even more variability about the line and the r-squared value drops to 0.55 (Figure 2d).

Table 8: Proportion of area of wetland type by ecological region in the 2006-2008 WSTMP.

	Area (%)			
Wetland Type	Prairie Parkland	Paleozoic Plateau	Eastern Broadleaf Forest	Laurentian Mixed Forest
Aquatic Bed	0.214%	0.360%	0.741%	0.487%
Cultivated Wetland	0.421%	0.0387%	0.392%	0.0940%
Emergent	3.37%	1.92%	8.44%	6.77%
Forested	0.402%	1.29%	2.46%	17.2%
Scrub-Shrub	0.418%	0.214%	3.24%	8.14%
Unconsolidated Bottom	0.517%	0.229%	0.911%	0.494%
Sub-Total Wetland	5.34%	4.05%	16.2%	33.2%
Deepwater	1.56%	1.31%	3.75%	8.13%
Total Wetland and Deepwater	6.90%	5.35%	19.9%	41.3%

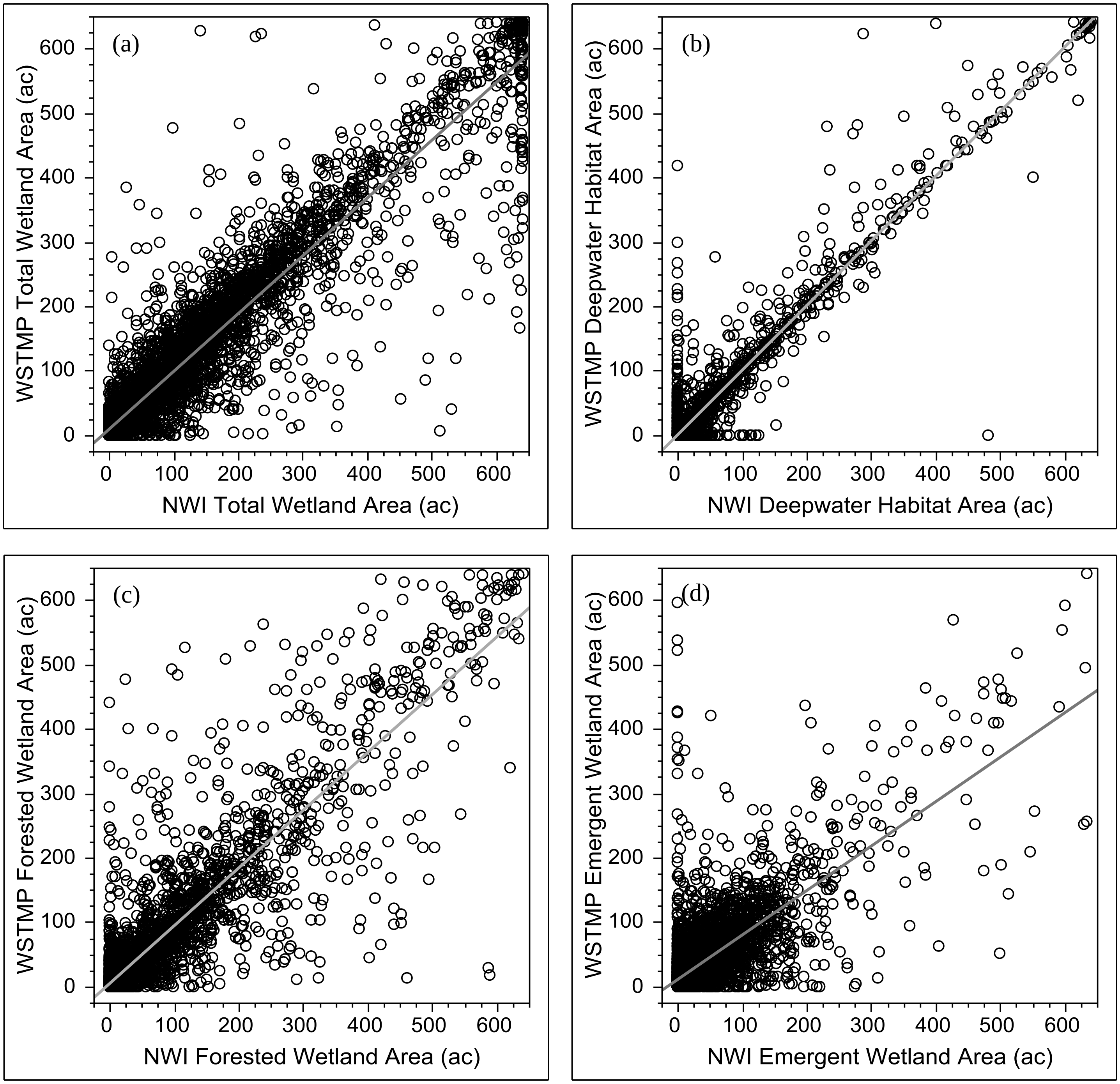

Figure 2: Comparisons of total wetland area (a), deepwater habitat (b), forested wetland (c), and emergent wetland (d) for the WSTMP and the NWI.

A paired T-test was performed for each of the six wetland types (not counting deepwater habitat) from these two programs for the entire state of Minnesota. Statistically significant differences were found for all wetland types except for forested (Table 9), but these differences are quite small; typically less than one-half of a percent. Overall, differences between wetland types offset one another and the total wetland percent is statistically equal for the two datasets. Three wetland types were found to be more frequent in the WSTMP data (aquatic bed, cultivated wetland, and emergent), while two types were more frequent in the NWI (scrub-shrub and unconsolidated bottom). Caution should be exercised in interpreting these differences because this analysis may be affected by differences in mapping methods.

Paired T-tests for total wetland percentage was performed for each of the four ecological regions. This analysis found that the total wetland estimates for the WSTMP were slightly higher than the NWI for the Paleozoic Plateau (0.46% ±0.38%) and the Prairie Parkland region (0.35% ±0.29%) and somewhat lower for the Laurentian Mixed Forest region (-1.08% ±0.43%). The difference in the total wetland frequency for the Eastern Broadleaf Forest region was not statistically significant. Looking in more detail at the comparisons within each region, by wetland type, some patterns emerge (Figures 3a, b, c, & d). Aquatic bed and cultivated wetland types are more frequent in the WSTMP than the NWI across all regions, although the difference is typically small and not always statistically significant. On the other hand, unconsolidated bottom wetlands are less frequent in the WSTMP across all regions (again not always statistically significant).

Table 9: Statewide paired T-test comparison of percent wetland area for NWI and the status and trends program by wetland type. This analysis excluded 9 PSUs because of the data gaps in the NWI for Minnesota.

	Aquatic Bed	Cultivated Wetland	Emergent	Forested	Scrub-Shrub	Unconsolidated Bottom
Mean Difference (%)	0.452	0.234	0.325	0.040	-0.849	-0.433
Std. Dev. (%)	1.798	1.704	7.072	7.620	8.069	3.695
Std. Error (%)	0.025	0.024	0.100	0.108	0.114	0.052
Upper 95% CI	0.502	0.281	0.522	0.251	-0.625	-0.330
Lower 95% CI	0.402	0.187	0.129	-0.172	-1.073	-0.535
N	4981	4981	4981	4981	4981	4981

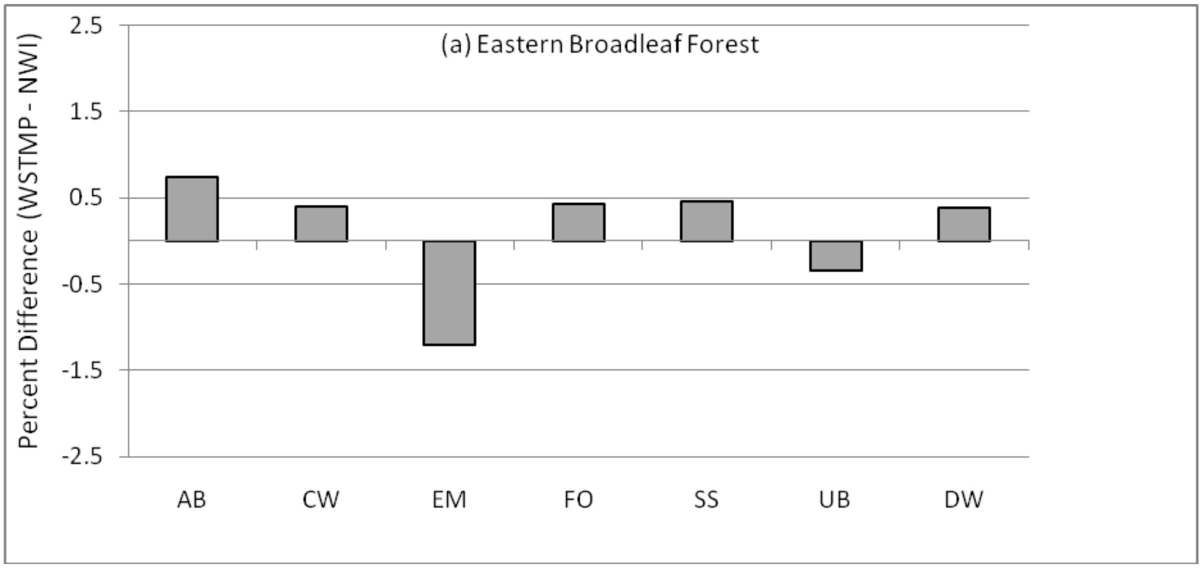

Figure 3 (a): Difference in wetland area between the WSTMP and NWI by wetland type for the Eastern Broadleaf Forest region. Shaded bars indicate statistically significant differences based on a paired T-test ($\alpha = 0.05$).

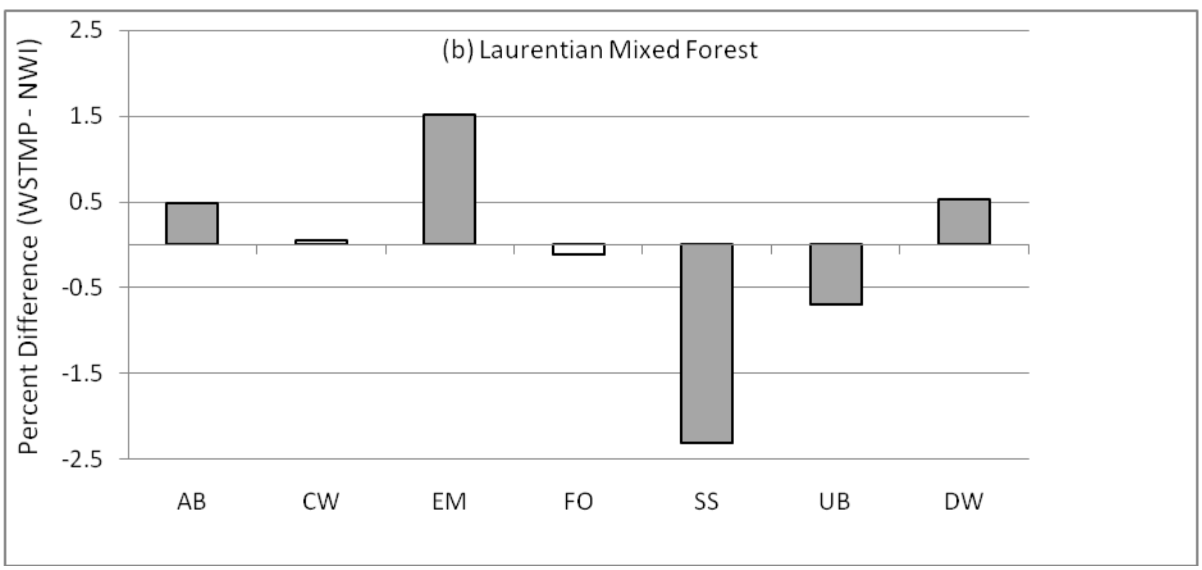

Figure 3 (b): Difference in wetland area between the WSTMP and NWI by wetland type for the Laurentian Mixed Forest region. Shaded bars indicate statistically significant differences based on a paired T-test ($\alpha = 0.05$).

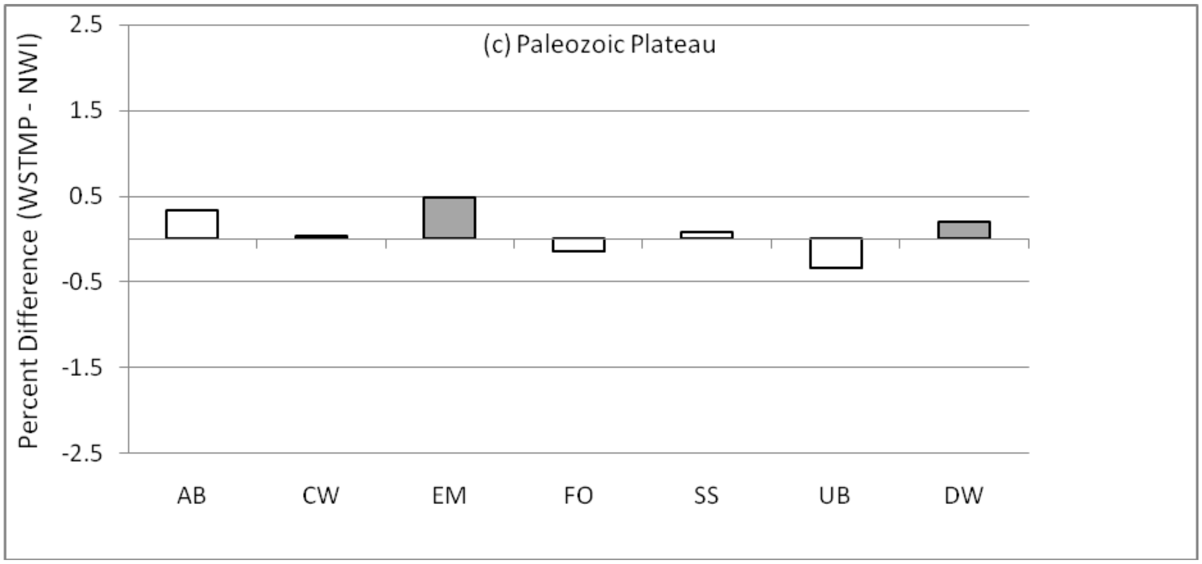

Figure 3 (c): Difference in wetland area between the WSTMP and NWI by wetland type for the Paleozoic Plateau region. Shaded bars indicate statistically significant differences based on a paired T-test ($\alpha = 0.05$).

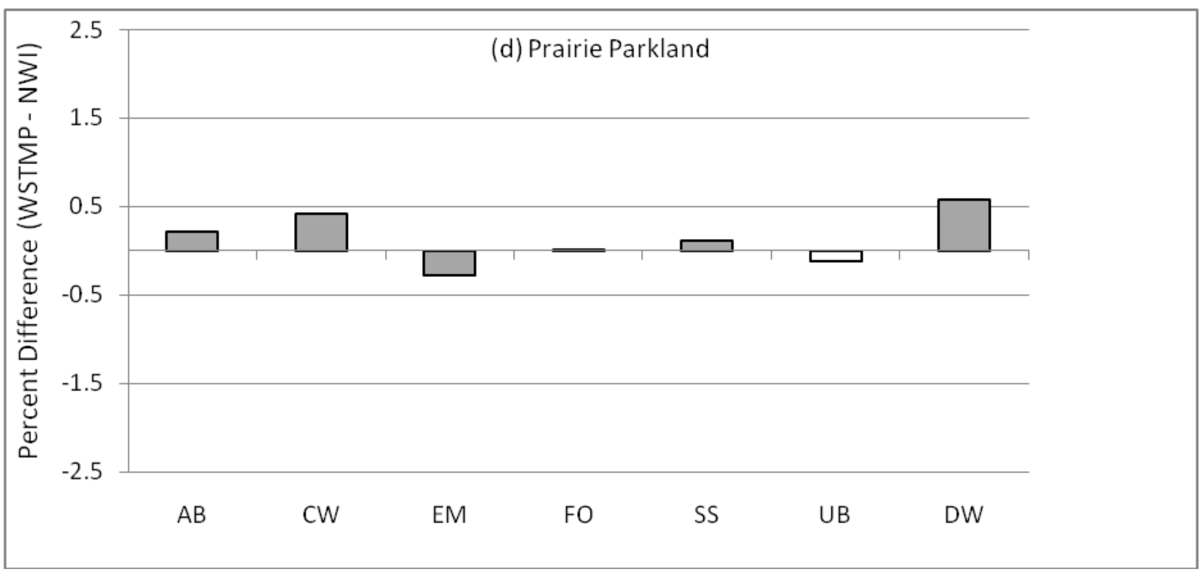

Figure 3 (d): Difference in wetland area between the WSTMP and NWI by wetland type for the Prairie Parkland region. Shaded bars indicate statistically significant differences based on a paired T-test ($\alpha = 0.05$).

Discussion

Annual Variability

The annual panel of 250 PSUs was included in the design to assess the influence of year-to-year changes and thus the validity of the assumption that three panels from each year of the cycle could be combined. Only 5 PSUs were found to have changed in wetland area from 2006 to 2007 and only 13 PSUs changed in wetland area from 2007 to 2008. Given that the vast majority of the annual panel showed no change, it seems logical to conclude that the data from all three years of the first cycle can be combined to provide a single, statewide baseline assessment.

Total Wetland Area

There are several previous estimates of wetland area in Minnesota. One of the earliest of these was a study by Anderson and Craig (1984) that estimated that there were 8.7 million acres of wetland in Minnesota based on an analysis of soils data and land use data from 1969. This is significantly less than the 10.62 million acres of wetland estimated by the WSTMP. This difference is likely due partly to a broadening understanding of what constitutes a wetland and better data for the WSTMP. Anderson and Craig (1984) used land use and soil attributes for 40-acre blocks. The land use data were produced using interpretation of high-altitude, black and white, 1:90:000 scale imagery (Nelson et al. 1981). The print scale for the stereo photos for WSTMP was 1:12,000. It seems clear that the Anderson and Craig (1984) estimate of wetland area is low.

The Minnesota Board of Water and Soil Resources tabulated a total wetland area of 10.6 million acres using the NWI (BWSR 2001), an estimate of wetland area essentially equal to the WSTMP estimate of 10.62 million acres. This result may suggest that there has been no net change in wetland acreage since the NWI, a conclusion which might appear to conflict with studies suggesting that wetlands have been lost (Genet and Olson 2008; Oslund et al. 2009). However, there are a couple of facts that might reconcile this apparent discrepancy.

First, while Minnesota law requires compensatory replacement for wetland loss, it does not generally require this replacement to occur locally. A wetland loss in one location may have been replaced elsewhere within the state. Earlier studies suggesting wetland losses may be occurring were generally limited in geographic scope. Thus, while there may be instances of localized wetland loss, it is possible that on a statewide basis that these losses have been offset.

Second, differences in source data and mapping methods between the NWI and WSTMP has resulted in identification of some wetlands that were missed by the NWI, potentially offsetting any losses. The NWI program produced 1:24,000 scale wetland maps for Minnesota using aerial photography from the National High Altitude Imagery Program (NHAP) collected between about 1976 to 1984 (mostly spring imagery). NHAP acquired black-and-white film imagery at an approximate scale of 1:80,000 for a portion of northeast Minnesota and color-infrared film at an approximate scale of 1:58,000 for the rest of the state (MnGeo 2007). The NWI program had a tendency to err on the side of omission of wetlands, especially in areas that only had 1:80,000 scale black and white imagery, missing many forested and drier-end emergent wetlands. A pilot study conducted to update the NWI for a forested region of Minnesota near Duluth using 1:15,840 scale film imagery and 1-meter resolution, summer digital imagery found nearly four times as many wetlands than the original NWI (Gernes and Norris 2006). Further comparison of wetland estimates for the northeast region is presented later in this report.

A more recent estimate of wetland area for Minnesota was published as part of the National Resources Inventory (NRI) conducted by the U.S. Department of Agriculture. The NRI estimates that Minnesota has about 10.88 million acres of wetland on non-federal lands with a margin of error of 0.456 million acres (USDA 2009). If deepwater habitat is included, the NRI estimate is 13.94 million acres with a margin of error of 0.461 million acres. The NRCS uses a sampling approach and an assessment method that involves aerial photography, field office records, soil survey maps, and other ancillary data. This program includes approximately 70,000 primary sampling units with a nominal size of ¼ square mile spread across the 48 coterminous states. Imagery for this program has varied; however, the most recent specifications are for film imagery collected at 1:7,920-scale with a digital imagery ground sample distance of 6-inches (USDA 2010).

The NRI wetland estimate for Minnesota cannot be directly compared to the WSTMP estimate because the NRI does not count wetlands on federal lands. However, we can extrapolate from the NRI estimate. The NRI states that there are 3.34 million acres of federal land in Minnesota (USDA 2009), most of which is located in wetland rich northeastern Minnesota. Conservatively assuming an average wetland land cover of 30% and deepwater land cover of 10% for these lands, the statewide totals would be 11.88 million acres of wetland and 15.28 million acres of total wetland and deepwater habitat in Minnesota. Using this assumption, it would appear that the 2007 NRI estimate for wetlands in Minnesota is higher than the estimate from the WSTMP by roughly 1.3 million acres. Even considering the margin of error for both programs, the upper 95% confidence limit for WSTMP is 10.98 million acres of wetland is less than the lower 95% confidence limit for the NRI of 11.43 million acres (based on the extrapolation described above).

There are a number of possible reasons for the difference in the statewide wetland estimates between the WSTMP and the NRI. Probably the most important reason is the difference in sampling design. Both programs use an inter-penetrating, rotational panel design, with subsets of segments (or PSUs) assigned to different rotating panels and a smaller subset that is sampled every year. However, the WSTMP program uses a spatially-balanced, random sample selection method, whereas the NRI documentation indicates that selection is based on geographical and historical factors. For example land enrolled in the USDA Conservation Reserve Program (CRP) has a significantly higher chance of selection than forested land (USDA 2009). Therefore, the NRI is not an unbiased sample. Other reasons for the differences in the results from these two programs could also include differences in source imagery and methodology as well as potential errors in extrapolating the NRI results from non-federal lands to a statewide estimate.

Wetland Type Distribution

While there is agreement on the total wetland area between the WSTMP and the NWI, there are differences in the distribution among wetland types. Reasons for these differences include both methodology and natural influences.

The WSTMP program uses summer as well as spring imagery to classify wetland types, whereas multi-season imagery was probably not available for the NWI. The lack of multi-seasonal imagery for the NWI would likely lead to erroneously classifying many aquatic bed wetlands as unconsolidated bottom wetlands because non-persistent aquatic vegetation (e.g. *Nymphaea odorata or Potamogeton sp.*) would not likely be developed enough in spring imagery to be visible. This may explain the general tendency for higher frequency of occurrence of aquatic bed wetlands and lower frequency of occurrence of unconsolidated bottom wetlands in the WSTMP.

Differences in classification rules may also lead to the observed differences in the wetland types between the NWI and the WSTMP. For example, the NWI only mapped about 60 farmed wetlands for the entire state of Minnesota, even though the official policy appears to have been to map farmed prairie pothole wetlands (Dahl et al. 2009). It seems likely that there was a systematic bias against mapping farmed wetlands for the NWI in Minnesota. It should be noted that the cultivated wetland class is one of the most difficult wetland types to accurately interpret due to a typically ephemeral inundation period for these wetlands combined with varying degrees of human disturbance. The accuracy assessment for the WSTMP data indicated that there is a commission error rate for cultivated wetlands of 36%. It should come as little surprise that there might be significant differences in the distribution across wetland types, especially for some of the easily confused wetland types.

Wetland class may also change due to ecological succession or changes in climate. For example, a scrub-shrub wetland may develop into a forested wetland over time. These changes can be affected by disturbances in the water regime. While precipitation during the 2006-2008 baseline assessment for the WSTMP is fairly comparable to that during the NWI imagery acquisition (approximately 1976 to 1984), the 10-year rolling average precipitation for the period preceding the WSTMP (1996-2005) is about 1.5 to 1.9 inches/year higher than the rolling average preceding the NWI (1966-1975) for most of Minnesota with the exception of the northeast, which actually showed a slight decrease in long-term average precipitation (Figure 4) (Western Regional Climate Center 2010). Differences in precipitation are likely to lead to difference in wetland water regime and thus potentially affect wetland type, but how much of an effect this has is unknown.

Minnesota is located on the boundary between the semi-humid climate of the eastern U.S., where annual precipitation exceeds evapotranspiration, and the semi-arid climate to the west, where evapotranspiration exceeds precipitation. In Minnesota, the boundary between these climate regimes cuts the State roughly into east-west halves (DNR 2010). Wetlands in glacial landscapes, like Minnesota, may be highly sensitive to changes in temperature and precipitation, especially if they are relatively isolated from groundwater systems (Winter 2000). A shift in long-term precipitation patterns of even an inch or two might have an effect on the frequency and distribution of wetland occurrence. Wetlands that were on the drier end of the water regime may shift to wetland types with longer periods of inundation (Neimuth et al. 2010). Lands that were once dry enough to cultivate, might experience more frequent flooding causing farmers to forgo planting in these areas, potentially increasing wetland area.

Geographic Distribution

The fact that WSTMP had a slightly higher wetland area than the NWI in the Prairie Parkland and Paleozoic Plateau regions may seem to contradict earlier studies (Genet and Olson 2008; Oslund et al. 2009); however, the potential reasons for this apparent very slight gain are similar to those previously discussed in this paper with respect to the statewide wetland estimate. Briefly, the reasons include the possibility that wetlands lost within parts of these regions are replaced elsewhere within the region and that the WSTMP may have lower errors of omission than the NWI (or it may have higher errors of commission). Furthermore, as mentioned above, it may be that a trend of increasing precipitation for these regions (Figure 4) may have an offsetting effect. However, it should be kept in mind that while the differences between the WSTMP and the NWI were found to be statistically significant for the Prairie Parkland and Paleozoic Plateau regions, the actual magnitude of these differences were very small (< 0.5%).

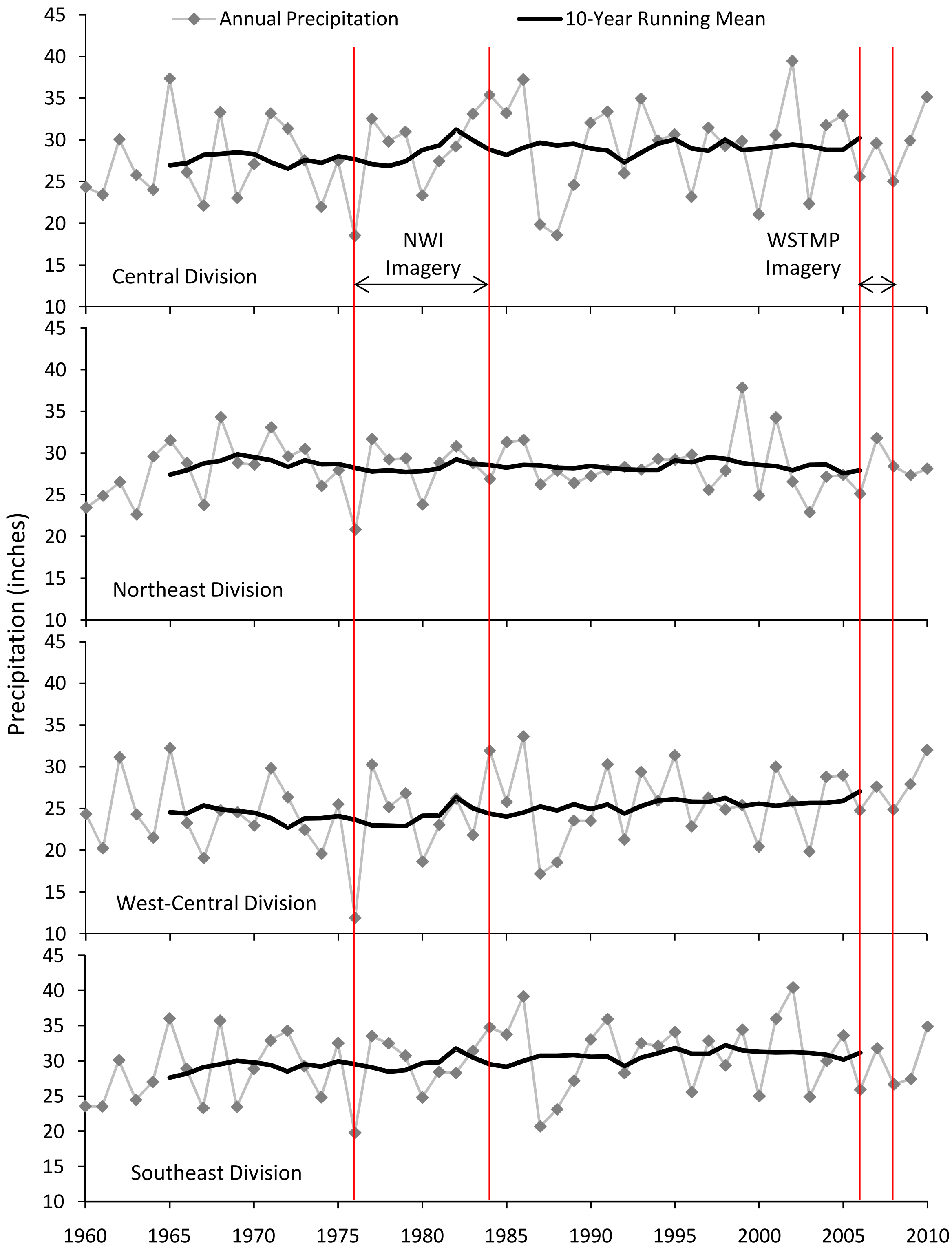

Figure 4: Regional precipitation trends for Minnesota from 1960 to 2010 (source: Western Regional Climate Center 2010). The Eastern Broadleaf Forest, Laurentian Mixed Forest, Prairie Parkland, and Palezoic Plateau regions are approximated by the central, northeast, west-central, and southeast climate divisions, respectively.

Perhaps somewhat more perplexing is the fact that the WSTMP mapped a slightly lower amount of wetland for the Laurentian Mixed Forest region than the NWI. The metadata for the NWI suggest that the NWI under-represents forested wetlands especially in northeastern Minnesota where the base imagery was 1:80,000 scale black and white aerial photos (MnGeo 2007). However, forested wetlands, which comprise the dominant wetland form in this region, were not statistically different between the WSTMP and the NWI. The greatest difference between the two datasets was for scrub-shrub wetlands (Figure 3b) with the WSTMP showing generally less scrub-shrub wetland.

For the purpose of illustration, we examined the differences between the NWI and the WSTMP for a single PSU in northern Minnesota (Koochiching County). The total wetland area for this PSU is 453 acres according to the WSTMP and 640 acres according to the NWI (Figure 5a & 5b).

An examination of recent high-resolution CIR imagery along with ancillary data supports wetland interpretation of the WSTMP for this PSU. The CIR imagery shows a distinct signature that corresponds with the upland area identified in the WSTMP data (Figure 6). This area in the WSTMP data also corresponds with a slope that divides flatter areas shown on the LiDAR shaded relief map and with soil map units that have little or no inclusions of hydric soil (Figures 7 & 8).

The shape of the upland area in the WSTMP data also corresponds well with the upland area on the USGS topographic quadrangle (Figure 9). As such, we believe that the WSTMP interpretation of this plot is better than the NWI and that some of what the NWI had classified as forested and scrub-shrub wetland is, in fact, upland. Further investigation into these differences for other PSUs is warranted.

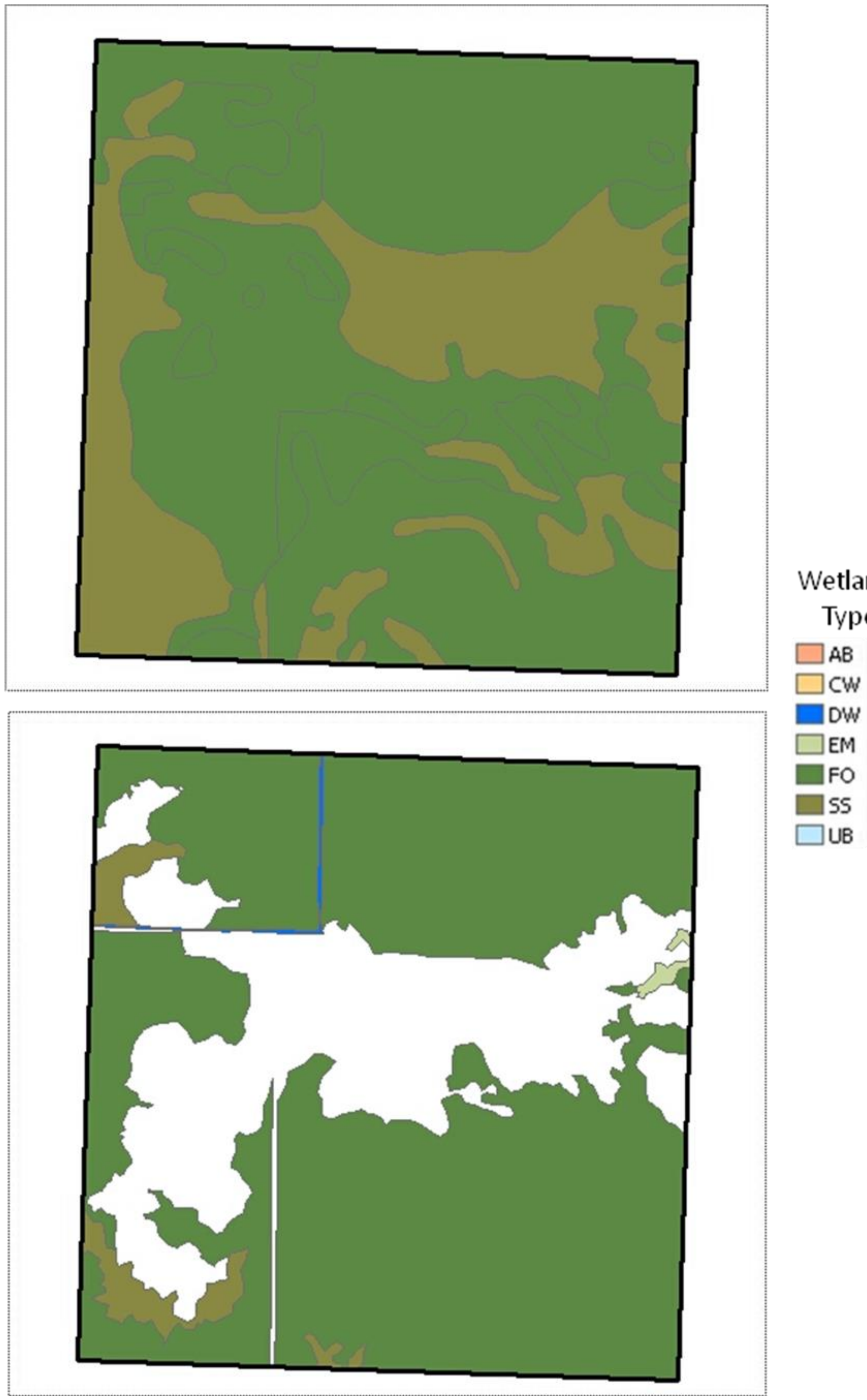

Figure 5: Wetland classification map for a single PSU located in Koochiching County of northern Minnesota. Figure 5(a) is the classification of the National Wetland Inventory circa 1980. Figure 5(b) is the classification from the Minnesota Wetland Status and Trends Monitoring Program 2006-2008.

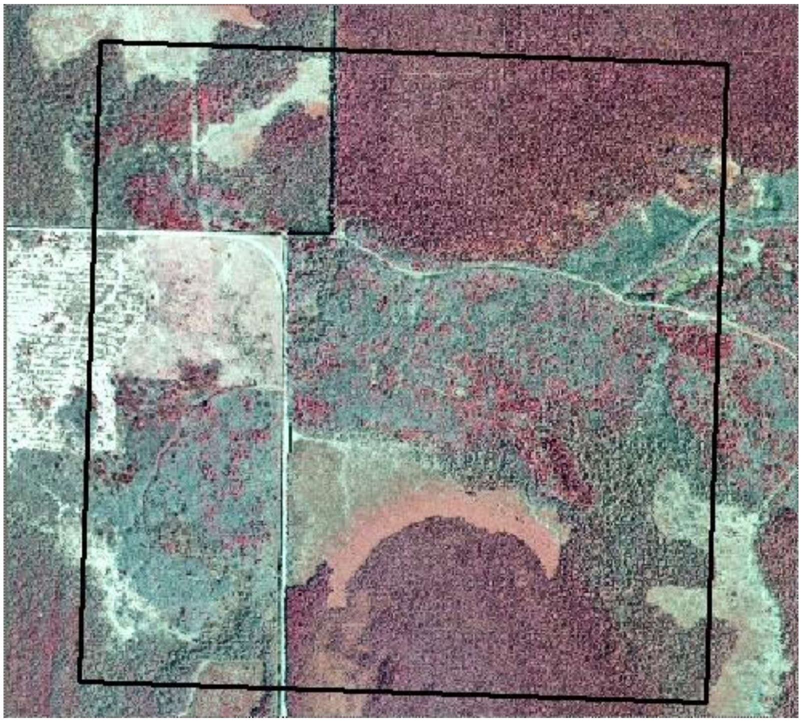

Figure 6: Spring color-infrared aerial photo of the example PSU in Koochiching County in northern Minnesota. The red colored areas indicated live vegetation, in this case predominantly black spruce.

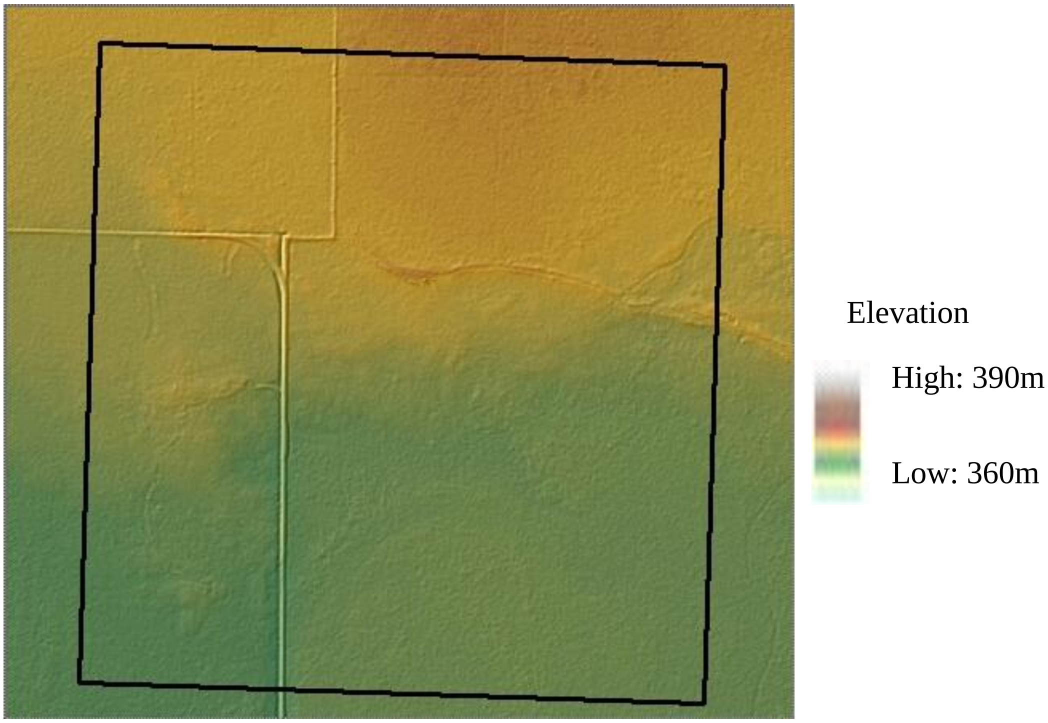

Figure 7: A shaded relief map from LiDAR for the example PSU in Koochiching County in northern Minnesota. A general transition in elevation occurs in the area delineated as upland by the WSTMP.

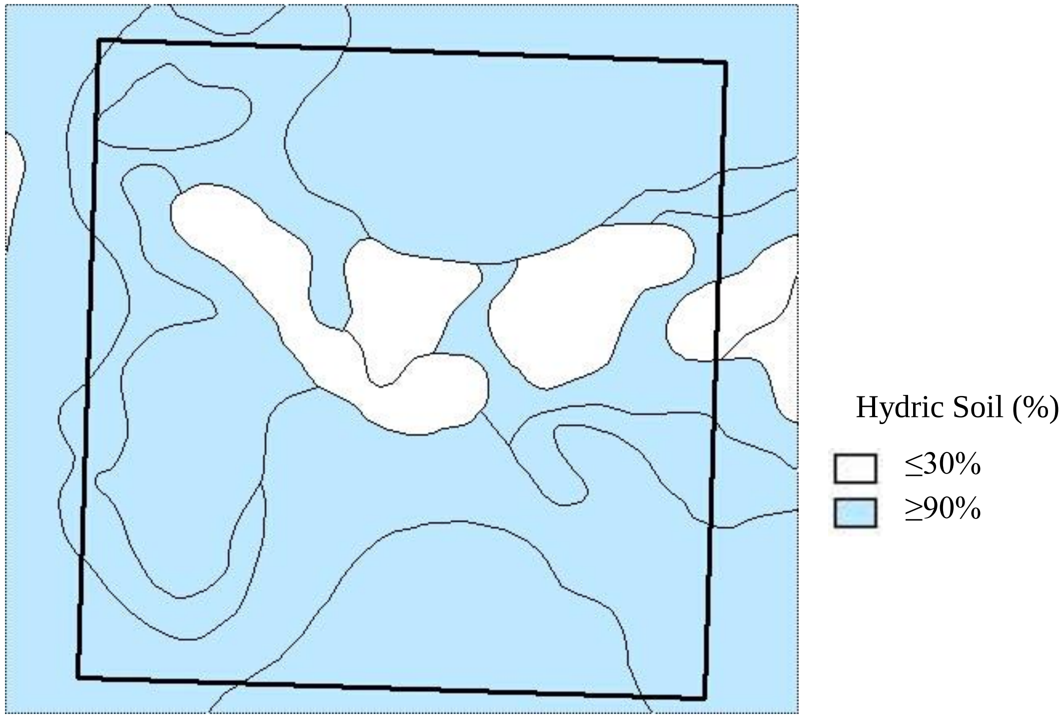

Figure 8: Hydric soil classification for the example PSU in Koochiching County in northern Minnesota.

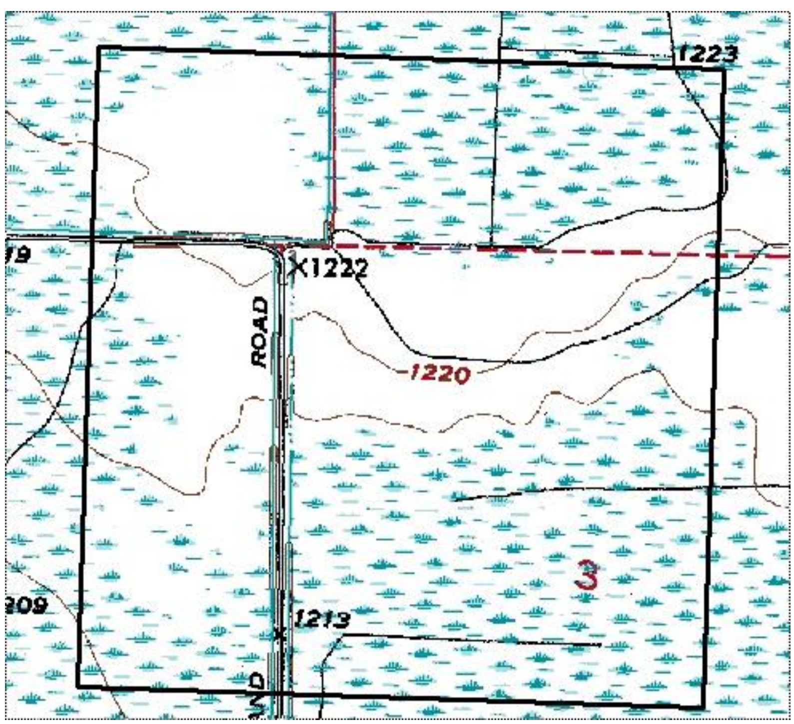

Figure 9: USGS topographic quadrangle map of the example PSU in Koochiching Count in northern Minnesota. The blue symbols indicate wetland area.

Summary & Conclusions

The Wetland Status and Trends Monitoring Program data from 2006 to 2008 provides the most comprehensive and up-to-date assessment of the current status of wetlands in Minnesota. Based on these data the current total wetland area for Minnesota is 10.62 (±0.363) million acres. If deepwater habitats are included, the total area is 13.24 (±0.410) million acres. Field validation efforts indicate that the WSTMP data correctly distinguish between wetland and upland 94% of the time and correctly classify wetland and upland cover types 89% of the time. Analysis of the 250 annual PSUs generally shows little change in wetland area from year-to-year, although there was a single instance of a relatively large wetland gain (15.9 acres) for a single PSU resulting from a wetland mitigation project.

Wetlands are not evenly distributed across the state. The Prairie Parkland and Paleozoic Plateau regions have wetland and deepwater land cover over 6.90% and 5.35% of their total area, respectively. Wetlands and deepwater habitats cover 19.9% and 41.3% of the Eastern Broadleaf Forest and Laurentian Mixed Forest regions, respectively.

Remarkably, the statewide estimate of wetland area based on WSTMP (2006-2008) is the same as that from the National Wetland Inventory for Minnesota (1976-1984). However, there are differences in the geographic distribution as well as differences in the distribution of wetland types. These differences are likely a result of differences in source data, methodology, mapping policies, climate, and ecological succession. Therefore, caution should be used in attempting to draw conclusions about wetland change between these two surveys. The difficulties in comparing these wetland estimates illustrates the need for an ongoing status and trends monitoring program that is based on consistent source data, methods and classification rules.

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Appendix – Additional Statistical Summary Tables by Ecological Region for WSTMP 2006-2008

Table A.1: Wetland area within primary sampling units by region (acres) reported to the nearest acre.

Wetland Type	Prairie Parkland Province	Paleozoic Plateau	Eastern Broadleaf Forest Province	Laurentian Mixed Forest Province
Aquatic Bed	2,018	577	5,261	6,644
Cultivated Wetland	3,962	62	2,785	1,283
Emergent	31,710	3,073	59,896	92,462
Forested	3,791	2,067	17,481	235,183
Scrub-Shrub	3,938	343	23,029	111,067
Unconsolidated Bottom	4,872	367	6,468	6,746
Deepwater	14,673	2,099	26,615	111,002
Total PSU Area (mi^2)	1,472	251	1,109	2,133

Table A.2: Proportional wetland area by region (%) reported to four significant figures.

Wetland Type	Prairie Parkland Province	Paleozoic Plateau	Eastern Broadleaf Forest Province	Laurentian Mixed Forest Province
Aquatic Bed	0.2143%	0.3597%	0.7410%	0.4867%
Cultivated Wetland	0.4206%	0.03873%	0.3923%	0.09403%
Emergent	3.366%	1.915%	8.437%	6.774%
Forested	0.4025%	1.289%	2.462%	17.23%
Scrub-Shrub	0.4180%	0.2141%	3.244%	8.137%
Unconsolidated Bottom	0.5172%	0.2286%	0.9110%	0.4943%
Wetland Sub-Total	5.339%	4.045%	16.19%	33.22%
Deepwater	1.558%	1.308%	3.749%	8.132%
Wetland + Deepwater	6.987%	5.353%	19.94%	41.35%
Total Region Area (mi^2)	25,147	4,136	18,903	36,196
Total Region Area (acres)	16,094,080	2,647,040	12,097,920	23,165,440

Table A.3: Estimated wetland area by region (acres) reported to four significant figures.

Wetland Type	Prairie Parkland Province	Paleozoic Plateau	Eastern Broadleaf Forest Province	Laurentian Mixed Forest Province
Aquatic Bed	34,480	9,521	89,640	112,800
Cultivated Wetland	67,690	1,025	47,460	21,780
Emergent	541,800	50,700	1,021,000	1,569,000
Forested	64,770	34,110	297,900	3,991,000
Scrub-Shrub	67,280	5,667	392,400	1,885,000
Unconsolidated Bottom	83,240	6,052	110,200	114,500
Wetland Sub-Total	859,300	107,100	1,959,000	7,694,000
Deepwater	250,700	34,620	453,500	1,884,000
Wetland + Deepwater	1,110,000	141,700	2,413,000	9,578,000