AMBIENT AIR QUALITY, PRECIPITATION CHEMISTRY, AND WETLAND CHEMISTRY AT LOSTWOOD NATIONAL WILDLIFE REFUGE, NORTH DAKOTA 1986-1991

by

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Introduction

Lostwood National Wildlife Refuge (Lostwood) covers 10,888 ha in Burke and Mountrail counties, northwestern North Dakota (ND). The refuge is 37 km south of Saskatchewan and 113 km east of Montana. Lostwood lies within the 20- to 30-km wide Missouri Coteau, a dead ice moraine of moderate relief (30-90 m) deposited by the Wisconsin glacier over a previously occurring escarpment (Clayton 1967; Freers 1973; Bluemle 1977). The refuge's rolling topography (elevation 698-766 m) is interspersed with about 4100 prairie wetlands of all types and sizes. Lostwood contains an average of about 24 Class II and III wetlands/km^2, and 3 Class IV wetlands/km^2 (classification by Stewart and Kantrud 1971). Additionally, alkaline wetlands utilized by threatened species (piping plover [*Charadrius melodus*]) and large lakes used by migrant birds are also present at Lostwood. This wetland diversity attracts at least 37 breeding bird species.

Lostwood's knob-and-kettle topography consists almost entirely of non-integrated drainage; rainfall and snowmelt collect in wetland basins via surface runoff and subsurface seepage (LaBaugh 1986; Winter 1989). Presence of glacial till is evidenced by erratic and thin, gravelly, mostly loam soils. Primary soils are Zahl-Williams and Zahl-Max loams, characterized by thinly developed, well-drained, fine loamy soil complexes, on 3-25% slopes. On hilltops and upper slopes, Zahl loam makes up about 60% of the Zahl-Max complex. On lower slopes, Max loams comprise 25-50% of the Zahl-Max complex. The dominant plant community is western wheatgrass-needlegrass, but topographical relief creates varied soil moisture regimes that create a diverse plant community, including species typically found in the western short-grass and eastern tall-grass prairies.

The climate at Lostwood is semi-arid, with mean annual precipitation of 42 cm (range 23-74 cm) (U.S. Fish Wildlife Service, refuge files). Temperature extremes of -40°C in winter to 38°C in summer can occur. Prevailing northwest winds 16-32 km/h are common. The growing season is 90-100 days. May, June and July are the wettest months (54-year average of 5.13, 8.43, and 5.99 cm, respectively). In July and August, violent thunderstorms often occur, sometimes accompanied with downpours of rain or hail. Some winters lack snow, while others are severe with snowstorms from October through mid-May. All wetlands, except 6 major lakes, may be completely full one year and completely dry 10 years later.

Within the refuge lies the 2257-ha Lostwood Wilderness Area established through Public Law 93-632 (1975). Class I air quality must be maintained in accordance with the Clean Air Act (Amendments of 1977, Public Law 95-95, Part C; Subpart I; Section 162), and North Dakota Air Pollution Control Regulations (Title 33, Article 15, Prevention of Significant Deterioration of Air Quality, 15-02). The U.S. Fish and Wildlife Servicd-Air Quality Branch assists National Wildlife Refuges in gathering

air quality data for National Wilderness Areas. In 1982, the North Dakota State Department of Health (NDSDH) completed an inventory of all oil and gas sources of SO_2 emissions within 50 km of the Lostwood Wilderness Area. This report (NDSDH 1983), covering 1 January to 31 December 1982, reviewed annual emissions of SO_2 for 280 individual oil wells and 2 natural gas plants that process oil field gases, and H_2S for 978 wells within the study area. The baseline date established for SO_2 emissions in northwestern ND is 16 December 1977. By 1982, SO_2 emissions from the 280 wells had increased by 732%. About 40% of SO_2 emissions were from the Flaxton oil field, and was to be corrected with the new gasification plant at Lignite, ND. This left 7,600 tons of SO_2 emissions from other wells and point sources within 50 km, 6,174 tons above the allowable baseline. The SO_2 tonnage reaching the Lostwood Wilderness Area was likely greater than this because the report only considered oil and gas sources within a 50-km radius of the wilderness area. Beyond the 50-km radius, there were 3,731 oil-producing wells in the state (mostly in central and western ND), and 2 coal-burning power plants (one 72 km northwest of Lostwood in Estevan, Saskatchewan, and another 365 km southeast).

Potential total emissions of SO_2 around Lostwood Wilderness Area fueled concern over air quality and potential impacts on wetlands, particularly freshwater wetlands. Specific conductance (micromhos/cm^3) and pH ranges for temporary and seasonal freshwater wetlands equal 40-700+ (Stewart and Kantrud 1971) and 5.5-7.4 (Cowardin et al. 1979) respectively. Scientists had not considered acid deposition as a problem in prairie wetlands because alkaline soils are prevalent and presumably have a high buffering capacity (Arndt and Richardson 1992). In other areas of known acid deposition, initial snowmelt can produce a pH pulse into receiving waters (Galvin and Cline 1978, Johannessen and Henriksen 1978, Johannessen et al. 1980, Cadle and Dasch 1984, Reynolds 1983, Barrie and Vet 1984), a phenomena sometimes referred to as "acid shock." Where acid deposition occurs, acids and metals (decreasing pH increases metal activity) concentrate at the bottom of the snow column and may rapidly flush out during initial snowmelt.

At the Cottonwood Lake Study Area in south central ND (La Baugh et al. 1987), one semipermanent wetland (P1) during 1979's initial snowmelt in early April had a pH from 4.1 to 5.8 and specific conductance between 8 and 17. By late April, after sediments thawed, pH was 6.6 to 6.8 with specific conductance between 522 and 700 (J. LaBaugh, pers. comm.). These data suggest that during snowmelt, pH levels in a semipermanent wetland could be affected by acid deposition. Temporary and seasonal wetlands typically are small (<0.4 ha) compared to most semipermanent wetlands, go dry prior to freezing, and are usually not recharged from alkaline subsurface seepage. These conditions plus inactive frozen sediments, reduce the ability of temporary and seasonal wetlands to buffer initial acid depositions. This "acid shock" could suppress abundance of some invertebrate species that are active just prior to or during initial snowmelt, e.g., fairy shrimp (*Anostraca* sp).

Wetland hydrology and water chemistry ultimately determine invertebrate diversity, abundance, growth, and behavior (Reid 1985, Swanson et al. 1988). Aquatic invertebrates reach greatest abundance when in concert with thriving, diverse plant communities (Reid 1985). Aquatic invertebrates maintain a functional wetland through nutrient cycling and vegetation decomposition, thereby providing a rich protein base for vertebrate populations (Reid 1985). Breeding waterfowl rely on a readily available source of aquatic invertebrates for successful reproduction (Krapu and Swanson 1975). Shorebirds and many passerine species also consume aquatic invertebrates obtained directly or indirectly from wetlands (McNicol et al. 1987). However, changes in ions and nutrients can change the invertebrate composition through alteration of either the vegetation structure or primary productivity of wetlands, thus indirectly affecting avian populations through food limitation (Stromberg and Loncore 1987, Reid 1985, Swanson et al. 1988).

Many wildlife species depend on prairie wetlands. Potential for acid deposition and effects on freshwater wetlands and associated invertebrate populations in the prairie pothole region need to be understood. Even if wetland water quality is unaffected by acid deposition, baseline data are needed for future comparison because increased fossil fuel development is likely. Therefore, the objective of this study was to document baseline water quality, investigate possible acid deposition, and synthesize relevant air quality information.

Methods

Data Collection

Snowcore

Snowcore samples were collected just prior to initial snowmelt at 7 sites in 1988 and 6 sites in 1989 (Attachment 1 and Map 1). The 1988 data analysis was declared invalid due to a chemical laboratory error. Lack of funds or snow prevented snowcore analysis in 1986-87 and 1990-91.

Sites were selected where snowpack was likely, avoiding sun-exposed west slopes that would melt snow prematurely. Six stainless steel pie-plates enclosed in polyethylene bags were placed on the ground before the ground froze, and secured in place with wooden pegs. Steel posts were driven into the ground just below plate locations and maps drawn to show plate locations in relationship to the post (Map 1). At the time of collection, a doubly rinsed (with deionized water), 10-cm diameter PVC pipe was driven through the snow column to obtain snowcore samples. Only the column's bottom portion (slush consistency) was submitted for analysis. If an insufficient sample size occurred, another column from the same site but different plate

was added to this sample. Samples were stored in 3-ml polyethylene bags (previously rinsed twice with deionized water), closed with a cotton string, placed upright in coolers with containers of frozen tap water, and immediately driven to the USGS chemical laboratory in Bismarck, ND.

Analyses completed were: specific conductance, pH, Ca, Mg, Na, K, alkalinity (total $CaCO_3$), sulfate, chloride, As, Cd Cr, Cu, Fe, Pb, Mn, Se, Zn, Al, ammonium, nitrate, and phosphorus (total). For quality control, one site had 4 samples collected for analysis: 2 combined, 2 kept separate of which 1 was analyzed with deionized water.

Rainwater

Water from rainfall events $\geq$ 0.50 cm/24-hr (beginning at 0800 hr) was collected for analysis in a precipitation collector, Model 301 located at Lostwood's headquarters (legal description: SWNW35,R91W,T160N). Collector buckets were cleaned and handled following instructions from the North Dakota State Department of Health and Consolidated Laboratories (e.g., polyethylene gloves worn). Analysis of rainwater samples, transported by bus on the day collected, was completed by USGS in 1989, and Minnesota Valley Testing Laboratories (MVTL, Bismarck, ND) who forwarded samples to EMSI (Camarillo, CA) in 1987-1988 and 1990-1991. Analysis included: pH, specific conductance, Ca, Mg, Na, K, carbonates as $CaCO_3$, sulfate, chloride, nitrate-nitrogen. Analyses of Mg, bicarbonates as $CaCO_3$, nitrite-nitrogen and Al were added in 1990. Records were kept for directional movement of frontal systems that brought rain, and type of rain that fell, (i.e., steady drizzle, light mist, thunderstorm) from 1988-1991.

Wetlands

Freshwater wetlands (Class IIIA, Stewart and Kantrud 1971) were chosen for water quality analysis: 3 in 1986, 5 in 1987-1989 (includes same original 3) plus an additional wetland in 1989 (Attachment 2 and Maps 2-7). Samples were collected from 2 sites/wetland, 1 m from a permanent marker (located in the deepest part of the basin) along 2 randomly selected azimuths. Samples, collected at the same time of day for each year, were taken at the surface and at 6-cm intervals to just above the bottom sediment. All tests were done by trained refuge staff using instruments identified in Attachment 3.

In 1986, 1987 and 1989, pH, specific conductance, dissolved oxygen, and alkalinity were calculated bimonthly from mid-April until the wetland went dry (procedures outlined in Attachment 3). Dissolved oxygen and pH calculations were determined on site, while specific conductance and alkalinity calculations were completed in the Refuge laboratory. In 1987, additional tests were completed: common

ion (Ca^+, Mg^+, Na^-, K^+, bicarbonate as $CaCO^-_3$, carbonate as $CaCO^-_3$, SO^-_4, and Cl^-), trace elements (As, Cd, Cr, Pb, Hg, Se, Zn, Cu, Fe, and Mn), and nutrient (N as NH^+_4, N as NO^-_3, and P as PO^-_4). Two water samples/wetland (wetlands 1-5 used) were collected at a depth of 6 cm once/month during one of the bimonthly collecting trips. Samples were preserved as instructed by MVTL (Attachment 4), packed in ice, and submitted to the lab within 24 hr of collection.

Air Quality

The air quality data consisted of measurements on 9 variables, NO, NO_2, O_3, CO, SO_2, H_2S, wind direction (WD), wind speed (WS), and standard deviation of wind direction (SIG), measured at 15 locations throughout ND in 1989-1996 (Map 8). However, not all variables were measured every year at every location (Attachment 5). Data for Lostwood were available for 3 years: 1989-1991. Measurements were taken on NO, NO_2, H_2S, and SO_2 almost daily in 1989, daily in 1990, and for the first 14 days in January in 1991. Air quality data were obtained from NDSDH.

Data Analyses

Descriptive statistics; including sample size, mean, median, standard deviation, minimum, maximum, range and coefficient of variation; were calculated for each variable in the snowcore, rainfall, wetland, and air quality data sets. Median values were similar to mean values for most variables, suggesting that skewness was slight, and therefore transformations were unnecessary. Observations with values below detection level were assigned values equal to the detection limit prior to conducting analyses.

For rainfall data, ANOVA was used to assess the effects of year and type of precipitation (i.e., steady drizzle and thunderstorm) on 4 variables: pH, specific conductance, bicarbonates, and alkalinity. Specific conductance, pH, bicarbonates, and alkalinity were plotted against the amount of rain by precipitation type, and against year and wind direction.

For wetland chemistry data, selected variables were plotted against date and wetland to look for trends and patterns. For comparison purposes, pH data from seasonal wetlands in the Cottonwood Lake Study Area (Swanson 1987) in east-central ND during 1992-1994 were also summarized.

For air quality data from the Lostwood monitoring site, the variables NO, NO_2, H_2S, and SO_2 were plotted against date by year, and against year. Maps were produced showing the mean concentration for each variable at each monitoring site.

Descriptive statistics, plots, maps, and other analyses were generated with SAS

(SAS Institute 1989) software.

Results and Discussion

Snowcores

Snowcore data consisted of 28 environmental variables measured at 5 locations in 1989. Descriptive statistics for all variables are shown in Attachment 6. The mean pH of the 5 snowcore samples were 6.090, with values ranging from 5.85 to 6.30.

Rainfall

Rainfall data, consisting of measurements on 17 variables, were collected from 1987-1991. Summary statistics by year and for all years averaged are given in Attachment 7 (three pages). The mean pH for all years combined was 5.575. Means, ranges, and sample sizes by year were as follows:

YEAR	MEAN pH	RANGE	N
1987	5.3190	4.940 - 5.650	10
1988	5.6600	5.090 - 6.410	10
1989	6.0675	5.240 - 6.700	12
1990	5.4611	3.900 - 6.700	18
1991	5.3667	4.700 - 6.300	15

ANOVA results (Attachment 8 [four pages]) indicate that there was a difference among years for pH ($F=3.72$; $df=4,60$; $p=0.0091$), bicarbonates ($F=34.91$; $df=4,60$; $p<0.0001$), and alkalinity ($F=11.66$; $df=2,40$; $p=<0.0001$), but not for specific conductance ($F=1.71$; $df=4,60$; $p=0.1593$). The type of precipitation (TP), steady drizzle versus thunderstorm, had no effect on any of the 4 variables (Attachment 9 [four pages]). Plots of pH, specific conductance, bicarbonates, and alkalinity against the amount rain (ATIN), year, and wind direction (WD) are given in Attachment 10 (three pages).

Deutschman and Ell (1986) reported pH equivalences for the period 1981-1984 of 4.84, 4.91, and 4.99 near the ND towns of Dunn Center, Canfield Lake, and Woodworth, respectively. Mean pH of precipitation sampled weekly at 3 National Atmospheric Deposition Program/National Trends Network (NADP/NTN) sites in ND in early 1980's ranged from 5.25 at Theodore Roosevelt National Park in western ND to 5.53 near the town of Woodworth in east-central ND (Deutschman and Ell 1986).

Munger (1982) reported a mean pH of 5.27 for Lake Tewauken in southeastern ND. These values are all less than or well within the range of pH values observed at Lostwood.

Wetlands

Wetland chemistry data consisted of 2 data sets. The first data set consisted of samples collected from 5 wetlands. Summary statistics for the 30 variables are given in Attachment 11. The pH averaged 6.890 and ranged from 6.75 to 7.00 in 1987. The pH decreased with date and varied among wetlands (Attachment 12 [two pages]). Specific conductance, alkalinity, and bicarbonate all increased with date.

The second wetland chemistry data set consisted of samples collected from wetlands in 1986-1989. Summary statistics by year, averaged across wetlands, are given in Attachment 13. Summary statistics by year and wetland are given in Attachment 14 (four pages).

Mean pH and sample size by year were as follows:

YEAR	MEAN pH	N
1986	6.826	3
1987	6.938	5
1988	all wetlands dry	0
1989	7.481	6

Temperature, pH, dissolved oxygen, alkalinity, and specific conductance were not statistically related to the depth at which the sample was taken (Attachment 15). In most years, pH decreased with date (Attachment 16 [three pages]) and varied among wetlands (Attachment 17 [three pages]).

Mean pH values from seasonal wetlands at Cottonwood Lake Study Area in east-central ND for the years 1992-1994 were similar to those from Lostwood during 1986-1989 and are given below:

YEAR	MEAN pH	N
1992	6.700	1
1993	6.820	1
1994	7.030	2

Summary statistics for additional variables measured at Cottonwood Lake Study Area can be found in Attachment 18.

Air Quality

At Lostwood, levels of NO, NO_2, H_2S, and SO_2 fluctuated within years and exhibited some seasonal patterns (Attachment 19 [three pages]). For example, H_2S levels were zero or near zero except during spring (1989) and spring and summer (1990), and SO_2 levels were highest in winter. Differences in mean levels of NO, NO_2, H_2S, and SO_2 were also apparent among years (Attachment 20), but levels for 1991 should be interpreted with caution as they reflect conditions only during the first 14 days of January. Attachments 21 (two pages) and 22 (five pages) provide results from air quality monitoring by year, and averaged across years. Maps showing mean level of CO H_2S, NO, NO_2, O_3, and SO_2 at 15 monitoring sites are in Maps 9-14.

Conclusions

The results of this evaluation do not suggest that fossil fuel operations had a measurable effect on wetlands or their biota at Lostwood. While we did find some significant differences in rainfall quality data among years (i.e., pH, bicarbonates, and alkalinity) that might suggest some influence, measurements taken from 6 Lostwood wetlands indicate the pH values were within the range expected for this wetland class in ND. Comparative data for seasonal wetlands at the Cottonwood Lake Study Area (Swanson 1987) were slightly higher than those from Lostwood wetlands but pH values reported by Duetschman and Ell (1986) were slightly less. For Lostwood, we were unable to detect input from air pollutants from fossil fuel activities; however, the buffering capacity of wetlands may have moderated pH shifts from acid precipitation. Impacts to the biological community were not measured.

Rainfall and wind direction data also support our conclusion that any impact to Lostwood wetlands was low. When plotted against the quantity of rain received, neither of the 4 rainfall variables (pH, bicarbonates, alkalinity, and specific conductance) showed a dilution effect; if any of the air quality variables had been concentrated, we expected to see a decline with dilution from rainfall. Further, the intensity of precipitation events did not appear to influence the air quality variables; we hypothesized that different intensity storm events would wash contaminants from the air at different rates. Small sample sizes associated with the rainfall data limited the resolution possible in our analysis.

Water quality data from wetlands showed a seasonal trend with pH decreasing seasonally whereas bicarbonates, alkalinity and specific conductance increased. Increases in the latter 3 parameters are consistent with patterns of concentration

associated with seasonal events but the decrease in pH was an enigma. It is possible that organic acids leaching from decomposing plant material affected this decrease but that is impossible to judge without additional data. In any event, the mean pH values found were within the range expected of this wetland class in the prairie pothole region and they are similar to values obtained from the Cottonwood Lake Study Area in south-central ND.

Although we did detect some fluctuation among years and some seasonal differences, air quality data also did not suggest that Lostwood had elevated concentrations of common air pollutants associated with the fossil fuel industry. In fact, most of the pollutants of concern were actually present in lower concentrations at Lostwood than in most other locations in ND.

In summary, the fossil fuel industry in ND is undoubtedly releasing air pollutants as a byproduct of their normal operations, but those pollutants do not appear to have had a measurable impact on wetlands at Lostwood. Our findings are consistent with the conclusions of Duetschman and Ell (1986) who found that emissions were within air quality emission standards. Although we did not collect data on wetland biota, it is unlikely that pH has impacted aquatic invertebrates given the pH values observed in the study wetlands. Prairie pothole wetlands have tremendous buffer capacity to mitigate pH shifts due to the calcium-rich environment typical in the region. It is possible, however, that pH depressions may impact invertebrates in shallow wetlands during spring melt when frozen sediments reduce the interaction of glacial till with surface water or in temporary wetlands that recharge groundwater. However, for wetlands that freeze solidly in winter (termed aestival wetlands; see Daborn 1969), it is not likely that pH depression would impact flying insects in any substantial way because they overwinter in larger wetlands that do not freeze in winter (Danks 1978). Impacts on invertebrates, especially crustaceans, that overwinter as eggs in aestival habitats need to be evaluated. Shallow wetlands are among the first to thaw in the spring to provide feeding habitat for migratory birds.

This baseline work was done in the late 1980's and early 1990's. Conditions may have changed since that time. Studies should be conducted in the next few years to determine if water quality, wet deposition chemistry, and air quality have changed from the baseline conditions documented in this report. In addition, episodic acidification of wetlands due to spring snowmelt should be evaluated, and potential impacts to aquatic invertebrates investigated.

Baseline water quality data was also collected for Iverson Lake, a 24.7 ha lake on Lostwood. Appendix A presents important historical documentation and baseline water quality data for Iverson Lake. This baseline data reflects conditions in 1987-1990 and should be updated with water quality studies in the next few years.

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Terry

In April of 2001, I sent a copy of a final report entitled "Ambient Air Quality, Precipitation Chemistry, and Wetland Chemistry at Lostwood National Wildlife Refuge, North Dakota, 1986-1991" to all parties listed below without giving the Air Quality Branch a chance to review before distributing the report. Minor changes were requested and completed to the main body of the report which did not change it's length but did provide some important recommendations about future monitoring. Attached is the "new" body of the Final Report, pages 1-13. There are no other changes in the attachments or maps found in the old report's pages 14-87.

To save paper, I have not re-copied the maps and attachments, pages 14-87, of the report in hopes that everyone will agree to just replace the main body of the report. If you need the entire report copied, please let me know.

Thank you to everyone for your patience and help in completing this document.

Sincerely,

Karen

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