Status and Trends of Wetlands in Minnesota: Wetland Quantity Trends from 2006 to 2011

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MN Department of Natural Resources
Ecological & Water Resources

"Healthy Watersheds Throughout Minnesota"

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Contents

Abstract

The State of Minnesota has developed a wetland status and trends monitoring program (WSTMP) to provide scientifically-sound data regarding long-term changes in wetland quantity and quality. Modeled after the national status and trends program, the Minnesota program assesses changes in wetland acreage and type over time using repeat assessment of permanent, random plots using remote sensing and photo-interpretation. This program maps land cover change for 4,990 plots over repeating 3-year sampling cycles. The analysis presented here includes the results from the first two complete sampling cycles, 2006–2008 and 2009–2011. A small, but statistically significant net gain in wetland acreage was identified for this period. The total wetland gain within the sample plots was 200.4 acres and total wetland loss was 77.4 acres, resulting in a net gain of 123 acres. Extrapolating these results statewide indicates that Minnesota had a net gain of 2,080 acres of wetland during the study period, or about 0.02% of Minnesota's total wetland area of 10.62 million acres. In spite of achieving the State's no-net loss goal for this reporting period, there are still reasons to be concerned. Most of the observed gains were unconsolidated bottom type wetlands (ponds) that typically have limited wildlife habitat value. Also, a substantial portion of the wetland gain could not be attributed to any obvious cause, raising questions about the permanence of this change. Furthermore, there has also been a net conversion of 1,890 acres of emergent wetlands to cultivated wetlands. Although this is not classified as a loss of wetland, it does entail a loss of wetland quality. Further monitoring is required to better understand both the change in wetland quality as well as the relative permanence of these changes in wetland quantity.

Introduction

Wetlands provide many ecological services, such as flood attenuation, water quality protection, wildlife habitat, and groundwater recharge (Mitsch and Gosselink 2000). The U.S. federal government and the State of Minnesota both recognize the value of these ecological services through an established policy goal of "no net-loss" of wetlands (CEQ 2008; Minn. Statutes 103A.201). Assessing compliance with a no net-loss policy requires unbiased data regarding the quantity and quality of wetlands over time. To address this need, the State of Minnesota has developed a probabilistic wetland status and trends monitoring program (WSTMP).

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). Other studies have demonstrated more recent wetland losses for portions of Minnesota. Oslund et al. (2010) examined wetland quantity changes in southwestern Minnesota by re-interpreting National Wetland Inventory (NWI) data using recent aerial photography for 176 sample plots. The NWI for Minnesota was developed using interpretation of high-altitude aerial photography from circa 1980. Oslund and his co-authors compared the original NWI to aerial photos acquired from 2004 through 2007. Genet and Olsen (2008) quantified changes in wetland quantity and quality for 146 randomly selected sites in the Redwood River watershed. They used a different sampling design and their study area was a fraction of the size of Oslund et al. (2010), but these authors used a similar assessment method and period (circa 1980–2003).

While these studies have provided useful information, they are not spatially comprehensive enough to assess statewide wetland changes. In addition, the State of Minnesota made important changes to its wetland policy and rules in 1991 with the passage of the Minnesota Wetland Conservation Act (WCA). Without a current and comprehensive wetland assessment since the passage of the WCA, it is impossible to say whether the rate of wetland loss has been altered by these changes to wetland policy or whether there are regional differences in wetland change.

At the national scale, the U.S. Fish and Wildlife Service implements the National Wetland Status and Trends Program (Dahl and Bergeson 2009). This program uses repeated photo-interpretation of land cover for about 5,000 randomly selected permanent plots to assess wetland gains and losses. Unfortunately, the sample density is not sufficient to draw reliable conclusions at the scale needed for state-level assessments.

The Minnesota WSTMP is modeled after the National Wetland Status and Trends Program. Like the national program, the Minnesota WSTMP assesses changes in wetland acreage and type over time using repeat assessment of permanent plots with remote sensing and photo-interpretation. The WSTMP maps land cover changes for 4,990 randomly-selected, permanent plots over repeated 3-year cycles (Kloiber et al. 2012). The results of the baseline sampling cycle from 2006 to 2008 estimated that the total wetland area for Minnesota was 10.62 million acres (Kloiber 2010).

In addition, the Minnesota WSTMP incorporates a wetland quality assessment based on detailed field surveys of plant and macroinvertebrate communities along with a physical and chemical evaluation (MPCA 2007). The results of the wetland quality baseline assessment have been previously summarized elsewhere (Genet 2012). The analysis presented here focuses on the wetland quantity trend results from the first two sampling cycles of the Minnesota WSTMP.

Methods

Details of the WSTMP design and procedures are described by Kloiber et al. (2012), but are briefly summarized here.

Changes in land cover are mapped for 4,990 randomly-selected, permanent plots located throughout Minnesota (Figure 1). All plots are one-square mile in area except for those that happen to fall on the state boundary, which are clipped to the boundary. Sampling occurs on a repeating three-year cycle: 250 plots are surveyed annually and the remaining 4,740 plots are divided equally into three sample panels with one panel surveyed each year of the sample cycle. Sample plot locations were selected using the generalized random tessellation stratified (GRTS) design (Stevens and Olsen 2004). The GRTS design was used to ensure adequate spatial distribution of sample plots.

Land cover was mapped and classified (Table 1) for all plots for the initial, baseline sample cycle (T1, 2006 to 2008) using photo-interpretation and the data were stored in a GIS data layer. A GIS record, in the form of a polygon, was created for each photo-interpreted land cover feature. Special modifiers were added to the land cover attributes to indicate manmade (m) and artificially flooded (af) features. Extensive field validation was used to measure the accuracy of the land cover classification (Kloiber 2010). The classification process correctly distinguishes between wetland and upland 94% of the time and correctly classifies the more detailed land cover types 89% of the time.

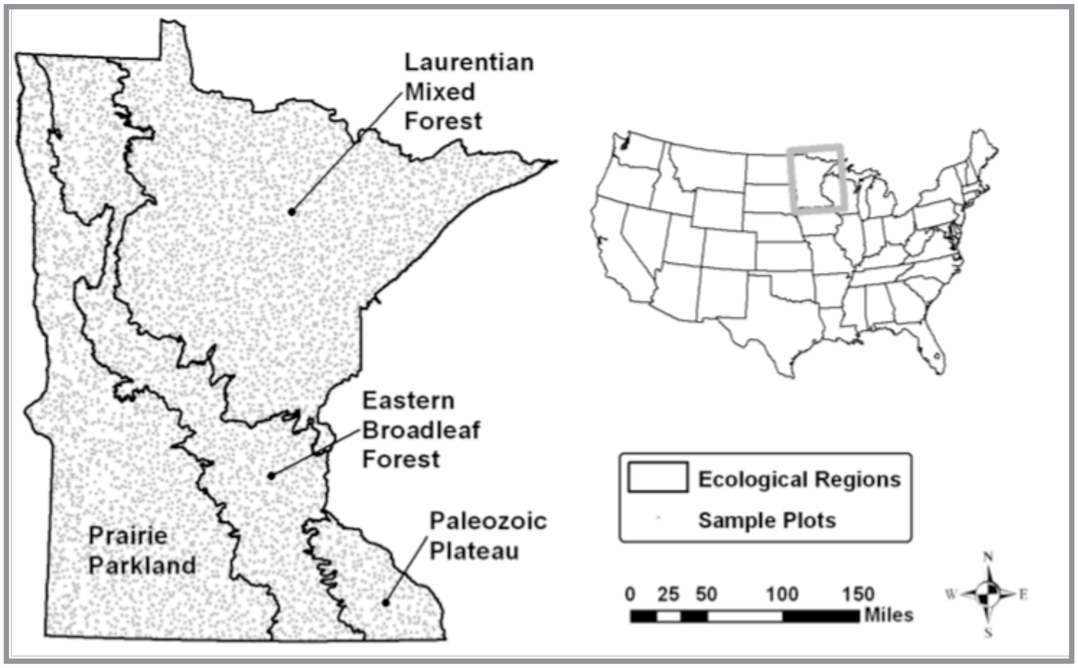

Figure 1: Study location includes 4,990 randomly selected one square-mile plots distributed across four distinct ecological regions of Minnesota, U.S.A.

Table 1: Land Cover Codes for the Minnesota Wetland Status and Trends Monitoring Program

System	Code	Class Name	Description
Deepwater	DW	Deepwater	Lakes, reservoirs, rivers, streams
Wetland	FO	Forested wetland	Forested swamp
	SS	Shrub swamp	Woody shrub or small tree marshland
	EM	Emergent wetlands	Marshes, wet meadows, and bogs
	AB	Aquatic bed	Wetlands with floating and submerged aquatics
	UB	Unconsolidated bottom	Open water wetland, shore beaches and bars
	CW	Cultivated wetland	Wetlands in agricultural fields
Wetland modifiers	*m*	Manmade	DW, UB, AB or EM of artificial origin
	af	Artificially flooded	Aquaculture, sewage treatment, wetland treatment systems, mine tailing ponds
Upland	U	Urban	Cities, incorporated developments
	R	Rural development	Non-urban developed areas, infrastructure
	A	Agricultural	Cultivated lands and managed upland pasture
	N	Natural	All natural upland including forested and wooded land as well as grassland, prairies, and state and federal agricultural set-aside lands.
	O	Other / Transitional	All uplands not otherwise classed

Land cover polygons from the baseline assessment (T1) were overlaid on aerial photography from the second sample cycle (T2, 2009 to 2011). Changes in wetland extent (gains, losses or change of type) were recorded by splitting land cover polygons as necessary to reflect changes and entering the updated land cover attribute in a second database field. Photo-interpreters also classified the cause of each change as either "direct" when there was direct visual evidence of the cause such as a new road or new drainage structure, or "indirect" when the cause of the change could not be ascertained from the imagery. The area and land cover change attributes for all polygons were imported into statistical software (JMP® version 10.0 - SAS Institute) for analysis.

Features that did not change and non-target changes were excluded from further analysis. Non-target changes included changes between upland land uses and changes between upland and artificially flooded features (labeled "af"). Features with the "af" modifier typically serve an industrial or commercial purpose, have little natural wetland function, and usually do not meet the wetland definition. Examples include mine tailing discharge basins from active mining facilities and wastewater stabilization ponds. However, conversion of natural wetlands to a feature with an "af" modifier was considered as a loss, and change from an "af" feature to a wetland without this modifier was regarded as a gain. Changes between wetland and deepwater habitats (DW) were treated as a change of wetland type rather than a wetland loss or gain.

The acres of wetland gain, loss and change of type were tabulated for all sample plots. To extrapolate the results statewide, the area of the measured changes in each plot was first normalized by dividing by the plot size. We then calculated the mean of these normalized proportional changes and multiplied this by the area of the state. Wetland changes were also calculated for four ecological regions of the state (Figure 1) based on the Ecological Classification System (Cleland et al. 1997) as modified by the Minnesota Department of Natural Resources (MNDNR 2013). These regions were selected for use in this analysis because the type and abundance of wetland resources in each of them are fairly distinct (Kloiber 2010).

Results

Results are presented for changes observed within the sample population (i.e., within the sample plots) and for statewide and regional changes extrapolated from the sampling data.

Changes within the Sample Plots

Combining land cover data for all three sample panels and the annual panel resulted in a large dataset of 195,123 polygons. The total wetland gain within the sample plots was 200.4 acres (Table 2a) and total wetland loss was 77.4 acres (Table 2b) resulting in a net gain of 123 acres (Table 2c). About half of the wetland gains occurred on agricultural land. Other land cover types with relatively large contributions to wetland gains were natural upland and rural developed lands. Wetland losses mostly occurred on agricultural and rural developed lands, although the losses for these land cover classes were smaller than the gains. Wetland losses and gains for urban land were considerably lower than for other land cover categories.

Sixty-one percent (61%) of the wetlands gained overall were from directly observable causes, while almost all of the observed wetland losses (89%) were attributed to direct loss.

The most common type of wetland gained was the unconsolidated bottom type (i.e., ponds) with 135 acres (67%) of the wetlands gained in this form (Table 2b) and 72% of these were classified as man-made. The next most common type of wetland gain was the emergent wetland type comprising 44.9 acres or 22% of the wetlands gained. However, 48 acres of emergent wetland were lost. Thus, there was a net loss of 3.1 acres of emergent wetlands, while there was a net gain of 115 acres of unconsolidated bottom wetlands. Cultivated wetlands had a net gain of 14.5 acres, while forested and scrub-shrub wetland had net losses of 2.25 acres and 1.80 acres, respectively.

Changes in wetland type were considerably larger than either wetland gains or losses (Table 2c). The total area of wetlands that changed type within the sample plots over this assessment period was 4,486 acres. There was a relatively large net shift away from aquatic bed wetlands of about 1,400 acres. There was also a relatively large net shift of about 1,460 acres toward deepwater habitats, suggesting possible climatic effects. Another notable category of wetland type change was the conversion from emergent wetland to cultivated wetland. While smaller than the other wetland type changes noted above, the net conversion of 112 acres is almost equal to the total net gain of wetlands.

Table 2 (a–c): Wetland gain, loss and type change within sample plots from T1 (2006-2008) to T2 (2009-2011). D–Direct, cause of change is directly attributable; I–Indirect, cause of change cannot be readily determined; (m)–manmade; (af)–artificially flooded

Table 2a: Sum of observed wetland gains within sample plots (acres)

Non-Wetland Land Cover for 2006-2008	Wetland Land Cover for 2009-2011															
	Aquatic Bed		Aquatic Bed (m)		Cultivated Wetland		Emergent		Forested		Scrub-Shrub		Unconsolid. Bottom		Unconsolid. Bottom (m)	
	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I
Agriculture		0.05			1.7	15.0	1.8	13.7					0.04	22.0	46.9	
Natural Upland			0.5		2.0		11.1	13.6		0.6	0.2	0.4	1.9	14.1	14.8	
Rural Developed							3.7						0.4		29.4	
Urban							0.1								4.9	
Aquatic Bed (maf)															0.7	
Unconsolid. Bottom (maf)								0.9								
Total	0	0.05	0.5	0	3.7	15.0	16.7	28.2	0	0.6	0.2	0.4	2.34	36.1	96.7	0

Table 2b: Sum of observed wetland losses within sample plots (acres)

Wetland Land Cover for 2006-2008	Non-Wetland Land Cover for 2009-2011									
	Agriculture		Natural Upland		Other Transitional		Rural Developed		Urban	
	D	I	D	I	D	I	D	I	D	I
Aquatic Bed							0.3			
Cultivated Wetland	1.1			0.2			1.2	1.7		
Emergent	25.7		0.1	1.3	10.2		3.8		0.6	0.1
Emergent (m)		5.4	0.1				0.7			
Forested	0.4				0.7		1.7			
Scrub-Shrub	1.1						1.2			
Unconsolid. Bottom				0.2			1.5			
Unconsolid. Bottom (m)	0.5		1.8				15.8			
Total	28.8	5.4	2.0	1.7	10.9	0	26.2	1.7	0.6	0.1

Table 2c: Sum of observed changes of wetland type within sample plots (acres)

Wetland Land Cover for 2006-2008	Wetland Land Cover for 2009-2011																					
	Aquatic Bed		Aquatic Bed (m)		Cultivated Wetland		Deepwater		Deepwater (m)		Emergent		Emergent (m)		Forested		Scrub-Shrub		Unconsol. Bottom		Unconsol. Bottom (m)	
	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I
Aquatic Bed								1698.1			0.3	154.3						0.2	0.5	267.1		
Aquatic Bed (m)											0.2	3.8		1.3						0.7	1.0	1.2
Cultivated Wetland											3.6										126.3	13.7
Deepwater		285.3									0.7	53.1						0.7		11.5		
Deepwater (m)				0.2							0.2			4.7								
Emergent		17.1			72.2	42.6	7.9	103.2	1.3								1.6	3.8	22.3	363.6	41.6	3.2
Emergent (m)		0.03				0.7				0.2										2.0	14.5	8.6
Forested											32.8	0.6							0.9	1.2		
Scrub-Shrub								0.2			14.2	60.4							0.4	1.6	2.1	
Unconsol. Bottom	0.8	401.9			0.1	3.3		0.2			32.8	519.2		2.3		0.4	2.6					
Unconsol. Bottom (m		1.4	0.1	21.2		0.4			3.6		3.2	14.6	7.2	20.1			0.9	0.7		0.0		
Total	0.8	705.7	0.1	21.3	72.3	47.1	7.9	1801.8	4.9	0.2	88.0	805.9	7.2	28.4	0	0.4	5.1	5.3	24.1	647.7	185.4	26.7

Wetland change by plot ranged from a gain of +22.6 acres (or +3.5% of the plot) to a loss of -19.8 acres (or -3.1% of the plot); however, the vast majority of plots (96.7%) had no change in wetland area (Figure 2). Changes in the extent of wetlands were tabulated by sample plot and the percentage of the various wetland changes was calculated by dividing the change area by the total area for each sample plot (Table 3). The magnitude of wetland change expressed as a percentage of the total sampled area is quite small. For example, the total net wetland change was found to be +0.00385% or about +2.5 acres of wetland gained for every 100 square miles of sampled area.

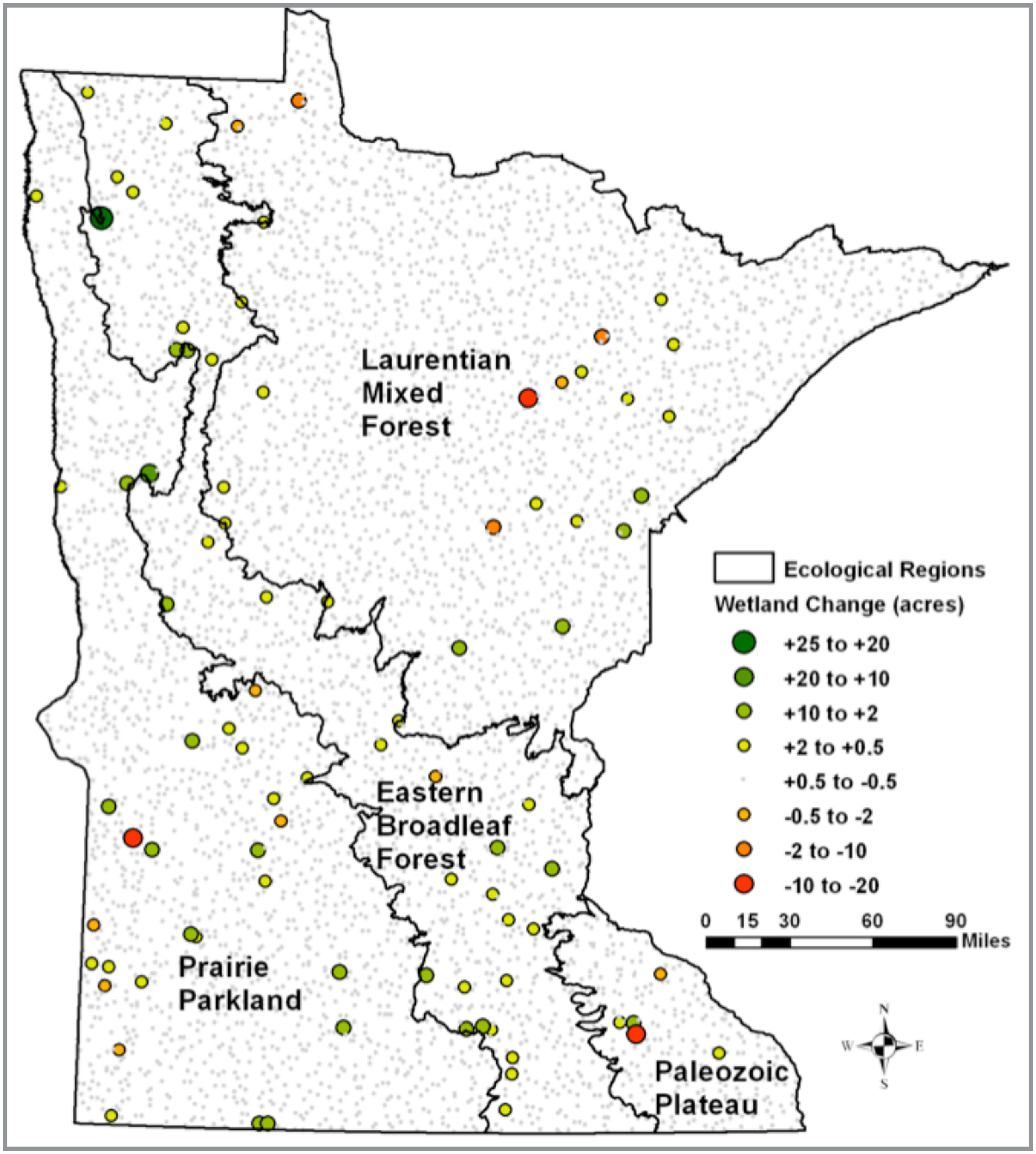

Figure 2: The geographic distribution of wetland changes in acres is shown for all plots in the monitoring program.

Table 3: Summary statistics for the changes in wetland proportion normalized by plot area (%)

	Mean Change (%)	Standard Error
Direct Gain	+0.00376%	0.00091%
Indirect Gain	+0.00252%	0.00058%
All Gain	+0.00628%	0.00110%
Direct Loss	-0.00215%	0.00081%
Indirect Loss	-0.00028%	0.00018%
All Loss	-0.00242%	0.00083%
Net Direct Gain/Loss	+0.00164%	0.00118%
Net Indirect Gain/Loss	+0.00221%	0.00061%
Net All Gain/Loss	+0.00385%	0.00134%
Direct Type Change	0.012%	0.0045%
Indirect Type Change	0.130%	0.0257%
All Type Change	0.142%	0.0261%

Hypothesis Testing for Change

A formal test for normality, the Kolmogorov-Smirnoff-Lillifors test (SAS Institute 2012), indicates that the data are not normally distributed. Consequently, hypothesis testing was performed using a non-parametric test that does not have strict requirements for the data distribution. A Wilcoxon signed rank test (SAS Institute 2012) was used to determine if the paired-differences are significantly different from zero. This test indicates that all three change categories (direct, indirect, and combined) are significantly different from zero with a confidence level greater than 99% (Table 4). Thus, there has been a net gain of wetlands for Minnesota when comparing the two assessment periods.

Table 4: Hypothesis Testing for the Net Change of Wetland Proportion

	Net Direct Change	Net Indirect Change	Net All Change
Mean	+0.00164%	+0.00211%	+0.00385%
Standard Deviation	0.0836%	0.0429%	0.0946%
Standard Error of the Mean	0.00118%	0.000607%	0.00134%
N	4990	4990	4990
Hypothesized Value	0	0	0
Signed Rank Test Statistic	1621	700	4182.5
Signed Rank Test Prob > |t|	<.0001	<.0001	<.0001

Extrapolation to Statewide Change

Because the sample was randomly selected, the proportional wetland changes described above can be assumed to be representative of statewide changes. Therefore statewide changes were estimated by multiplying the mean proportional change of the sample by the total state area of 84,382 square miles and then converting to acres (Table 5). Over the assessment period the state has had an estimated net gain of 2,080 acres of wetland from both direct (885 acres) and indirect causes (1,200 acres). In addition, an estimated 76,800 acres of wetland changed from one type to another during the assessment period. Of particular note, there was a net change of 1,890 acres of emergent wetland converted to cultivated wetland.

Table 5: Statewide Extrapolation of Wetland Changes

	Statewide Change (acres)	Standard Error
Direct Gain	+2030	491
Indirect Gain	+1360	314
All Gain	+3390	592
Direct Loss	-1160	439
Indirect Loss	-149	96
All Loss	-1310	449
Net Direct Gain/Loss	+885	639
Net Indirect Gain/Loss	+1200	328
Net All Gain/Loss	+2080	723
Direct Type Change	6700	2420
Indirect Type Change	70100	13900
All Type Change	76800	14100

Annual Variability

A subset of 250 plots was monitored every year for changes in wetland extent over the six-year study period (2006 through 2011). An analysis of this subset was used to evaluate the potential for annual variability to influence the results. This analysis shows that very few of the annual plots change from one year to the next (Figure 3). The amount of annual wetland change resulting from indirect causes is of particular interest because we believe that this may reflect changes in wetland extent resulting from year-to-year climate differences. There were no recorded changes in the annual plots from indirect causes for the second and fourth annual assessment periods (2007-08 and 2009-10). There was only one recorded indirect change in the first and fifth annual assessment periods (2006-07 and 2010-11). The area of the indirect change was also small. The largest indirect change occurred from 2010 to 2011 and was 4.8 acres in area, which is 0.003% of the total area in the 250 annual sample plots. None of the year-to-year changes in wetland area resulting from indirect causes were statistically different from zero.

There was a 12.4 acre gain in wetland area from directly observable causes in the first annual assessment period (2006 to 2007) and a direct loss of 4.97 acres in the third period (2008 to 2009). The other assessment periods showed almost no change (<1 acre) from directly observable causes.

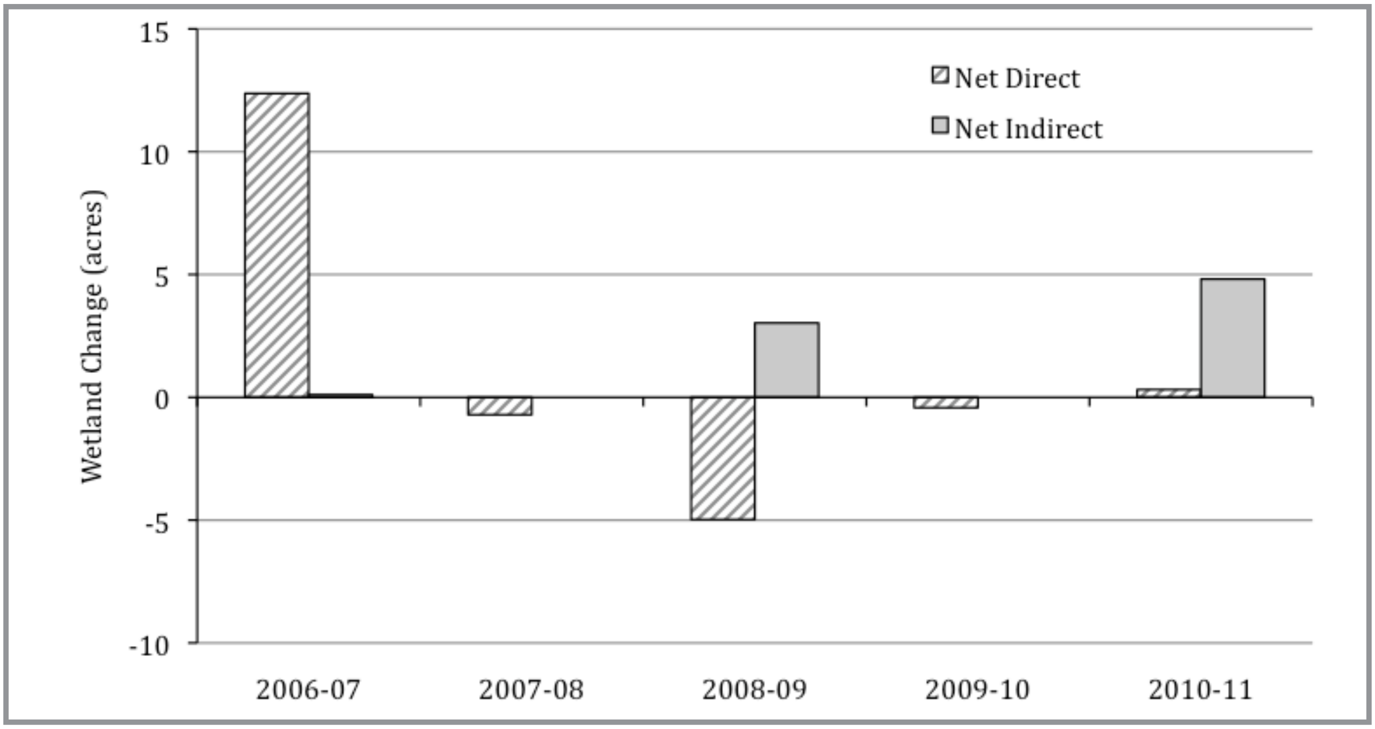

Figure 3: Annual net wetland gain and loss observed in 250 annual sample plots between 2006 and 2011.

Geographic Distribution of Change

As with the statewide analysis, only a few plots within each of the four analysis regions (Figure 2) have undergone any change in wetland area over the study period. The proportion of sample plots with observed wetland changes for the Eastern Broadleaf Forest, Laurentian Mixed Forest, Paleozoic Plateau, and Prairie Parkland regions were 5.2%, 2.5%, 4.8%, and 3.1%, respectively.

The extrapolated total wetland gain was highest for the Prairie Parkland (1,760 acres) and lowest for the Paleozoic Plateau (325 acres) (Figure 4a). The highest regional loss occurred in the Prairie Parkland (-530 acres), while the lowest regional loss occurred in the Eastern Broadleaf Forest (-32 acres) (Figure 4b). Almost all of the net wetland change occurred in either the Eastern Broadleaf Forest (+794 acres) or the Prairie Parkland (+1230 acres) while net changes for the Paleozoic Plateau and Laurentian Mixed Forest were very small (Figure 4c).

The net wetland gain for the Eastern Broadleaf Forest and Prairie Parkland are statistically significant using the Wilcoxon signed rank test. However, the difference between the direct gains and the direct losses for the Prairie Parkland was found to not be significantly different from zero. Thus, it appears that the overall net wetland gain for this region can largely be attributed to sizeable indirect gains. In addition, the estimated conversion of emergent to cultivated wetland for the Prairie Parkland was 1,290 acres.

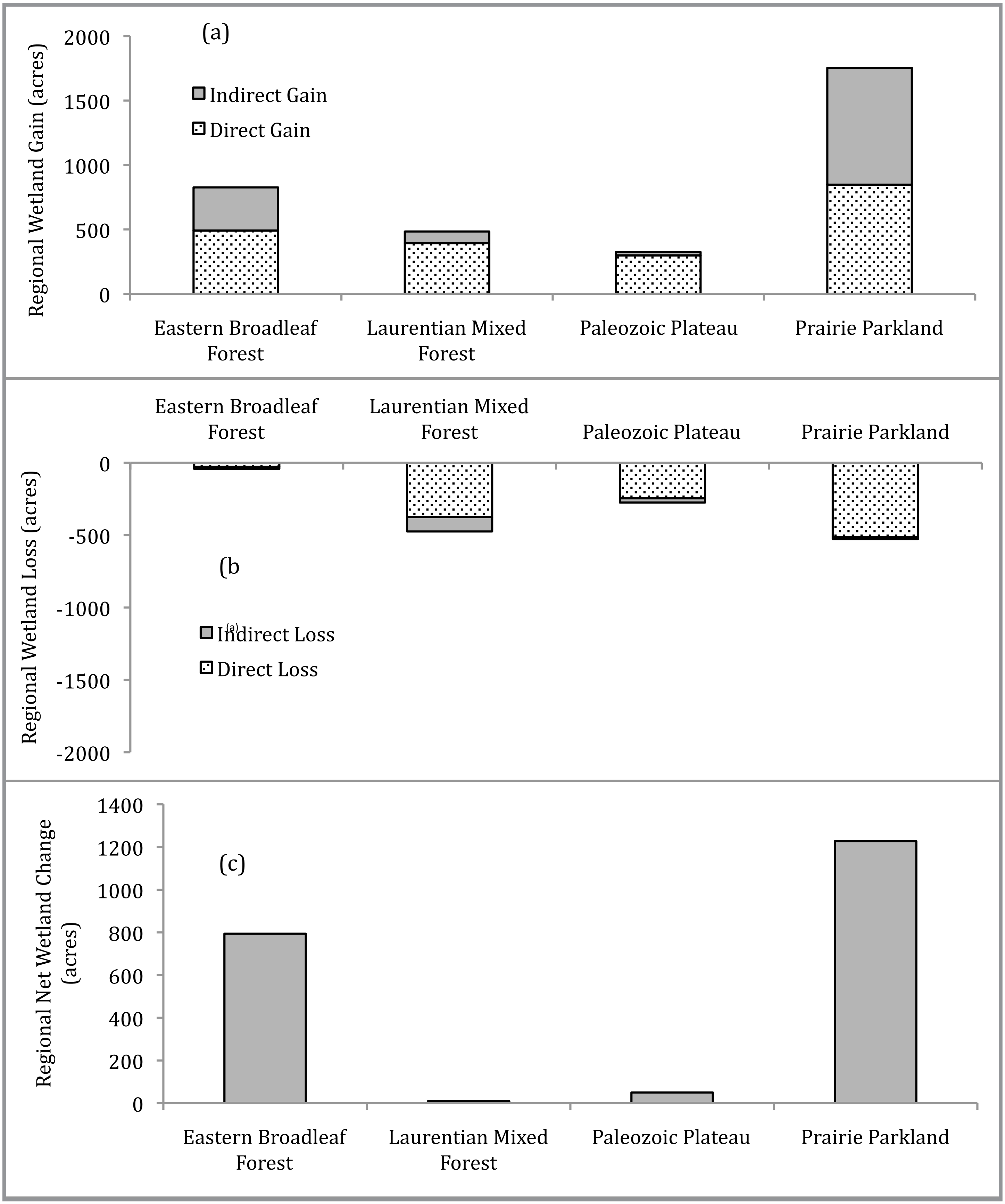

Figure 4: Geographic distribution of (4a) direct and indirect wetland gains, (4b) direct and indirect losses from the sample, and (4c) the net wetland change extrapolated for each region.

Discussion

No-Net Loss Policy Assessment

The 1991 Minnesota Wetland Conservation Act established a statewide policy calling for no-net-loss in the quantity, quality and biological diversity of the state's wetlands. The results from the first two sample cycles of the wetlands status and trends monitoring program, covering the period 2006 to 2011, revealed an overall net gain of wetlands for the state, suggesting that this goal was met with respect to wetland quantity for the study period. However, there are a number of reasons to be cautious about declaring that the policy objective has been met.

First, the net gain of 2,080 acres of wetland was nearly equaled by the area of emergent wetlands converted to cultivated wetlands (1,890 acres). While these lands retained some residual wetland characteristics for the study period, their ultimate fate is unclear. Relatedly, it is important to note that photo-interpretation methods have limitations with respect to mapping cultivated wetlands. In fact, this is an inherently difficult class of wetlands to correctly classify regardless of the method due to the typical lack of any wetland vegetation. The ability to classify these wetlands is generally improved by examining many years of imagery. Future assessments from this program may improve in this regard as the imagery record expands.

Second, this study only addresses the wetland quantity aspect of the State's no-net loss policy. The fact that most of the wetlands gained were classified as unconsolidated bottom, a classification characterized by a lack of emergent or observable submersed vegetation, raises questions about the quality of these wetlands, particularly for fish and wildlife habitat. Specifically, are these newly created ponds providing an equivalent level of ecological service as the wetlands that have been lost? The baseline wetland quality assessment conducted under the WSTMP indicates that many wetlands are in poor condition -- 46% of the depressional wetlands assessed were considered in poor condition with respect to plant diversity and 20% were in poor condition with respect to the macroinvertebrate community (Genet 2012). An assessment of trends in wetland quality is expected to be available in 2014.

Third, a substantial portion (39%) of the observed wetland gains could not be attributed to an obvious cause, suggesting they may be due to climatic factors or other phenomena of unknown duration or permanence. Conversely, nearly all (89%) of the wetland loss was due to obvious causes, most of which are likely to be permanent.

Finally, while the wetland gain is statistically significant, proportionally, the change is quite small. The extrapolated net gain of 2,080 acres represents 0.02 percent of Minnesota's current 10.6 million acres of wetlands (Kloiber, 2010). The fact that the amount of change is relatively small is not completely unexpected, given that this is the result of only the first two sample cycles of the WSTMP, covering a relatively brief six-year period. Longer-term data over several sample cycles will be needed to determine if the observed direction and rate of change are typical.

Comparison to the National Status and Trends Results

Nationally, the U.S. Fish and Wildlife Service reported annualized wetland change for all wetlands types of -58,500 acres/year, +32,000 acres/year, and -13,800 acres/year for the reporting periods 1986-97, 1998-2004, and 2004-2009, respectively (Dahl 2011). Expressed as a percentage of all wetlands, these changes correspond to -0.055%, +0.030%, and -0.012%; whereas, the annualized wetland change observed under the WSTMP for Minnesota expressed as a percentage of the baseline wetland area is +0.007%. Dahl (2011) notes that the rate of wetland loss has been slowing significantly over the past 60 years and that the rate of loss varies regionally. The results from the Minnesota WSTMP are generally consistent with the national wetland survey.

The results from the WSTMP are also consistent with the findings from the past two national surveys of wetlands trends in the sense that the national program noted a net national gain in freshwater wetlands primarily due to gains in un-vegetated wetland "ponds" (Dahl 2006; Dahl 2011). Of the wetlands gained in Minnesota for the current study period, a major portion (67%) was classified as unconsolidated bottom wetlands, or ponds.

Wetland Trends for Southwestern Minnesota

Other studies have documented relatively recent net losses of wetlands in the southwestern agricultural region of Minnesota. For example, Oslund et al. (2010) report that the Prairie Pothole Region of Minnesota, a region that roughly corresponds to the Prairie Parkland in our study, lost about 4.3% of its wetland area over a ~27 year period from circa 1980 to 2007. Most of this loss was thought to be the result of repair and enhancement of agricultural drainage systems for wetlands that were already partially drained. Genet and Olsen (2008) found a 21% loss of depressional wetland area for the Redwood River watershed from 1980 to 2003, a watershed that falls within the Prairie Parkland.

One of the key differences between these two studies and the WSTMP study is the time period for the assessment. The wetland losses shown by these two previous studies occurred over a time period that pre-dates the WSTMP assessment period. Importantly, the time period for these studies partially overlaps a period prior to the 1985 implementation of the Swampbuster provisions of the federal farm program, which significantly slowed the loss of wetlands on agricultural land (Dahl 2000, Haufler 2005). On an annualized basis, the rate of loss for the studies by Oslund et al. (2010) and Genet and Olsen (2008) were -0.16%/year and 0.91%/year respectively, compared to the observed gain of +0.007%/year under the WSTMP.

More recently, Wright and Wimberly (2013) identified a significant net conversion of grassland to corn/soybean production throughout the Western Corn Belt during the period 2006 to 2011. In Minnesota, they noted that a significant proportion of this conversion occurred on lands characterized by excess wetness (based on NRCS Land Capability Class), suggesting a wetland loss for a period that is approximately contemporaneous with the WSTMP results reported here. The apparent differences between the results of these two studies are attributable to differences in methodology and reporting. Wright and Wimberly (2013) focused on conversion of grassland to corn/soybean and vice versa. The observed conversion of emergent wetlands to cultivated wetland (1,890 acres) under the WSTMP would have been considered as a likely wetland loss by Wright and Wimberly (2013) but is classified as a type change in the WSTMP. In addition, their results do not account for other types of wetland gain or loss that influence net change, such as the gain of open water wetlands identified by the WSTMP. Thus, we believe that the results of these two studies are not contradictory.

In another recent study, Johnston (2013) examined wetland-to-agricultural land conversion in the Prairie Pothole Region of North and South Dakota. Findings from this study indicate that wetlands in these neighboring states continue to be converted to agricultural production. There are clearly instances within our data set that demonstrate this same wetland-to-agricultural land conversion in Minnesota; however, the Johnston (2013) study did not examine sources of wetland gain, nor did it include data from Minnesota. Therefore, comparisons cannot be made with regard to the net wetland change.

The aforementioned studies all suggest that agricultural drainage is an important factor in wetland loss in the prairie regions of Minnesota and the Dakotas. The extensive, ongoing installation of drain tile throughout the agricultural regions of Minnesota in recent years has been observed by many, at least anecdotally. In one of the few documented reports, the Bois de Sioux Watershed District in northwest Minnesota identified a nearly thousand-fold increase in the amount of permitted pattern tile installed in the District from 1999 to 2012 (unpublished data, Bois de Sioux Watershed District). While the WSTMP data show a net gain of 1,230 acres of wetland for the Prairie Parkland, the data also show that 1,290 acres of wetlands were converted from emergent to the cultivated wetland type. How much of this conversion is related to agricultural drainage is not known, nor is it known whether these are permanent changes or if they reflect an intermediate step toward complete loss of wetland characteristics. A more complete picture should become more evident with future sample cycles.

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Appendix

Illustrated Examples of Wetland Loss

Example 1. Loss due to agricultural conversion
Most wetlands that were lost over the first monitoring cycle (2006-08 to 2009-11) were converted to agricultural land cover (Table 2b). Conversion to agricultural land consumed 34.2 acres of wetland in the sample plots or about 44% of all wetland losses. However, it should be noted that 101 acres of wetland were gained in the sample plots from conversion of agricultural land to wetland. A relatively large emergent wetland located in Lac Qui Parle County provides a good illustration of wetland loss within a sample plot due to agricultural conversion (Figure A1). This wetland existed in a partly-drained state during the initial assessment period. A ditch was present, but the ditch was ineffective at completely eliminating the wetland. In the return assessment period, all evidence of wetland vegetation was gone and cultivation is evident throughout the site. The result is a loss of about 24 acres of wetland, of which 19.8 acres were within one of the WSTMP sample plots.

Figure A1: The image on the left shows a partially drained emergent wetland in summer of 2008. The yellow line shows the approximate wetland boundary. The image on the right shows the same area in spring of 2011, but the wetland has been completely drained and all wetland vegetation has been removed.

Example 2. Loss due to construction/development

Construction and development were also significant drivers of wetland loss. Interestingly, most of the losses due to development occurred in rural areas rather than established urban areas. Thirty six percent of all wetland losses were due to rural development as opposed to 1% from urban development (Table 1a). A roadway expansion and relocation project in St. Louis County provides an illustration of this type of wetland loss (Figure A2). In this case, a single-lane, undivided highway was replaced by an improved two-lane, divided highway which was relocated slightly to the west. As a result, a forested wetland was split by the new highway and about 3 acres of wetland were lost within the sample plot.

Figure A2: The image on the left shows a forested wetland dominated by black spruce in the spring of 2006, while the image on the right shows the same site in summer of 2010 with the same wetland split by a relocated and expanded rural highway.

Example 3. Transitional loss

A broad shallow swale located in Olmsted County provides an example of a wetland undergoing a land cover conversion (Figure A3). In this case, the wetland vegetation has been stripped and bare soil is evident. The land change is part of a larger project as evidenced by the extent of bare soils. Because the project was underway at the time of the acquisition of aerial photography, the ultimate land cover is uncertain and the code for transitional land was applied. For analysis purposes, the WSTMP treats all transitional land cover as upland. Therefore, this change was treated as a 10 acre wetland loss. However, the shape of the feature, the presence of berms, and the context of the site suggest that this may only be a temporary loss. The site appears to be in transition to becoming a detention basin for storing and treating stormwater runoff. As a result, we anticipate that in the next assessment period that this site will become a wetland gain. The type and quality of the resulting wetland remains to be seen.

Figure A3: The image on the left shows a wetland complex with elements of aquatic bed, scrub-shrub, forested, and emergent wetland in summer of 2008. The yellow line depicts the boundary of an emergent wetland. The image on the right shows extensive grading activity in spring 2011. The portion of the wetland complex that has been affected by the grading activity was classified as transitional during the second assessment period.

Illustrated Examples of Wetland Gain

<u>Example 4. Wetland gain on agricultural land</u>
Agricultural land was the largest contributor to wetland gain. There were 101 acres of wetland gained on agricultural lands within the sample plots. This is slightly more than half of all the observed gains. Wetlands lost to agricultural land also led all other categories with a loss of 34.2 acres within the sample plots. Almost 70% of wetland gains on agricultural land occurred as unconsolidated bottom wetlands. An example of this type of gain can be seen in an expanded wetland in Becker County (Figure A4). The image does not include any clear visual evidence that this wetland gain was caused by direct human intervention; as such, this change was attributed to indirect causes. However, upon further investigation it was learned that this area is adjacent to a waterfowl production area owned by the U.S Fish and Wildlife Service, suggesting that this may be a permanent change. Over time, this wetland may change, developing wetland vegetation and providing additional wetland benefits.

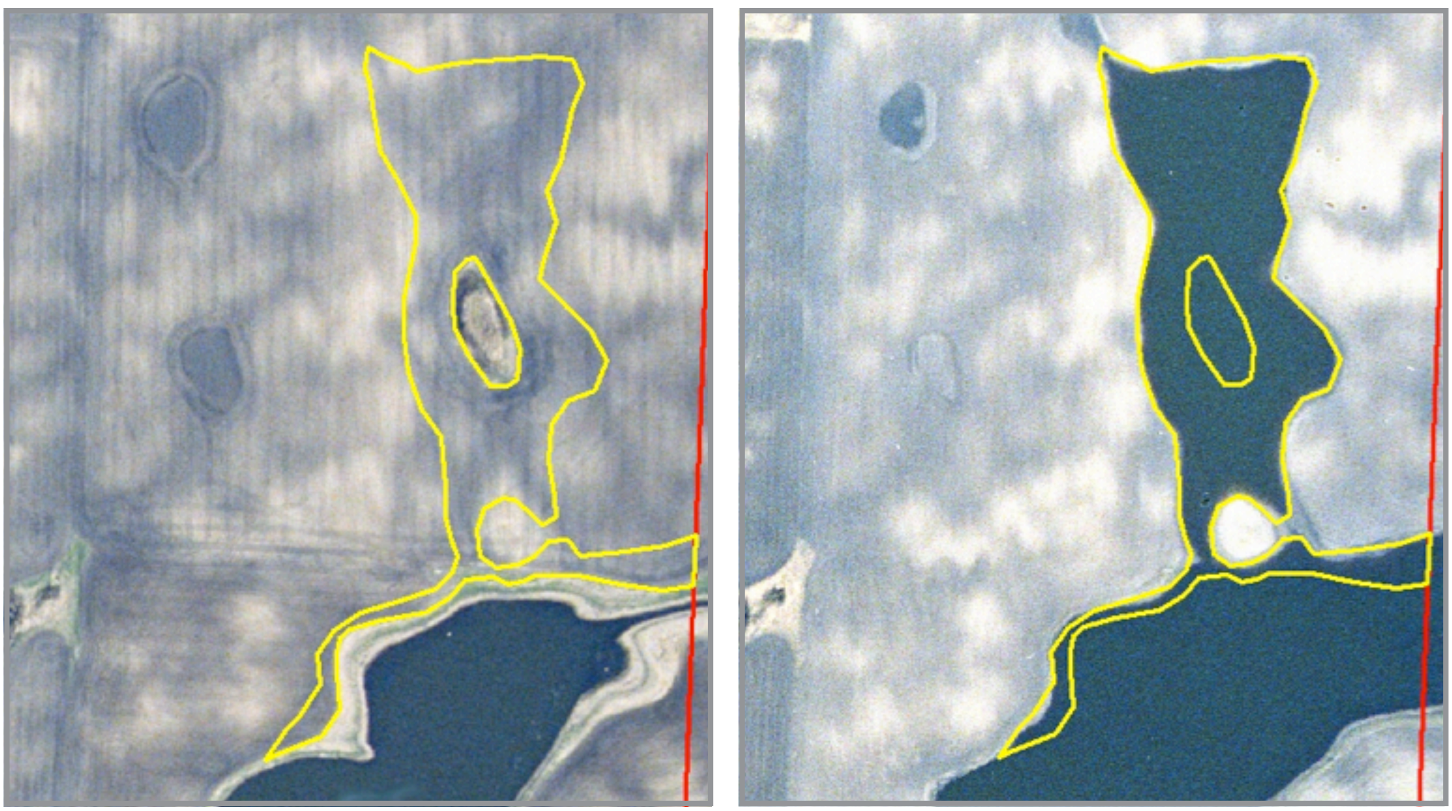

Figure A4: The image on the left shows an agricultural field surrounding a small scrub-shrub wetland and adjacent to a larger open water wetland to the south. In spring, this area shows a clear pattern of cultivation. The yellow line shows the extent of the wetland gain, while the red line shows the edge of the sample plot. The image on the right shows the same area in spring 2010. The area has been inundated by water.

Example 5. Wetland gain on natural/undeveloped land

Wetland gains on natural uplands including both natural forests and grasslands was the second most common setting for wetland gains with a total of 59.1 acres gained within the sample plots. Losses to natural upland within the plots totaled only 3.7 acres. One example of a wetland gained from natural upland is illustrated by an apparent wetland restoration in Lincoln County (Figure A5). Approximately 56 acres of land within an agricultural setting appear to have been set aside as natural grassland along a small stream channel. Imagery from 2008 to 2011 show that a berm was created to pond about 1.65 acres of water.

Figure A5: The summer 2008 image on the left shows a stream channel passing through an area of natural herbaceous vegetation located within a broader agricultural landscape. The image on the right shows the same area in spring 2011 with a newly created unconsolidated bottom wetland. Grading lines can be seen suggesting that a berm was created with the intent to retain water in this area.

Example 6. Wetland gain on urban/suburban developed land

Very little wetland gain occurred in urban areas, possibly due to land availability constraints. Of the little gain that occurred, almost all it was in the form of ponds. These ponds are typically small as illustrated by the gain of a 0.25 acre pond in Dakota County (Figure A6).

Figure A6: The image of the left shows a large suburban residential parcel in Dakota County in spring 2006. The image on the right shows a newly created unconsolidated bottom wetland (pond) adjacent to the driveway in spring 2010.