

Bowdoin National Wildlife Refuge Salt Mitigation Impact Review

Open-file report to Montana Reserve Water Rights Compact Commission, Technical Advisory Team



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By: J.W. Bauder^{1/}, K. Hershberger^{2/}, and H. Sessoms^{2/}

^{1/} Professor of Soil and Water Quality

^{2/} Water Quality Research Associates

Department of Land Resources and Environmental Sciences
Montana State University, Bozeman, MT 59717-3120

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Chapter 1 Introduction

Overview of charge and arrangements with RWRCC Technical Team

In fall 2005, the Montana Reserve Water Rights Compact Commission (RWRCC) technical advisory team, under the direction of Stan Jones, contacted members of the Montana State University – Bozeman Extension Water Quality team (MSU-EWQ) and requested technical assistance in preparing science-based responses to selected questions and scenarios related to salinity and water management associated with the Bowdoin National Wildlife Refuge. Additionally, the RWRCC technical advisory team requested an independent assessment of consequences and impacts of various water and salinity management strategies pertaining to Bowdoin National Wildlife Refuge (Refuge).

The specific request of the RWRCC technical team to MSU-EWQ was to provide best professional judgment assessment and interpretation of potential impacts to the aquatic ecosystem of the Milk River, productivity of irrigated land and to short and long-term soil productivity downstream of the Refuge, resulting from various water management scenarios being considered in negotiations between stakeholder parties. The technical advisory team also requested opinions regarding various issues related to water chemistry, salt transport and migration, and lake bed sediments. RWRCC indicated that impartial, science-based interpretation and assessments were needed to guide the RWRCC in addressing stakeholder issues and concerns specific to the proposed water management scenarios. To guide the MSU-EWQ team effort and to articulate the issues and concerns that the RWRCC technical team sought input on, the RWRCC prepared a list of questions which were to be addressed on the basis of professional judgment, available data, prior experience, and published literature. The list of questions was prioritized, and an approach was developed by MSU-EWQ to provide quantifiable responses to issues identified as most important to moving ahead toward a negotiated solution to the situation of increasing salinization of Dry Lake, a component of the Bowdoin NWR. There was also some expressed concern about gradual salinization of Bowdoin Lake due to extended drought, increasing limitations on water available for flushing salts into Dry Lake, and introduction of salts to Bowdoin Lake through groundwater seepage, natural runoff, irrigation return flows, and weathering of lake-bottom sediments.

MSU-EWQ reviewed documentation and reports made available by the RWRCC technical team, US Fish and Wildlife Service (USFWS), and consultants contracted to work with the technical team. Subsequently, MSU-EWQ met with the technical team, USFWS representatives, the Refuge manager, and consultants for the technical team. MSU-EWQ then consulted with irrigation project managers for the USDI Bureau of Reclamation, which provides oversight, technical assistance, water management and contracting assistance to the irrigation districts along the Milk River. The purpose of the consultation was to gain additional information about mechanics of water management within the Milk River irrigation project, and particularly the Malta and Glasgow irrigation districts, in relation to

deliveries of water to the Bowdoin Refuge. After review of additional data provided or identified during the joint meeting, MSU-EWQ conducted an on-sight visit to Bowdoin Refuge. MSU-EWQ then met with Refuge manager, members of the Glasgow irrigation district, local area farmers-irrigators, and the Valley County Extension agent. Additionally, time was spent conducting a reconnaissance survey of the Malta and Glasgow irrigation districts, the Milk River and storage impoundments between Malta and Glasgow, and irrigation water delivery infrastructure.

Background

At the time of writing this document by MSU-EWQ, the RWRCC is negotiating a water rights settlement with USFWS Bowdoin National Wildlife Refuge. The RWRCC is utilizing a water and salt balance model to analyze alternative water management scenarios, including converting the refuge from a closed basin system to a flow-through system. Output from the model is to be used to aid in evaluation of various water management options for the Refuge. The scenario of a flow-through system, as proposed in initial discussions with the RWRCC technical team, was to release water of varying salt concentrations into Beaver Creek, a tributary to the Milk River. Due to lack of dilution capacity of Beaver Creek, modeling efforts are being undertaken with consideration for discharges from the Refuge to Milk River, at some confluence location downstream of discharges from Nelson Reservoir and upstream of Juneberg Bridge crossing (USGS HUC 06164510 Milk River at Juneberg Bridge).

MSU-EWQ subsequently submitted a proposal and scope of work to address the questions prepared by RWRCC technical team. Additional and/or modified questions and scenarios were also presented for consideration and are addressed in this report. The scope of work proposed by MSU-EWQ consisted of a prioritized approach to “assessing in a quantifiable manner key issues which seem most important to moving ahead toward a negotiated solution to the increasing salinization of Dry Lake, a component of the Bowdoin National Wildlife Refuge” (wording provided by the RWRCC technical team).

The following constitutes a list of questions identified by the RWRCC and presented to MSU-EWQ:

1. Roughly how much salt blows away by wind from the Dry Lake bed? Where does it go? How does wind transported salt affect soils, vegetation, and the hydrologic cycle in salt deposition areas? *Addressed in Chapter 2.*
2. What are the sources of salt that presently exist in the soils and water bodies of Bowdoin Refuge? What are contributing sources of salts to Bowdoin Refuge? *Addressed in Chapter 3.*

3. How much Refuge water can be released into the Milk River without adversely impacting downstream irrigators, aquatic values, or exceeding DEQ standards? *Addressed in Chapter 4.*
4. What are the likely impacts of accidental spills of Bowdoin NWR if salts are not released gradually? *Addressed in Chapter 5.*
5. What are the hazards to Bowdoin NWR and the downstream water users of doing nothing? *Addressed in Chapter 6.*
6. Will salts presently stored in sediments of Dry Lake and/or Lake Bowdoin leach or diffuse out and contribute salts to Beaver Creek or Milk River due to subsurface flow? *Addressed in Chapter 7.*

In response to the initial list of questions, MSU-EWQ proposed an approach to addressing the issues and providing quantifiable assessments of circumstances associated with the identified issues, based on currently available data. Considering time and budgetary constraints, the principal approach agreed to consisted of literature review, data search, data interpretation, analysis of existing data, and preparation of responses based on available data. It was agreed between MSU-EWQ and the RWRCC technical team that in some cases, responses to questions and scenarios would be predicated on RWRCC model generated salinity/mixing scenarios.

Deliverables

This written report specifically addresses the questions and scenarios presented by the RWRCC technical team and attempts to identify and quantify impacts of saline discharges from Bowdoin National Wildlife Refuge to the Milk River on irrigated crop production, soils, aquatic life, and native vegetation. Information in the report consists of professional opinions and quantifications of consequences of various water management scenarios, substantiated or supported by existing data, in addition to information gathered and assessed through literature review. No additional (original) data or statistics were generated or developed as a consequence of new field or laboratory research.

Overview of findings and processes specific to the Bowdoin Refuge salinity issue

In order to understand and analyze the salinity situation within Bowdoin NWR, specifically associated with Lake Bowdoin and Dry Lake, it was necessary to first investigate the nature, source, chemistry, and physiochemical behavior of salts that are likely present in the Bowdoin Refuge complex. Thus, the following is presented as a preface to findings and reporting resulting from MSU-EWQ investigations and studies.

A number of studies have been conducted under conditions similar in many aspects to the Bowdoin - Dry Lake circumstance. Probably the most relevant study of significance is that reported by Nimick (1997), which consisted of an extensive assessment of salinity

characteristics and behavior in Benton Lake National Wildlife Refuge. Benton Lake Refuge, managed by USFWS, is located approximately 10 miles north of Great Falls, MT, within Cascade County. Benton Lake Refuge is physiographically and climatically similar to Bowdoin Refuge, having similarly sourced geologic parent materials, similar climate, similar source water (to some degree), and having been managed with objectives and an approach similar to that adopted for the Bowdoin Refuge. Historically, the management approach used parts of Benton Lake Refuge as ‘sacrifice’ areas for transfer and temporary storage of salts. Additionally, flushing and dilution, via flooding and dispersal of salts through air-borne transport off-sight, have been experienced at Benton Lake Refuge.

Benton Lake, like Bowdoin Refuge, is a hydrologically isolated pool. Historically (before anthropogenic influence), the primary water supply to Benton Lake consisted of rainfall, snowmelt, and runoff from small ephemeral streams during flood events. Interestingly, since the establishment of the Benton Lake National Wildlife Refuge, significant inflows of water to Benton Lake Refuge come from diversions from Muddy Creek, a perennial stream with water partially sourced by irrigation-related diversions from the Sun River. Much like Bowdoin Refuge and Dry Lake, a significant issue of concern in the Benton Lake Refuge is salt accumulation within water bodies of the Refuge. Many of the principals pertinent to Benton Lake Refuge have direct application to the circumstances of the Bowdoin Refuge. Key points can be summarized as follows. Text in italics inserted below are provided by MSU-EWQ regarding the relevance of Nimick’s findings relative to Bowdoin Refuge.

1. Benton Lake has existed as a closed (*or semi-closed in the case of the Bowdoin and Dry Lakes*) basin water body since its formation during the most recent glaciation period and prior to anthropogenic (human) influence. Benton Lake continues to function as a closed basin water body, with no substantial mechanism for surface outflow. *It is reasonable to assume that Bowdoin Lake, Dry Lake, and the associated water impoundments of the Refuge existed as a closed (or semi-closed) basin lake since its formation during the same glaciation period. Only under circumstances of high-flow flood events within the Beaver Creek drainage, when surface waters were discharged to Bowdoin Refuge, have flushing events occurred. Even in those circumstances, the lower elevation of Bowdoin Refuge, relative to the Beaver Creek drainage, resulted in accumulation of water and salt in Bowdoin Refuge when floodwaters receded.*
2. Dissolved solids have been delivered to Benton Lake and various ‘managed’ pools of the refuge (*and similarly in the case of the Bowdoin Refuge complex*) through a generally continuous process, either by runoff from adjacent landscapes, as seepage discharged to the lake system, or as water pumped in from Muddy Creek (*or in the case of Dry Lake as overflow or discharge from Bowdoin Lake. Bowdoin Lake sources water from seepage, diversions from Dodson canal, surface runoff, and irrigation return flows*). More recently, (since development of the Greenfield’s Irrigation District, headquartered at Fairfield, MT), additional dissolved solids have been delivered to Benton Lake via diversions from Muddy Creek, a tributary to the Sun River. *A somewhat similar circumstance exists in Bowdoin Refuge, although occasional flood flows through Beaver Creek do provide a mechanism for some salt flushing from the Bowdoin Refuge complex.*

Most likely these flood-induced flushing events serve only to remove any salt-rich impounded water and/or salts accumulated on the lakebed surface or in the shallow surficial depths of soil in the lakebed.

3. Analyses of water samples and soil samples collected by Nimick (1997) and review of previously collected data revealed that in circumstances where water was discharged into a dry lakebed of Benton Refuge, resultant salinity values of water in the lakebed were higher than the inflow values and higher values occurred at the ends of pools farthest from the inflow point. Per Nimick: "These higher values probably resulted from pre-existing water that was pushed by inflowing water and from the initial dissolution of salts as the water was pushed over the dry lakebed. The general increase in specific conductance observed throughout the pools may have resulted from dissolution of salt crusts that had formed on the lakebed during the previous hot summer days."

In the Benton Lake report, Nimick (1997) wrote "... the amount of salt in many closed-basin lakes is much less than the total amount of salt delivered to the lake over the period of existence of the lake." This can be attributed to a number of circumstances. Nimick hypothesized that: 1) salts that precipitate in lakebed sediment as lake water evaporates are primarily sulfates and carbonates; 2) these salts form in the surficial lakebed sediments, i.e., close to the surface; 3) some of these salts are removed by wind erosion when the lakebed is dry (this mechanism has been previously reported); 4) when a pool or dry lakebed is reflooded (wetted), sulfate salts dissolve readily while only a small amount of the carbonates dissolve because the water quickly becomes saturated with respect to carbonates; 5) carbonates become sequestered in the lakebed sediments but sulfates do not; 6) other processes such as diffusion (into the pore water of the saturated zone below the lakebed floor), advection, and various ion-removal mechanisms (not defined) may also be important.

4. Nimick (1997) collected sediment and surficial salt crust samples from Benton Lake. He reported that these samples contained calcite (calcium carbonate) but no sodium-magnesium sulfates, and proposed that the presence of sodium-magnesium sulfates is indicative of evaporation at the surface, where more soluble salts are precipitated; if the soil or lakebed remains wet, the sodium-magnesium sulfates will remain in solution. *MSU-EWQ team members J. W. Bauder and K. Hershberger collected surficial salt crust and surficial soil samples from the southeastern end of Dry Lake, e.g., within the lake adjacent to the lake discharge point into a drainage way to Beaver Creek. Samples were dried and shipped to Agvise Laboratory, Northwood, ND, for analyses. The predominant salt precipitates in the samples consisted of sodium sulfate, consistent with that reported by Nimick (1997) for Benton Lake. Additional characterization of the samples is presented subsequently in this report.* Solubility of sodium-magnesium sulfate minerals decreases as temperature decreases. Additionally, freezing results in concentration of salts and greater likelihood of precipitation. The consequence of these two processes can enhance mineral precipitation in winter and form salt crusts susceptible to wind erosion.

Results of laboratory-controlled evaporation/salt precipitation experiments conducted by Nimick (1997) confirmed that sodium-magnesium sulfate minerals are the primary precipitates from Benton Lake water. The experiment also confirmed that carbonate minerals also precipitate, but to a lesser extent. *Geology, source water chemistry, and climatic conditions of Bowdoin and Dry Lake are similar to the conditions contributory to the salts of Benton Lake. Thus, it is reasonable to assume that the salt composition-signature and physio-chemical behavior of salts which Nimick (1997) reports for Benton Lake is characteristic of circumstances in the Dry Lake unit of Bowdoin Refuge. Sampling of surficial salt precipitates and soils within Dry Lake confirms this assumption.*

5. Nimick provides a summary of the processes contributory to salt deposition, salt movement, and salt removal from closed-basin systems such as Benton Lake (*and to a similar extent Dry Lake*). From Nimick (1997) “The primary components of the salt balance are inflow events, which (potentially) freshen the water while delivering additional salts; evaporation, which concentrates salt in the remaining lake water and leads to precipitation of evaporate minerals; and removal mechanisms, which cause salts to be lost from the lake or isolated in the lakebed.” Nimick states that “Several important removal mechanisms have been identified . . . , including burial, entrapment or sequestration (through precipitation) of salts in the lakebed sediments, removal of dry lakebed material by wind, advection of salts through subsurface basin leakage, and diffusion of concentrated lake water into the pore water in lakebed sediment.”

“Dissolved solids in pore water of lakebed sediment potentially could move vertically, either by movement of the pore water or by diffusion through pore water if hydraulic or concentration gradients were present (Kadlec, 1982).” Both upward movement of salts (due to evaporation at the surface) and downward movement of salts (during wetting events following dry lakebed conditions) can occur. This movement is likely limited to distances of 1 meter or less, due in part to extremely fine-grained sediments and the perennial presence of a saturated zone within 1 meter of the lakebed surface. In the Benton Lake study, no estimates of net movement of salts in either direction were made. *It is our professional opinion that neither significant net downward nor net lateral movement of dissolved salts occurs from Dry Lake due to the collective consequence of three circumstances: 1) extremely restricted saturated hydraulic conductivity due to sodium-induced dispersion of fine soil material; 2) geologic consolidation of glacially derived parent materials underlying the lakebed and perimeter landscape; and 3) continuous saturation of the subsoil materials, thus minimizing the hydraulic gradient. There is likely some lateral migration of salt beyond the wetted perimeter of Dry Lake. However, this migration is likely limited to less than a few hundred feet and occurs in response to increases or decreases in the static water table or water surface elevation in Dry Lake.*

Nimick wrote that a crude salt balance suggested salts are being removed from dry portions of Benton Lake via wind. *Although the MSU-EWQ team was not charged with completion of a salt balance, it is reasonable to conclude and substantiated by anecdotal*

reports that some salts are being removed from Dry Lake by wind. Additionally, "... no salt would have been lost to wind erosion after pool filling because the lakebed sediment was maintained wet...." Again, this is a reasonable assumption for Dry Lake as well.

These findings by Nimick have implications to Bowdoin Refuge. Nimick's observations substantiate that under long-term absence of flushing, salt removal by wind transport offsite does not likely result an equilibrium condition. Salinity levels will progressively increase in the water depositional area as the period of accumulation is extended. Thus, in the event that surplus water is discharged from Refuge impoundments into Dry Lake or flooding and flushing from Beaver Creek occurs, it is reasonable to expect that water exiting Dry Lake via drainways to Beaver Creek will be of significantly higher salinity than water entering Dry Lake. It is also reasonable to assume that the most saline water in Dry Lake will occur at locations farthest from the inflow source of flushing water and as the first flows exiting Dry Lake. This may have implications for 'managed flushing' events to reduce salts in Dry Lake, i.e., initial flushing may be most effective by minimizing flow volumes across the lakebed, thereby concentrating dissolved salts into smaller volumes for discharge down-gradient.

A significant distinction between Benton Lake and Dry Lake is that the latter is not a truly closed basin lake. Thus, if less salt is present than the total amount delivered to Benton Lake, it is reasonable to assume that significantly less salt is currently present in Dry Lake than has been delivered during the past period of management of Dry Lake as a salt repository. Based on additional information provided by Nimick (1997) and others, three mechanisms for salt removal or reduction in Dry Lake are likely: 1) eolian transport off the lakebed (wind erosion), 2) precipitation of relatively insoluble calcite salts within the lakebed sediments, and 3) periodic salt removal via flood and high flow flushing events into the Beaver Creek drainage. The following chapters will place Nimick's findings, along with other pertinent information, into the context of the six questions formulated by the RWRCC technical team.

Chapter 2

Wind blown salt

Question: Roughly how much salt blows away by wind? Where does it go? How does it affect soils, vegetation, the hydrologic cycle, and human health?

Circumstances conducive to eolian transport of salts from Dry Lake

In order to appreciate eolian transported salt movement from Dry Lake to downwind areas, it is important to understand the process and conditions that lead to both the presence of salt on the lakebed surface and erosion of the salt. Aggregation of information in a variety of science journal publications provides the basis for an overview of the sequence of events contributory to eolian transport of salt from dry lakebed surfaces such as Dry Lake.

1. The lakebed surface is wetted either as a result of snowfall and melt, rainfall, or inflow from adjacent ponds. A wetting (precipitation) or flooding event is antecedent to the window when eolian transport occurs.
2. The wetting event, if something other than rainfall or snowmelt, is a source of additional salt and will contribute to the salt crust subsequently susceptible to wind erosion.
3. Wetting solubilizes existing salts previously precipitated on the soil surface or integral to saline soil water within the shallow soil matrix.
4. Freestanding water is then removed from the surface via runoff, seepage below the surface, or evaporation, thereby exposing the lakebed to drying.
5. The surface is exposed to an extended period of drying conditions including low humidity, no rainfall, cloudless, possibly wind, and above freezing temperatures for an extended period of time (several days). Subsequent drying induces capillary rise of water and salts to the surface, concentrating salts in the remaining aqueous solution or soil water. With sufficient drying and concentration, salt precipitates from solution and crystallizes, resulting in the formation of an efflorescent, powdery salt crust.
6. Winds lift and remove salts from the lakebed (the wind both accelerates the drying process and causes initiation of saltation and air-borne salt crystals). Saltation, which is the rolling-bouncing-hopping along process of particle migration, causes additional disruption of the crystalline surface and fine soil particles as transported particles repeatedly fall back to the land surface.
7. With sufficient sustainable wind exceeding the threshold wind velocity (the wind speed at which particles become airborne), particles less than ten microns in diameter

(PM < 10 um) become airborne. These particles are then transported down gradient to some point where they settle out of the air.

8. Once a wetting-drying-eolian transport cycle is completed, additional wetting and increased wind conditions are generally required to reinitiate the eolian transport event.

It is possible to assign numeric values or specific criteria to circumstances that appear to result in eolian transport of lakebed salts. Defining criteria and associated metrics are summarized in Table 1.

Table 1. Criteria for circumstances which appear conducive to eolian transport of lakebed salts from Dry Lake, Bowdoin NWR.

Antecedent precipitation or wetting	Event of significant rainfall or wetting greater than 0.25 inches. This could be over-winter snowfall, spring or summer rain showers.
Initial drying and wicking	Extended frost-free period; air temperatures in excess of 32° F (more likely in excess of 60° F).
Period of drying, evaporation, and salt wicking to surface	5-7 consecutive days of warm, low humidity, fairly cloudless days with moderately gusty winds.
High wind circumstances	Wind speeds, either sustained or gusting, exceeding reported threshold wind velocities of 16.4 ± 1.5 miles per hour for periods of at least 1 hour.
Conditions with high likelihood of eolian transport of lakebed salts	Time period or window which is characterized as periods of low probability rainfall with extended periods of air temperatures above 60° F.
Wind direction	Wind direction from northwest-westerly to southeast-southerly.
Calendar periods of highest likelihood	Mid-June through early September

Applying these metrics to climate conditions of the Bowdoin and Malta area may indicate the number of annual events potentially conducive to eolian transport of salts from the Dry Lake bed. Complete weather records with all parameters of interest are not available for Bowdoin or Malta; therefore records for the Glasgow airport NOAA weather station were analyzed from 1997 to 2005. Based on these assumptions, conditions conducive to eolian transport occurred 2 to 8 times per year from 1997 to 2005 and 5 times per year on average. While the weather data from the Glasgow airport does not specifically represent conditions at Bowdoin Wildlife Refuge, it is reasonable to assume that similarities exist in occurrence of precipitation, air temperature, and occurrence of high-speed winds. Additionally, it was found that winds in the 16 mph range are common and abundant; hence precipitation appears to be the limiting factor for eolian transport conditions.

Literature and reliable circumstances

It is difficult to accurately quantify the amount of salt removed from Dry Lake annually via eolian transport, although it is well documented that salt transport from the lakebed occurs under some repeated circumstances. The suspicion that the amount of salt removed by eolian processes is significant is validated through personal observation, anecdotal evidence, and the work of Nimick (1997) on Benton Lake and by other researchers summarized here. To accurately estimate eolian salt transport from Dry Lake, a comprehensive baseline survey of Bowdoin NWR would be required along with detailed monitoring of inflow source quantity and chemistry. This data would need to be enhanced with additional sampling to complete a basin-wide salt balance. However, it is possible to present statistics from published literature to help gain a perspective of the magnitude of salt removal.

In Nimick's report (1997) on Benton Lake NWR, he describes an approach to identifying the fate of dissolved solids in the refuge. Nimick measured the magnitude to which precipitated salt concentration decreased during a period of wind-transported salt removal from the lake. Sediment samples were collected from a dry lakebed to determine what happens to lakebed salts when a pool is dry for most of the summer and no water (except precipitation) is added. Temporally repeated sampling of lakebed sediments during this dry period indicated a general decrease in concentration of soluble salts in the upper three-inch lakebed during the summer. As there was no appreciable rain during the study period, Nimick concluded that the measured decrease was attributable to removal of salt by wind. The median soluble salt decrease in 13 samples over a 3-month period was 810 mg/L, which was attributed to wind erosion. Nimick reported this to be equivalent to a decrease in soluble salts of 0.095 lb/ft² in the surficial lakebed sediments. Nimick also found that salt precipitates in lakebed sediments were primarily sulfates and carbonates. Carbonates are sequestered in the lakebed and sulfates are blown away. It is important to note that dissolved solid concentrations are not increasing in Benton Lake over time whereas dissolved solid concentrations are increasing in the Bowdoin complex.

Additional data from an Owens Dry Lake study in California (Tyler et al., 2000) reports seasonal wind transport of 0.5 lb/ft² salt from the dry lakebed. The Owens Dry Lake playa is large (~280 km²), surrounded by large expanses of wind-blown desert environment, and has a susceptible climatic environment for wind transport (dry and usually above freezing temperatures). The chemistry of the Owens Lake brine is dominated by sodium salts of carbonate, sulfate, and chloride (Friedman et al., 1976). These salts form a three to ten centimeter thick friable crust that is easily eroded by wind or sand saltation. Salt crust formation on the playa is a function of evaporation of underlying groundwater leading to precipitation of salts. This continuous process, along with environmental conditions and exposure of the salt flat, likely produce uncommonly large amounts of wind-blown salt.

A study conducted on Texas Double Lakes, a closed basin lake system in Texas, indicates approximately 0.02 lb/ft² of chloride are removed from the lake annually via eolian transport (Wood and Sanford, 1995). The significant difference between Texas Double Lakes and Owens Dry Lake (0.02 lb/ft² vs. 0.5 lb/ft²) is likely due to both physical and climatic differences between the two sites. Texas Double Lakes is an area of depressional basins,

inset as much as 200 feet in elevation below the prevailing landscape elevation whereas Owens Dry Lake is larger and surrounded by a wind-blown desert. Additionally, chloride was the solute chosen for analysis in the Texas study indicating that chloride is a major constituent within the basin. Chloride salts are known to form halite crusts and are generally less susceptible to wind erosion than sulfate salts.

In another relatable study, Argamon et al. (2006) state that severe dust storms in the Southern Aral Sea Basin have become common with the desiccation of the sea. These dust storms have had severe ecological consequences. Argamon attempted to identify deflatability properties of a number of soil and sediment surfaces of the Aral Sea. Many of the soils in the area are covered by three to five mm salt crusts formed by the capillary ascent of saline groundwater and evaporation at the soil surface. Threshold wind velocities of the four salt crusts examined ranged from 6.62 m/sec to 7.34 m/sec (14.8 to 16.4 mph). Results suggested that surface films formed in the presence of salt are most stable against wind erosion, indicative of a halite salt composition. Threshold friction velocity (TFV) is the friction velocity at which wind erosion is initiated. Argamon found that when surface films were ruptured, TFV decreased rapidly, and rapid removal of material by saltation started. Moistening the samples greatly increased their TFV.

The Wind Erosion Prediction System (WEPS) is a model that predicts soil erosion according to processes controlling wind erosion. WEPS can be used on a field or multi-field scale to predict soil loss/deposition including individual soil loss components of creep-saltation, suspension, and PM10 size fractions. The model uses wind speed criteria of 8 m/sec (18 mph) as a threshold wind velocity for determining if erosion can occur. Relevant data from these studies is summarized in Table 2.

Table 2. Summary of statistics quantifying eolian salt crust transport from various locations through the world.

Wind Threshold	Quantified salts removed	Salt crust thickness, composition	Dust deposition
Salt crust threshold wind velocity 7.34 ± 1.5 mps (Argamon et al., 2006)	Benton Lake: .095 lb/ft ² for 83 days in summer (Nimick, 1997)	Benton Lake: Sodium-magnesium sulfates primary precipitates (Nimick, 1997)	Dust deposition rates much higher within ~30 km downwind of playa. Plumes may reach 50 km, salt generally falls out within 35 km. Soluble salt content of dust deposition = 15-35% salt. (Reheis, 1997)
Exposed sea bottom threshold wind velocity 6.94 ± 0.39 mps (Argamon et al., 2006)	Owens Dry Lake: 10.8 ton/acre salt blown away annually (Tyler et al., 1997)	Owens Dry Lake: Sodium salts – carbonate, sulfate, chloride crusts of 3-10 cm thick (Tyler et al., 1997)	Owens Dry Lake: 20 – 70% of airborne dust composed of soluble salts (Tyler et al., 1997)
15 km/hr wind intensity necessary to transport particulates 0.10 to 0.154 mm diameter (Ortiz, 1990)	Texas Double Lake: 992,000 lb chloride removed from 5.0590×10^7 ft ² area/year (211 frost free days Lubbock Cty; 0.01961 lb/ ft ² annually) (Wood and Sanford, 1995)	Avg. thickness of salt/silt crust with very loose structure = 16.8 mm; 23.7% salt, the rest sediment (Hunink et al., 2004))	
16 mph typical threshold wind velocity for “everyday erosion” & 22 mph for dust storm events (World Meteorological Org.)		3-5 mm salt crust (Argamon et al., 2006)	

Blowing salt estimates

Attempts were made to derive estimates of wind-blown salt based on literature review, known criteria, limited assumptions, and reasonable calculations. Responses include estimates of wind-blown salt and air-borne salt dispersion patterns and how estimated quantities of blowing salts might impact soils, vegetation, and hydrology within the receiving area.

Numerous studies have been conducted attempting to characterize mechanisms and quantify circumstance-specific amounts of wind-transported salt from dry lakebeds, playas, and salt flats. Review of literature indicated a wide range in volumes of wind-transported salt under various circumstances (Table 3) and further confirms that eolian transport of salts is complex and specific quantification is likely unique to each circumstance.

Another approach to estimate salt removal is evaluation of various scenarios that might be representative of circumstances in Dry Lake. For instance, assuming that 1,000 acre feet of water a year are evaporated/evapoconcentrated in Dry Lake, with an inflow TDS of 6,000 mg/L, the salt load introduced to the surface of the lakebed (assuming all the salt precipitated and net loss to infiltration or drainage was negligible) would be approximately 16 million pounds, which equates to approximately 16,000 pounds of salt per acre. This would equate to 0.37 lbs/ft², which is greater than the figures available for Benton Lake or Texas Double Lake, but less than the value reported for Owens Lake. If all salt were removed via wind erosion, 8,000 tons of salt would be removed from Dry Lake.

An assumption-based approach might be to assume a wind erosion loss of 1/8th inch depth (0.32 cm) of accumulated salt per year. That would equate to 435 cubic feet of wind-eroded (fine particulate) salt per acre per year. If you further assume a loose salt layer bulk density of 0.25 g/cm³, approximately 7,080 lbs/acre of salt would be eroded via wind erosion per year. This would be equivalent to 3.5 tons/acre per year, or 3,850 tons/year from a 1,100 acre Dry Lake Bed.

According to the 1999 USGS report (Kendy, 1999), the simulated average annual salt flux into the Dry Lake Unit for 1990-1997 was 2,810 tons. Of that flux, 1,839 tons were delivered to Dry Lake Unit via transfers from other units. According to refuge staff and landowners, transfers to Dry Lake Unit have not been made for the past 10 years (approximately). If this is the case and the USGS estimates are accurate, it would suggest that approximately 971 tons of salt fluxed into Dry Lake annually since about 1997. Therefore, the total salt available for wind-erosion off the refuge from Dry Lake Unit would be less than 1,000 tons of salt per year. However, this cap seems small and may not account for salts stored within the Dry Lake bed potentially brought to the surface through the precipitation-evaporation-capillary rise process described.

Table 3. Wind-blown salt estimates from Dry Lake, Bowdoin NWR, based on reliable circumstances reported in the literature and MSU estimates based on assumptions.

Representative setting	Estimated seasonal salt removal by eolian process (total tons)	
	Dry Lake ^{1/} - complete lakebed area exposed	Dry Lake ^{1/} - 50% lakebed area exposed
Benton Lake: 0.095 lb/ft ² (Seasonal)	2,276 tons	1,138 tons
Owens Dry Lake: 0.50 lb/ft ² (Seasonal)	11,980 tons	5,990 tons
Texas Double Lake: 0.0196 lb/ft ² annually	469 tons	237 tons
Average	4,4908 tons	2,454 tons
MSU Extension estimate ^{2/}	3,850 to 8,000 tons	

^{1/}Assumes a full basin exposed lakebed area of approximately 1,100 acres.

^{2/}Based on select assumptions

Clearly, a wide range in estimates for wind-blown salt can be calculated, dependent on the assumptions applied to the calculation. Although it is not possible to assign an exact value to the amount of wind-transported salt that might be removed from Dry Lake during a ‘typical’ dry lakebed season, it is possible to gain an appreciation for the magnitude of salt removal.

Blowing salt deposition

It is likely that a significant component of wind-eroded salt from Dry Lake is deposited along a corridor parallel to the predominant wind direction. Anecdotal records and reports of significant salt transport events indicate that the predominant path of salt transport is south-southeast away from Dry Lake, although individual circumstances may dictate other directions of transport. Bureau of Reclamation AgriMet data for the Malta weather station (Table 4) reported a south-southwest mean wind direction for 2000 to 2006, which is generally in agreement with anecdotal records. The mean daily peak wind gust reported for the Malta AgriMet station easily exceeds the threshold wind velocity of approximately 16 mph outlined in the literature, indicating wind conditions conducive to eolian transport are common.

Table 4. Mean daily wind data for 2000 to 2006 for the Bureau of Reclamation, Malta AgriMet station.

Water Year (Oct.-Sept)	Mean wind direction (degrees)	Mean Daily Peak Wind Gust (mph)	Mean Wind Speed (mph)
2000	199.31°	22.89	5.93
2001	190.53°	22.89	6.19
2002	199.46°	24.37	6.63
2003	195.23°	22.48	5.91
2004	187.17°	23.07	6.43
2005	198.43°	23.41	6.27
2006	194.99°	23.21	6.47

Salt-rich dust from the Owens Dry Lake playa has been documented to travel in significant quantities to distances of at least 40 kilometers north and south of the playa (Reheis, 1997). Smaller, non-salt clay dust has been shown to travel more than 100 kilometers from the Owens Dry Lake playa. During one dust storm in the Owens Lake area, it was observed that many of the coarser salt particles dropped out of the plume within 35 kilometers of the source (MacKinnon et al., 1996). The long-term average distance of eolian transport of salts from the Double Lakes floor was estimated to be approximately 35 kilometers (21-22 miles). Chloride deposition patterns downwind from Texas Double Lakes indicate an exponential decline in chloride concentration with distance downwind from the lake floor (Wood and Sanford, 1995). The Double Lakes geography is somewhat of a pothole system on a semi-arid, prairie landscape (Wood and Sanford, 1995). The lakes are described as being incised 20 to 30 meters below the regional land surface, similar to Dry Lake of Bowdoin NWR.

Distance of significant transport and deposition is likely to be up to 10 to 20 miles, with some of the smaller grained particulate matter transported much farther distances. A large majority of air-borne salt is likely deposited within a matter of a several miles, particularly as the surface terrain roughens. Greater surface roughness and increasing terrain diversity result in a greater settling rate of particulate matter. The terrain roughens considerably to the southeast, south, and southwest, approximately three to five miles from the Dry Lake unit border. It is likely that the majority of deposition occurs in these few miles between the Dry Lake unit and the dry hills lying west and south of Bowdoin.

Transported salt affects on soils, vegetation, the hydrologic cycle, and human health in salt deposition areas

Prerequisite to discussion of salt effects on soils and vegetation is an understanding of salinity and sodicity. Salinity is often expressed as electrical conductivity (EC), but is also expressed as total dissolved solids (TDS). TDS is an expression of the amount of salt that would remain if a liter of water were evaporated to dryness (Hanson, 1999). Plants respond to the amount of TDS in the soil water. Measuring EC is a simple and practical way to

determine salinity. Soils with a saturated paste extract EC greater than 3,000 to 4,000 $\mu\text{S}/\text{cm}$ are considered saline. An important concept to recognize when dealing with salinity is that the EC of the soil saturation extract is approximately 1.5 to 3 times the salt concentration of the applied water with a 15% leaching fraction (CPHA, 1995). Salinity becomes problematic when an excess amount of soluble salts restrict the ability of a plant to withdraw water effectively from the surrounding soil (Bauder and Brock, 2001; Hanson et al., 1999; USDA NRCS, 2002; CPHA, 1995). At sufficiently high salinity concentrations, the osmotic gradient between soil water and plant root is reversed and plants become incapable of taking in water from the soil. As a consequence, elevated salinity levels decrease evapotranspiration (Chhabra, 1996). Salinity also influences the physical properties of a soil by acting as a soil flocculating agent and promotes a structurally stable soil (Buckland et al., 2002). Elevated electrolyte concentrations cause fine particles to aggregate, resulting in a pore size distribution that contains larger void spaces than a non-flocculated soil. A well-flocculated soil will exhibit good permeability and enhance the hydraulic conductivity of a soil. Soils with good aggregation will also shrink less than structureless soils, and will be less susceptible to cracking under field conditions (Mitchell and van Genuchten, 1992).

Sodium also affects soil structure, which relates directly to water holding capacity, water infiltration, hydraulic conductivity, and seedling emergence. The sodium adsorption ratio (SAR) is the calculation most often used to express sodium levels. SAR is defined as: $\text{Na} / \sqrt{((\text{Ca} + \text{Mg})/2)}$, where Na (sodium), Ca (calcium), and Mg (magnesium) are expressed in milliequivalents per liter (meq/L). Soil dispersion is the primary physical process associated with elevated sodium concentrations (Ayers and Westcott, 1976; Bauder and Brock, 2001; Brady and Weil, 1999; Chen and Banin, 1975; Frenkel et al, 1978; Hanson et al., 1999; Miller and Gardiner, 2001). Excessive amounts of exchangeable sodium can cause clay to swell, resulting in reduced permeability, which can significantly retard salt leaching (Hanson, 1999). An SAR of 12 or greater defines a sodic condition. Soil dispersion is most prevalent on smectitic-clay dominated soils, although silt-dominated soils frequently respond in this manner as well.

There is an interdependent relationship between EC and SAR whereby salinity can counterbalance sodicity. The relationship between salinity and sodicity is established in Ayers and Westcott (1976), which can be accessed in Appendix D.

Vegetation:

Particulate matter (depending on the composition) can damage vegetation both directly and indirectly. When exposed to particulates, plants may suffer increased disease, leaf cells may be damaged, yield and growth rates may be reduced, and plants may even die. Dust on leaves of crops, trees, and shrubs may inhibit photosynthesis and plant growth.

Salinity effects on vegetation are well known. Soil salinity concentrations above specific plant tolerances can result in reversal or interference of the osmotic gradient between plant roots and soil solution. When the osmotic potential of soil solution becomes equal to or greater than that within plant cells, the plant experiences a salinity induced drought. To increase osmotic potential within plant cells, the plant must expend more energy to produce

more solutes (Maas, 1984). This diversion of energy away from normal processes results in decreased plant growth. Salinity may result in poor stand development due to inhibition of germination, reduced growth rates, reduced yield, or in total crop failure in extreme conditions (Rhoades and Loveday, 1990). Additionally, depending on the constituents of the salt, it is possible that perennial forages act as bio-accumulators of constituents such as arsenic, selenium, and other trace elements.

Results from an unpublished test-plot study of Owens Dry Lake indicate that dust levels around the Owens Lake playa delayed recolonization of the outer edge of the playa by vegetation. Long-term deposition of playa dust in Nevada resulted in the “extension of salt-tolerant plant communities into areas that should otherwise support sagebrush dominated plant communities” (Young and Evans, 1986 from Reheis, 1997). Shifts in plant communities or decreases in crop yield have not been documented downwind of the Dry Lake Unit of Bowdoin. It is likely that producers are advertently or inadvertently providing adequate irrigation-induced leaching to compensate for added salinity from dust deposition.

Soils:

The majority of soils along the Milk River corridor from Saco to Nashua are loams and clays according to soil surveys of Phillips and Valley counties. Most of the clays inventoried have a moderate to high shrink/swell potential, characterizing them as smectitic. Smectitic soils are highly susceptible to sodium-induced dispersion. Therefore, there is a reasonable likelihood that salts blown from the Refuge could result in sodium-dispersed soils in depositional areas, resulting in reduced infiltration rates and hydraulic conductivities. Sodic soils have been reclaimed through the use of soil amendments. Standard reclamation of sodic soil conditions requires a continuous supply of calcium or magnesium cations to counteract the sodium (generally applied in the form of gypsum) along with sulfur application to reduce pH and increase gypsum solubility.

Hydrologic cycle:

Salt deposition may be affecting the hydrologic cycle in and around Bowdoin Wildlife Refuge through sodium-induced dispersion of soils and associated reductions in infiltration, hydraulic conductivity, and increased run-off.

Human health:

Particulate matter is a collective term used for very small solid particles found in the atmosphere. The effect of particulates on human health and the environment varies with the physical and chemical makeup of the particulates. A major human health related characteristic of particulate matter is particle size. Particles can range in diameter from 0.005 to 500 micrometers or microns (μm). Particles less than 2.5 μm in diameter are known as ‘fine’ particles; those larger than 2.5 μm are known as ‘coarse’ particles. Fine particles with diameters of less than 1 μm can be transported 1,000 kilometers or more from their source. Under the influence of gravity, larger particles do not remain suspended and tend to settle out of the air, sometimes creating localized areas of high particle deposition. Of particular interest are particulate matter less than 10 micrometers in diameter, referred to as PM-10. PM-10 is responsible for most of the adverse human health effects of particulate matter

because of the particles' ability to reach lower regions of the respiratory tract. In general, respiratory defense mechanisms are able to remove 99 percent of particles larger than 10 μm from the inhaled air stream. Smaller particles ($> 2.5 \mu\text{m}$), called inhalable, can cling to protective mucous and can be removed in the upper respiratory system. Fine particles ($< 2.5 \mu\text{m}$), also called respirable, can enter the lungs and end up in lung capillaries and air sacs. Carcinogenic compounds and heavy metals such as arsenic, selenium, cadmium, and zinc can also be concentrated in these particulates.

Numerous studies have linked particulate matter, especially fine particles, with a number of significant health issues including:

- Premature death;
- Respiratory related hospital admissions and emergency room visits;
- Aggravated asthma;
- Acute respiratory symptoms including aggravated coughing and difficult or painful breathing;
- Chronic bronchitis;
- Decreased lung function and shortness of breath.

EPA particulate matter standards have been established for 24 hour and annual averaging times (EPA, 1997). The standards for PM-10 are:

- Annual standard of 50 micrograms per cubic meter;
- 24-hour standard of 150 micrograms per cubic meter.

Studies indicate that air quality downwind of playas may not meet these standards. For instance, extensive drying of the Aral Sea in Central Asia has exposed large portions of the former seabed. Enormous dust storms originate from the area containing large amounts of salts and deposition causes water bodies and agricultural lands to become severely salty. Results of a laboratory experiment indicated that silty soil had the greatest potential for being a source of severe dust storms (Singer et al., 2003). The highest amount of PM-10 dust was 579.3 mg/m^3 generated from a silty soil. The lowest amount of PM-10 dust was from salt crust material (30.6 mg/m^3). Salt crusts from the desiccated Aral Sea bottom generated intermediate amounts of dust. Salt crusts in the study seemed to generate much lower PM-10 dusts, possibly due to the dense interlocking matrix of the halite salt crystallites. However, PM-10 dust concentrations from both materials listed greatly exceed EPA standards.

Additionally, large dust storms in the Owens Dry Lake area are known to exceed PM-10 air quality standards. PM-10 concentrations have been known to exceed air quality standards by as much as 23 times (Reheis, 2006). Moreover, aerosols sampled from Owens dust storms commonly contain significant amounts of arsenic concentrated in the <10 micron fraction (Reheis, 2006). While Owens Dry Lake may represent an extreme condition, results from these studies along with anecdotal evidence suggest that EPA air quality standards have been exceeded downwind of the Dry Lake Unit of Bowdoin Wildlife Refuge.

Chapter 3

Sources and composition

Question: What are the sources of salt that presently exist in soils and water bodies of Bowdoin Refuge? What are contributing sources of salts to Bowdoin Refuge?

As a means of understanding the composition and sources of salts in the Bowdoin Refuge complex, a literature review, data search, and analysis of existing data was completed. Based on that information, we have attempted to define the likely sources and quantify the relative contributions of sources of salt entering Bowdoin National Wildlife Refuge under the present management program.

A detailed and thorough assessment was completed for the following data sources:

- USGS data for Milk River and contributing streams upstream of Malta
- USGS data for Beaver Creek
- USGS and MBMG GWIC data for springs, wells, and private sources in Blaine, Phillips, and Valley counties
- Data gathered by the staff of Bowdoin Refuge and the MT-DNRC
- Private well test data from MSU Extension Well Test program
- Data from USGS study of Benton Lake
- Sediment and water samples collected from Lake Bowdoin and Dry Lake

Primary composition of salts in Dry Lake and associated health risks

As previously noted, the circumstances of Benton Lake National Wildlife Refuge provide a good starting point for addressing issues of salinity in the Bowdoin National Wildlife Refuge. Nimick (1997) provides a very detailed review of salinity circumstances of Benton Lake refuge, identifying the primary composition of salts in water of the Benton Lake Refuge as sodium-magnesium sulfate (very soluble) and magnesium-calcium bicarbonate (occurring only in aqueous phase) minerals. The primary ions in precipitation-induced runoff are magnesium, sodium, and sulfate. All of these minerals, with the exception of calcium carbonate formed on evaporation of calcium bicarbonate, are relatively soluble, and will redissolve from the lakebed if a dry pool is reflooded or wetted.

To determine the composition of salts in sediment and wind-transported fine material, Nimick (1997) collected sediment and surficial salt crust samples from Benton Lake. He reported that these samples contained calcite (calcium carbonate, i.e., limestone) but no sodium-magnesium sulfates. Calcium sulfate combined with sodium bicarbonate yields carbonate and sodium sulfate, which result in an increase in alkalinity. Nimick proposed the following sequence of circumstances and events:

1. Sodium-magnesium sulfates are indicative of evaporation at a wet soil surface or fringe of standing water, where more soluble salts are precipitated. If the soil or lakebed remains wet, sodium-magnesium sulfates will remain in solution.
2. Solubility of sodium-magnesium sulfate minerals decreases as temperature decreases. Additionally, freezing results in concentration of salts and a subsequent increase in likelihood of precipitation. The consequence of these two processes can enhance mineral precipitation in winter and form salt crusts susceptible to wind erosion.
3. Results of laboratory-controlled evaporation/salt precipitation experiments demonstrate that sodium-magnesium sulfate minerals are the primary precipitates from (Benton) lake water. The experiment also demonstrated that carbonate minerals also precipitate, but to a lesser extent.
4. Geology, source water chemistry, and climatic conditions of Bowdoin and Dry Lake are similar to conditions contributory to the salts of Benton Lake. Thus, it is reasonable to assume that the salt composition and physio-chemical behavior of salts which Nimick (1997) reports for Benton Lake are characteristic of the Dry Lake unit of Bowdoin Refuge. Sampling of surficial salt precipitates and soils within Dry Lake confirmed this assumption.

In March, 2006, MSU-EWQ team members J. Bauder and K. Hershberger collected surficial salt crust and surficial soil samples from the southeastern end of Dry Lake adjacent to the lake discharge point into a drainage way to Beaver Creek. Samples were dried and shipped to Agvise Laboratory, Northwood, ND, for analyses. The predominant salt precipitates in the samples consisted of sodium sulfate, consistent with that reported by Nimick (1997) for Benton Lake (Table 5). Additional characterization of the samples is presented subsequently in this report.

Carbonate minerals are relatively insoluble, especially compared to magnesium and sodium sulfates (Nimick, 1997) and precipitation of carbonate minerals results in the accumulation of carbonate minerals in lakebed sediments. Because analyses reported in Table 5 were completed on extractable-dissolved constituents, carbonate is minimal. The carbonate minerals that form as lake water evaporates do not readily or completely redissolve when a pool is refilled. Therefore, when a pool is refilled with natural runoff, the inflowing water becomes saturated with respect to carbonate minerals after only a portion of the available carbonates dissolve. When a pool is refilled with pumped water, no carbonates dissolve because pumped water is saturated or oversaturated with respect to carbonate minerals.

Table 5. Summary of surficial salt crust and soil sample analysis for samples collected from the vicinity of the discharge point of Dry Lake to a drainage way to Beaver Creek.

Constituent or parameter	Measured concentration/value
pH	7.9
calcium (Ca)	110 mg/l
magnesium (Mg)	46 mg/l
sodium (Na)	2910 mg/l
hardness	466 mg/l equivalent CaCO ₃
specific conductance	11,040 µS/cm
total dissolved solids (calc)	7066 mg/l
sodium adsorption ratio (calc)	58.87
carbonates	0.00 meq/l
bicarbonates	5.46 meq/l
sulfate-sulfur	2178 mg/l
chloride	28.0 mg/l

In summary, the principal salts in sediments, water accumulated in pools, and/or derived from source water are: sodium sulfate, sodium bicarbonate, calcium carbonate, calcium and magnesium sulfate, minor amounts of chloride salts, and minor but measurable fluoride salts.

Sources of salt to Bowdoin NWR

The principal sources of water to Bowdoin Refuge are sourced from Dodson Canal, irrigation return flows, and runoff and seepage from adjacent agricultural lands. The principal salts in these sources are sodium sulfate and bicarbonate, calcium carbonate (resulting from precipitation, but not found in solution form), calcium x magnesium sulfate, and lesser amounts of chloride, fluoride, and boron salts. Sodium-magnesium sulfate and magnesium-calcium carbonate minerals would be the primary precipitates produced from diverted water. Major ions in natural runoff are primarily magnesium, sodium, and sulfate. All of these minerals, with the exception of calcium carbonate, are relatively soluble and will dissolve from the lakebed if a dry pool is flooded or wetted.

Sodium, although sourced in part from water diverted from Dodson Canal to the Bowdoin Refuge complex, is also sourced from geologic accumulations, surrounding soils, and groundwater entering water bodies of the Refuge via seepage. The low ratio of sodium to

other cations in diverted water, relative to the high ratio of sodium to other cations in lake bottom sediments and remnant water of Dry Lake, suggests a progressive increase in soluble sodium and precipitation of less-soluble calcium and magnesium salts in the refuge. High SAR data of Dry Lake salt crusts and precipitates indicates a predominance of sodium, most likely sourced from seepage, irrigation return flow, lake bottom sediments, and geologic sources.

In summary, Dry Lake salt deposits are predominantly sodium-magnesium sulfates, similar to those reported by Nimick (1997). This signature suggests that the principal source of salts to soils and water bodies of Bowdoin Lake and Dry Lake is the predominant source of water to Lake Bowdoin, along with geologic material sourced from underlying and adjacent soil material. Nimick identifies several contributing sources to Benton Lake that appear to be applicable to the Dry Lake component of Bowdoin Refuge. Those sources include accumulations of salts from water diverted from Dodson canal, evapoconcentrated in Bowdoin Lake, and subsequently discharged over time to Dry Lake; irrigation return flows (although these appear to be relatively minor in scale), and seepage and surface drainage from adjacent wetlands and dryland cropped agricultural lands. It is likely that a significant portion of salts found in Dry Lake are sourced from the underlying soil parent material which is glacially derived till, with a significant saline component.

Chapter 4

Discharge feasibility

Question: How much Refuge water can be released into the Milk River without adversely impacting downstream irrigators, aquatic values, or exceeding DEQ standards?

In order to address this task, MSU-EWQ completed a literature review, data search, and analysis of existing data. A review of existing regulations and discharge permitting requirements was completed, along with assessment of permitted discharges of salt and/or sodium impaired water to surface waters of the state. MSU-EWQ reviewed three circumstances similar in nature to potential releases from Bowdoin NWR to the Milk River including regulations and rules specific to coalbed methane production water discharges to the Powder and Tongue Rivers, saline-sodic water releases from Priest Butte Lake to Teton River, and numeric water quality targets for salinity and sodicity set for Muddy Creek and the Sun River. The Priest Butte Lake discharge to the Teton River is similar in many regards to circumstance of the Bowdoin complex. The RWRCC technical team and consultants provided MSU-EWQ one water release scenario for review. Additionally, MSU-EWQ made some ‘reverse-engineered’ assessments. Based on scenarios of flows in the Milk River and irrigation water requirements, possible discharge allowances from the Bowdoin complex to Milk River were ‘reverse’ calculated. Water quality confines were established to be ‘protective’ for beneficial use, based on information about currently irrigated crops and soils downstream of Nelson Reservoir.

Current rules, regulations, permitting and discharge requirements in place in surface waters of Montana

The general approach to developing in-stream standards protective of existing beneficial uses is: 1) assess currently existing beneficial uses and define standards and criteria which are protective of those existing uses (crop, plant, aquatic species sensitivities, soil susceptibilities); 2) assess ambient in-stream conditions during those time periods when such waters are put to beneficial use or for those circumstances related to subsequent beneficial use (i.e., in-stream storage, bank storage); 3) assess the level to which existing conditions support beneficial use; and 4) assess the level to which pre-existing conditions have supported beneficial use. On the basis of these assessments, it is possible to define both protective narrative and numeric standards. Based on existing in-stream flow and water quality data, it becomes possible to assign numeric values to quality and quantity discharge allowances resulting in mixed flows protective of present and projected beneficial uses.

Neither salinity nor sodicity standards have been established for the Milk River, a principal beneficial use of which is irrigation. Dean Asham, DEQ Water Quality Division, suggested a good starting point for investigating discharge allowances from Bowdoin Refuge into the

Milk River would be the Montana DEQ-Board of Environmental Review Record of Decision pertaining to in-stream standards for salinity and sodicity and discharges of saline and sodic water into surface water bodies of southeast Montana. Review of the Records of Decision provides guidance with respect to salinity, sodicity, and non-degradation criteria. Dean suggested that acceptable standards for salinity and sodicity in the Milk River would likely be something comparable to the standards established for the Tongue and Powder Rivers. The following serves as an overview of current standards for beneficial use of surface waters of Montana.

1. MT-DEQ is the entity responsible for water quality permitting.
2. Enacting authority assigned to DEQ comes from Montana Water Quality Act (Title 75, Chapter 5, MCA), which regulates the discharge of pollutants into state waters through adoption of water quality standards and a permit process.
3. State water is defined as any body of water, irrigation system, or drainage system, on the surface or under ground, except ponds and lagoons used solely to treat, transport, or impound pollutants; and irrigation water that is used up and not returned to state water.
4. DEQ's water quality standards program has two levels of protection: 1) protection of designated uses of water, and 2) prevention of significant degradation of high quality waters.
5. Two issues needing to be addressed with respect to potential discharges to the Milk River are: 1) protection of designated uses from the perspective of plants and crops, ambient water quality, and soil conditions; and 2) in order to accomplish protection of the designated uses of water, state waters are classified according to the uses they are capable of supporting. Thus it will become necessary to define the uses Milk River is capable of supporting.
6. Standards designed to protect specific uses need to be applied to waters when assessing actions which will impact water quality.
7. Under those circumstances where 'non-degradation' is applicable, significance levels are established for new or increased discharges. If a proposed discharge would exceed the significance level, the discharger must apply for an authorization to degrade under 75-5-303, MCA.
8. The discharge of a pollutant (EC and SAR are considered pollutants under new rulings) to a state water requires a MPDES permit from DEQ. Through issuance of the MPDES permit, DEQ must require compliance with state water quality standards, including nondegradation requirements, and requires monitoring to ensure compliance.

9. In those circumstances where standards and numeric criteria are not specifically declared, i.e., for other constituents besides salinity and sodicity, the state's numeric and narrative water quality standards and non-significance criteria, which are applicable to those constituents generally, are applicable to discharge of water, effluent, and pollutants.
10. Before discharging water to state surface waters, a person (entity) must apply for and obtain a DEQ determination of whether the proposed discharge is non-significant under non-degradation significance criteria contained in the water quality rules. The rule authorizes DEQ to impose limits or conditions on discharges to ensure that all water quality standards, including Montana's non-degradation requirements, will be met. The rule further provides that the DEQ non-significance determination is not required if the person has applied for an MPDES discharge permit.
11. Produced Water General Discharge Permit, issued through the MPDES program, will be required for discharges of water from a constructed impoundment that is not located in ephemeral, intermittent, or perennial drainages, or the alluvial deposits underlying floodplains and terraces of these drainages. Impoundments must be sized to contain a normal volume of water plus a 25-year, 24-hour precipitation event. Limits are prescribed for effluent, and the quality of the impoundment water must be monitored. No permit is required for impounded water that infiltrates into ground water.

The Board of Environmental Review, Montana Department of Environmental Quality, issued a Record of Decision enumerating criteria of nondegradation established to be protective of beneficial uses of water for irrigation, dated April 25, 2003 (detailed above). The Record of Decision is specific to ARM 17.30.670 and 17.30.1202 pertaining to nondegradation requirements for EC and SAR for streams in the Powder River and Tongue River basins (Table 6). Although the nondegradation rules were developed for the purpose of management of water produced in conjunction with coalbed methane extraction, the information and decisions have relevance to the possibility of discharges from Bowdoin Lake complex to the Milk River.

Administrative rules indicate that numeric standards have been established for EC and SAR, and these two water quality parameters have been designated as harmful parameters with protection of beneficial uses, namely irrigation. The 2006 Record of Decision declares that if a change in EC and/or SAR of a receiving water body into which discharged water with an EC or SAR deemed significant under the harmful category occurs, the party or entity discharging would need an authorization to degrade prior to discharging. Further, the Record of Decision implies that degradation is defined as the circumstance when a discharge exceeds the numeric standard by 10% of the numeric standard. The Record of Decision also implies by the rule-making that degradation occurs when the ambient water quality in the stream at the end of the mixing zone below the point of discharge is 40% of the standard or above. Under either of these two conditions, no additional discharge is allowed without an authorization to degrade. The function of the numeric standard is to quantify a pollutant

level determined to be protective of designated uses, whereas the purpose of the nondegradation rule is to protect the increment of ‘high quality’ that exists between ambient water quality and the numeric water quality standard. The non-degradation criterion provides a margin of protection of the standard.

Table 6. EC ($\mu\text{S}/\text{cm}$ or mmhos/cm) and SAR standards for irrigation and non-irrigation seasons Powder River and Tongue River basin, Montana.

	Powder River		Tongue River		Tongue River Tributaries	
	EC ($\mu\text{S}/\text{cm}$)	SAR	EC ($\mu\text{S}/\text{cm}$)	SAR	EC ($\mu\text{S}/\text{cm}$)	SAR
2 March-31 October – Monthly average	2,000 (1,280)*	5.0	1,000 (640)*	3.0	500 (320)*	3.0
2 March-31 October – Maximum	2,500 (1,600)*	7.5	1,500 (960)*	4.5	500 (320)*	4.5
1 November- March Monthly average	2,500 (1,600)*	6.5	1,500 (960)*	5.0	500 (320)*	5.0
1 November- March Maximum	2,500 (1,600)*	9.75	2,000 (1,280)*	7.5	500 (320)*	7.5

* () approximations of TDS, based on relationship of $\text{TDS} = \text{EC} \times 0.640$.

Additional standards for other parameters are specified in Circular DEQ-7, Montana Numeric Water Quality Standards. DEQ-7 contains the surface water aquatic life and human health standards, and the ground water human health standards and is revised on an "as need" basis. DEQ-7 dated February 2006 is the most recent version.

Further perspective on standards for discharges that may be saline and/or sodic to waters of the state used for irrigation can be gained from information specific to Freezeout Lake, Priest Butte Lake, and permitted discharges to the Teton River. Although the Teton River TMDL (MT DEQ, 2003) does not set a specific limit on the salinity or sodicity of permitted discharges, the TMDL does specify that discharge from Priest Butte Lakes into the Teton River must be maintained such that the combined flow below the monitoring point (below the confluence of the discharge from Priest Butte Lake into Teton River and below the mixing zone) “not exceed 1,000 $\mu\text{S}/\text{cm}$ (or 700 mg/L) measured in the Teton River at the state highway 221 bridge”. Monitoring in the Teton River is completed upstream and downstream of the discharge point three times per week. Discharge from Priest Butte Lakes into the Teton River is adjusted based on the measured EC levels (MT DEQ, 1999). This approach establishes an in-stream standard below the discharge that requires continuous monitoring and/or the use of a prescribed flow-weighted mixing calculation to project allowable discharges from Priest Butte Lakes into the Teton River.

The Teton River TMDL specifically declares, “salinity targets for the Teton River have been developed with the same approach as used in the Powder and Tongue River of Montana but

have been tailored to the Teton watershed” (MT DEQ, 2003). Irrigation is the most sensitive use regarding salinity for the Teton River. Targets are intended to protect riparian plants and crops growing in the watershed now and those that are likely to be grown in the future. Crops are alfalfa, barley, wheat, and grass with alfalfa. In general, these targets are based on the salinity tolerance of the predominant and most sensitive irrigated crop, that being alfalfa. In the Teton River TMDL, the soil water threshold EC for alfalfa is 2,000 $\mu\text{S}/\text{cm}$. Taking into account the leaching fraction, in situ concentration due to evapotranspiration/evaporation, and a precipitation correction, the maximum EC value for river water without affecting alfalfa yield is 1,716 $\mu\text{S}/\text{cm}$. Additionally, targets are also established with an upper threshold limit to protect aquatic life. Table 7 is a summary of the salinity targets for the Middle and Lower Teton River.

Table 7. Salinity targets for the Middle and Lower Teton River established in the 2003 Teton River TMDL.

Parameter	Value	Time	Value Description
TDS	820 mg/L	May 1-September 30	Seasonal average
EC	1,000 $\mu\text{S}/\text{cm}$	May 1-September 30	Seasonal average
TDS	1,145 mg/L	All year	Instantaneous maximum
EC	1,400 $\mu\text{S}/\text{cm}$	All year	Instantaneous maximum

A similar approach is that established for the Sun River and Muddy Creek. In-stream standards have been set for Sun River and Muddy Creek as follows: 1,000 $\mu\text{S}/\text{cm}$ EC (660 mg/l TDS) average during the irrigation season (May 1 – September 30); 1,400 $\mu\text{S}/\text{cm}$ EC (960 mg/l TDS) year round average based on field corn. Correspondingly, permitted discharges need to be managed such that standards are not exceeded.

Historic salinity and sodicity of the Milk River

Water quality data were gathered from the USGS and the DNRC to determine historic salinity and sodicity levels within the Milk River. The following tables are aggregations of available salinity and sodicity data with associated flows for the Milk River.

Table 8 depicts average EC and SAR data for Milk River USGS stations with corresponding flows for the period of record. The year was broken down into four periods: January thru March represents baseflow conditions (and presumed not be influenced by rainfall, runoff, or irrigation return flows). April and May represent a period of spring snowmelt, runoff, and high rainfall. June thru August represent the irrigation season and September thru December represent a period of stream recharge and return to baseflow conditions.

Tables 9 and 10 depict average EC and SAR data with the associated flows at USGS stations along the Milk River for the irrigation and non-irrigation season. The defined irrigation season runs from April 1st to October 1st and provides a cushion of time pre and post typical irrigation dates. Non-irrigation season includes the period from October 2nd to March 31st.

Average water quality data for the Milk River during the irrigation and non-irrigation season were also collected by the DNRC. Tables with this data (EC, SAR, and associated flow) are included within the Appendix A.

Table 8. Average EC ($\mu\text{S}/\text{cm}$) and SAR data from Milk River USGS stations for four periods: Jan.-March baseflow; April-May snowmelt, runoff, and rainfall; June-Aug. irrigation season; Sept.-Dec. recharge and baseflow.

STATION	JANUARY-MARCH	APRIL-MAY	JUNE-AUGUST	SEPTEMBER-DECEMBER
USGS 06155030 Milk River near Dodson 1982-2004	EC – 765 $\mu\text{S}/\text{cm}$ SAR – n/a Flow – 1011 cfs	EC – 715 $\mu\text{S}/\text{cm}$ SAR – n/a Flow – 294 cfs	EC – 589 $\mu\text{S}/\text{cm}$ SAR – n/a Flow – 328 cfs	EC – 878 $\mu\text{S}/\text{cm}$ SAR – n/a Flow – 746 cfs
USGS 06164510 Milk River at Juneberg Bridge 1977-2004	EC – 1110 $\mu\text{S}/\text{cm}$ SAR – 4 Flow – 971 cfs	EC – 957 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 893 cfs	EC – 826 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 676 cfs	EC – 1181 $\mu\text{S}/\text{cm}$ SAR – 4 Flow – 280 cfs
USGS 06172000 Milk River near Vandalia 1969-1987	EC – 1128 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 1295 cfs	EC – 880 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 719 cfs	EC – 837 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 625 cfs	EC – 1209 $\mu\text{S}/\text{cm}$ SAR – 4 Flow – 133 cfs
USGS 0617230 Milk River at Tampico 1973-2004	EC – 1014 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 1299 cfs	EC – 937 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 1131 cfs	EC – 898 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 512 cfs	EC – 1195 $\mu\text{S}/\text{cm}$ SAR – 4 Flow – 184 cfs
USGS 06174200 Milk River near Glasgow 1969-1973	EC – 1352 $\mu\text{S}/\text{cm}$ SAR – 4 Flow – 208 cfs	EC – 811 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 1327 cfs	EC – 912 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 397 cfs	EC – 1160 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 161 cfs
USGS 06174500 Milk River at Nashua 1959-2004	EC – 1252 $\mu\text{S}/\text{cm}$ SAR – 4 Flow – 1435 cfs	EC – 1021 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 1647 cfs	EC – 1037 $\mu\text{S}/\text{cm}$ SAR – 3 Flow – 620 cfs	EC – 1339 $\mu\text{S}/\text{cm}$ SAR – 4 Flow – 249 cfs

Table 9. Average EC ($\mu\text{S}/\text{cm}$) and SAR with associated flow in the Milk River at USGS stations of interest during the irrigation season: April 1st to October 1st.

Station	Average EC ($\mu\text{S}/\text{cm}$)	Average SAR	Average Flow (cfs)	n	Date Ranges
USGS 06155030 Milk River near Dodson	665	n/a	556	84	1983-90, 1992-2005
USGS 06164510 Milk River at Juneberg Bridge	883	3	731-EC data 734-SAR data	126-EC 79-SAR	1978-93, 1995-96, 1998-2005-EC 1978-93-SAR
USGS 06155900 Milk River at Cree Crossing near Saco	1084	n/a	149	21	2000-05
USGS 06172000 Milk River near Vandalia	875	3	629-EC data 709-SAR data	60-EC 53-SAR	1969-73, 1982, 1984, 1986-EC 1969-73-SAR
USGS 0617230 Milk River at Tampico	935	3	671-EC data 1151-SAR data	97-EC 32-SAR	1973-77, 1987- 2005-EC 1973-77-SAR
USGS 06174200 Milk River near Glasgow	872	3	675-EC data 278-SAR data	27-EC 12-SAR	1969-73-EC 1970-73-SAR
USGS 06174500 Milk River at Nashua	835	4	1045-EC data 841-SAR data	233-EC 159-SAR	1959-2005-EC 1959-94, 1999- 2003-SAR

Table 10. Average EC ($\mu\text{S}/\text{cm}$), SAR, and associated flow for the Milk River at USGS stations of interest during the non-irrigation season: October 2 – March 31.

Station	Average EC ($\mu\text{S}/\text{cm}$)	Average SAR	Average Flow (cfs)	n	Date Ranges
USGS 06155030 Milk River near Dodson	843	n/a	590	60	1982-2003
USGS 06164510 Milk River at Juneberg Bridge	1190	4	569-EC data 246-SAR data	119-EC 71-SAR	1977-2005-EC 1977-93-SAR
USGS 06155900 Milk River at Cree Crossing near Saco	1006	n/a	387	16	2000-2005
USGS 06172000 Milk River near Vandalia	1212	4	782-EC data 312-SAR data	59-EC 48-SAR	1969-73, 1982-87-EC 1969-73-SAR
USGS 0617230 Milk River at Tampico	1129	3	829-EC data 532-SAR data	82-EC 31-SAR	1973-77, 1987-2004- EC 1973-77-SAR
USGS 06174200 Milk River near Glasgow	1300	4	178-EC data 143-SAR data	22-EC 10-SAR	1969-73-EC 1970-73-SAR
USGS 06174500 Milk River at Nashua	1359	4	785-EC data 686-SAR data	142-EC 92-SAR	1960-64, 1967, 1969, 1974-2005-EC 1960-64, 1967, 1969, 1974-94, 1999, 2001- SAR

The following Figure 1 is a plot of EC ($\mu\text{S}/\text{cm}$) as a function of date for four of the USGS stations along the Milk River: Milk River at Cree Crossing near Saco, Milk River at Juneberg Bridge, Milk River at Tampico, and Milk River at Nashua. Data plotted includes all data available for the period of record for the four stations. EC ranges from 500 to 2000 $\mu\text{S}/\text{cm}$ throughout the year. Salinity is lowest during irrigation season, when flows within the river would be the greatest. As noted in the figure, EC values were excluded when flows exceeded 1000 or 2000 cfs. Exceedences of these values were considered flood conditions. EC values measured during these circumstances underestimate average EC likely to occur in the river during the majority of the year.

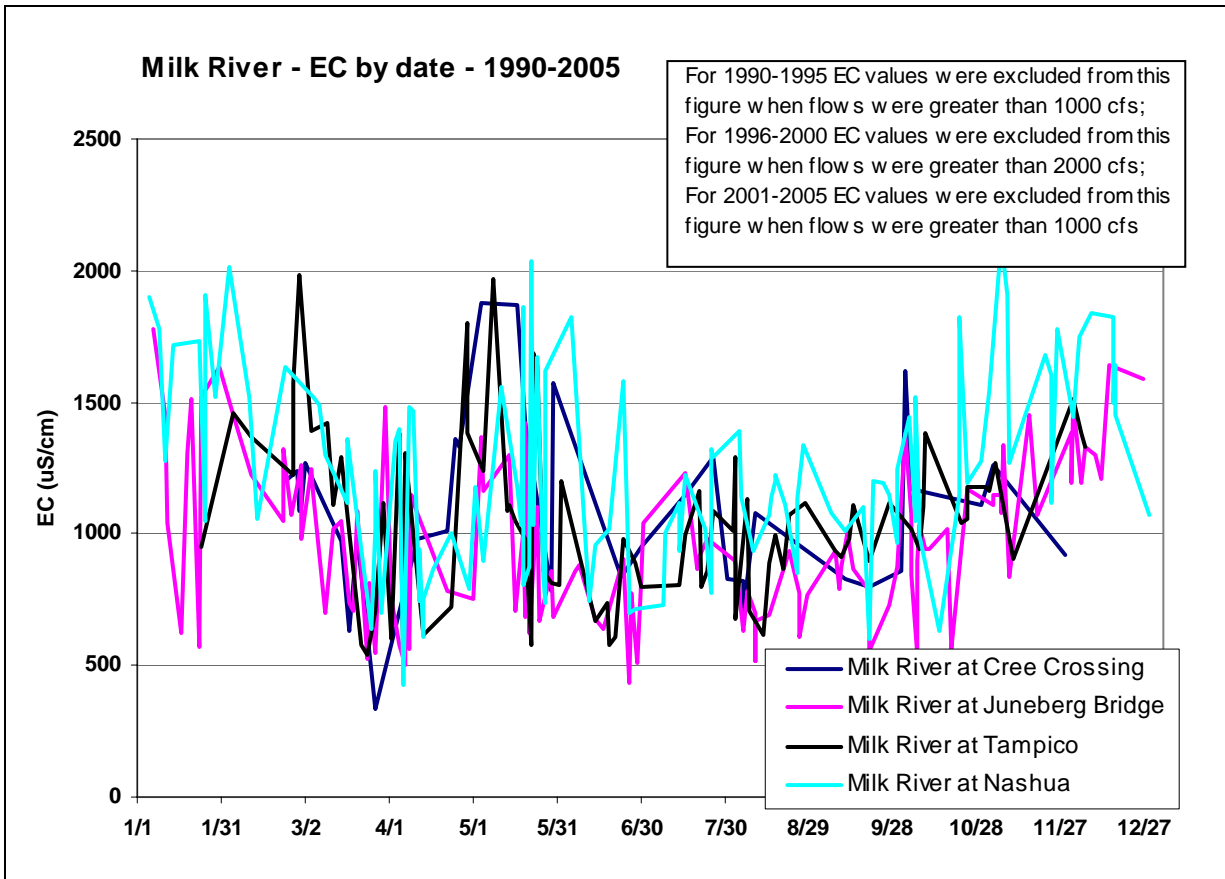


Figure 1. Milk River EC ($\mu\text{S}/\text{cm}$) as a function of date for non-flood flows at four USGS Milk River stations.

Soils, crops, native vegetation, and aquatics downstream of the potential discharge location

To understand potential impacts of Refuge releases to the Milk River on soils downstream of the proposed discharge site, soil series data were inventoried from soil surveys of Phillips and Valley Counties (USDA, 2004; USDA, 1984). Soil series were cataloged from Saco to Nashua within a one-mile distance from each side of the Milk River. Sixty-eight different soil series were identified within this distance. Table 11 lists the different soil series found along the Milk River by texture and location. Soils series inventoried are broken down into six stretches of stream between Saco and Nashua. As one would expect, many of the same series are found within each section. The majority of the soils within this area were loams and clays. Most of the clays inventoried have a shrink/swell potential listed as moderate to high, characterizing them as smectitic. A description of the properties including runoff, suitability, available water capacity (AWC), salinity, shrink/swell potential, and permeability of each soil series is included (when available from the soil survey) within Appendix B.

Table 11. Soils series by texture occurring within a one-mile distance of each side of the Milk River from Saco to Nashua, MT.

Soil Texture	Saco to Phillips County Line	Phillips County Line to Hinsdale	Hinsdale to Vandalia	Vandalia to Tampico	Tampico to Glasgow	Glasgow to Nashua
Loam	Attewan–Beaverell complex, Beaverell–Tinsley complex, Bullhook, Creed–Gerdrum complex, Degrand, Evanston, Glendive-Havre, Havre, Hillon-Joplin, Telstad-Joplin	Attewan, Hillon, Nishon, Phillips, Phillips-Elloam complex, Phillips-Nobe-Asher complex, Phillips-Scobey, Telstad	Cabbart-Delpoint complex, Evanston, Evanston-Lonna, Evanston-Marmarth, Marmarth-Cabbart, Telstad	Evanston-Lonna, Attewan, Phillips-Scobey complex, Phillips, Nishon, Telstad	Evanston-Lonna, Telstad, Nishon, Cabbart-Delpoint complex, Phillips, Nishon, Thoeny-Phillips complex	Evanston-Phillips, Hillon-Telstad, Lonna, Phillips-Elloam complex, Phillips-Scobey complex, Phillips-Nobe-Absher complex, Redvale
Sandy Loam		Parshall, Tally, Tinsley complex		Tinsley complex	Tinsley complex	
Silty Clay Loam	Kobase	Harlem, Havre, Havre-Glendive complex	Harlem, Havre, Havre-Glendive complex	Harlem, Havre, Havre-Glendive complex	Harlem, Havre, Havre-Glendive complex	Harlem, Havre, Havre-Glendive complex
Clay Loam	Ethridge, Ethridge-Gerdrum, Kevin-Sunburst, Lallie, Nishon, Scobey-Kevin, Sunburst-Kevin complex	Scobey, Scobey-Sunburst complex, Sunburst	Sunburst-Lisam complex	Scobey-Sunburst, Sunburst	Elloam, Scobey-Sunburst, Sunburst	Elloam, Scobey-Sunburst, Sunburst, Sunburst-Lisam complex
Clay	Harlake	Absher complex, Bowdoin, Harlem, Marias, Nobe-Liasam-Dilts, Thebo, Thebo-Lisam	Harlem, Lisam-Dilts, Lisam-Dilts-Rock outcrop complex, Marias	Harlem	Harlem, Nobe-Absher complex, Bowdoin, Harlem, Marias, Thebo, Thebo-Lisam	Bowdoin, Elloam gravelly clay, Harlem, Lisam-Dilts, Lisam-Dilts-Rock outcrop complex, Marias, Nobe-Absher complex
Silty Clay		Havre-Harlem, Lallie, Vaeda	Havre-Harlem, Lallie, Vaeda	Lallie, Havre-Harlem	Lallie, Vaeda	Lallie, Havre-Harlem, Vaeda
Silt Loam		Lonna, Lonna-Marias complex	Lonna-Marias complex			Lonna
Fine Sandy Loam	Hanly					
Other		Aquic Ustifluvents, saline, Typic Fluvaquents, gently sloping	Typic Fluvaquents, gently sloping, Ustic Torrifuvents, gently sloping	Typic Fluvaquents, gently sloping, Ustic Torrifuvents, gently sloping	Aquic Ustifluvents, saline, Typic Fluvaquents, gently sloping, Ustic Torrifuvents, gently sloping	Fluvaquentic Haploborolls, gently sloping, Typic Fluvaquents, gently sloping, Ustic Torrifuvents

Information regarding principal irrigated crops in this area was obtained from the USDA National Agricultural Statistic Service (2006). Appendix C contains a summary table listing irrigated crops within Phillips and Valley counties for 2004 and 2005 along with planted acres, harvested acres, yield, and production for each crop. Data gathered indicated alfalfa is the predominant irrigated crop grown within these two counties.

Salinity thresholds for irrigated crops of significant acreage likely to be grown or presently grown along the Milk River or Beaver Creek drainage are outlined in Table 12. Salinity thresholds are listed for both the applied water and the resulting saturated paste extract (Hanson et al., 1999 and CPHA, 2002). In some instances within the table, more than one crop species is combined, with the value of the most sensitive species reported. Additionally, some values are not reported due to lack of information regarding salinity thresholds. Alfalfa, dry edible beans, and corn are generally the most salt-sensitive crops grown in the Milk River region. Leaching fractions reported indicate the additional volume of water necessary upon application to prevent concentration of salinity within the root zone.

Table 12. Applied water and saturated paste extract salinity thresholds for irrigated crops presently and/or likely to be grown along the Milk River and Beaver Creek.

Crop	EC of applied water ($\mu\text{S}/\text{cm}$)		EC saturated paste extract (ECe , $\mu\text{S}/\text{cm}$)	
	@ which 0% reduction in yield is likely to occur	@ which 25% reduction in yield is likely to occur	@ which 0% reduction in yield is likely to occur	@ which 25% reduction in yield is likely to occur
All non-durum wheat ^{1/}	4,000 (10% leaching fraction)	6,400 (16% leaching fraction)	6,000	9,500
All barley	4,000 (10% leaching fraction)	8,700 (16% leaching fraction)	8,000	13,000
Alfalfa	1,300 (4% leaching fraction)	NA	2,000	
Durum wheat	3,900	NA	5,900	
Corn	1,100-1,200	NA	1,800	6,800
Dry edible beans	700	1,500 (12% leaching fraction)		2,300
Crested wheatgrass	2,300 (4% leaching fraction)	6,500 (11% leaching fraction)	3,500	9,800
Orchard grass	1,000 (3% leaching fraction)	3,700 (11% leaching fraction)	1,500	5,500
Tall fescue	2,600 (6% leaching fraction)	5,700 (12% leaching fraction)	3,900	8,600

^{1/}Generally applies to all wheat; winter wheat, spring wheat, semi-dwarf wheat is more tolerant, wheat forage slightly less tolerant.

In addition to crops grown in the receiving area, it was also important to identify native riparian vegetation occurring along the Milk River. According to Jones (2003), riparian habitats along the Milk River are characterized by oxbow marshes, shrub-dominated terraces, and cottonwood gallery forests. Cottonwood forests are the most characteristic riparian vegetation with three species of cottonwood occurring along the river including plains cottonwood (*Populus deltoides*), narrowleaf cottonwood (*Populus augustifolia*), and black cottonwood (*Populus balsamifera* ssp. *Trichocarpa*). Plains cottonwood is the predominant cottonwood species; narrowleaf cottonwood is also common. Jones reports that cottonwood stands can also include a shrub and small tree layer. Species include boxelder (*Acer negundo*), peachleaf willow (*Salix amygdaloides*), red-osier dogwood (*Cornus sericea*), yellow willow (*Salix lutea*), chokecherry (*Prunus virginiana*), western snowberry (*Symphoricarpos occidentalis*), Wood's rose (*Rosa woodsii*), and silver buffaloberry (*Shepherdia argentea*). Native grasses that occupy these stands include western wheatgrass (*Pascopyrum smithii*) and thickspike wheatgrass (*Elymus lanceolatus*). Silver sage (*Artemisia cana*) and western wheatgrass are also known to grow along the river. Jones further indicates that saltgrass (*Distichlis spicata*), three-square bulrush (*Schoenoplectus pungens*), and black greasewood (*Sarcobatus vermiculatus*) are common along more alkaline streams. Marsh plants that grow in the area include broadleaf cattail (*Typha latifolia*) and hardstem bulrush (*Schoenoplectus acutus*). Of the plant species identified by Jones and having published salinity tolerance data, red-osier dogwood appears to be most sensitive to salinity growing along the Milk River riparian corridor. According to published tolerances, it can withstand an E_c (saturated paste extract EC) of 2,000 $\mu\text{S}/\text{cm}$. A table is included within Appendix C listing native riparian species and associated salt tolerances.

The current status of aquatics and their sensitivity to salinity was also addressed. According to Montana Fish, Wildlife, and Parks website, the Milk River is home to numerous fish species including: Bigmouth Buffalo, Black Bullhead, Black Crappie, Blue Sucker, Brassy Minnow, Brook Stickleback, Brook Trout, Brown Trout, Burbot, Channel Catfish, Cisco, Common Carp, Creek Chub, Emerald Shiner, Fathead Minnow, Flathead Chub, Freshwater Drum, Goldeye, Iowa Darter, Lake Chub, Lake Whitefish, Largemouth Bass, Longnose Dace, Longnose Sucker, Minnow, Mountain Sucker, Northern Pike, Northern Redbelly Dace, Paddlefish, Pallid Sturgeon, Pearl Dace, Plains Minnow, Rainbow Trout, River Carpsucker, Sauger, Sauger x Walleye Hybrid, Sauger/Walleye, Shorthead Redhorse, Shortnose Gar, Shovelnose Sturgeon, Smallmouth Bass, Smallmouth Buffalo, Spottail Shiner, Stonecat, Walleye, Western Silvery Minnow, Western Silvery/Plains Minnow, White Crappie, White Sucker, and Yellow Perch. The lower portion of the Milk River provides critical spawning and rearing habitat for migratory and resident fish, including native species of the Missouri River, such as Blue Sucker, Channel Catfish, Freshwater Drum, Paddlefish, Sauger, Shorthead Redhorse, and Shovelnose Sturgeon.

Minimal data has been published regarding tolerances of different fish to salinity, although salinity can be an important factor in stream fish assemblages (Higgins and Wilder, 2005). Salinity within a stream is made of many different ions, most usually calcium, magnesium, potassium, chloride, bicarbonate, and sulfates. The relative amounts of each ion is unique to each waterbody, thus generic salinity tolerances are not possible. Mount et al. (1997) found

the most toxic ion was potassium, followed by bicarbonate, magnesium, chloride, and sulfate. Don Skaar, Pollution Control Biologist for MT FWP, conducted a literature review on effects of sodium salts on aquatic life for the MT Dept of Environmental Quality when conductivity standards were established in 2003. He reviewed available literature for information that met the following criteria: 1) Studies had to be based on exposure to sodium sulfate or sodium bicarbonate (applicable to Bowdoin as the predominant anion in this system is sulfates – magnesium and sodium sulfates); 2) If studies were conducted in the laboratory, they had to use either a natural water source for testing or reconstituted water in which there was a full complement of major ions; 3) Organisms that were tested had to occur in Montana waters, or were considered to be acceptable surrogates; and 4) Toxicity endpoints from these studies had to be clearly attributed to the effects of salts or salinity. Through his literature review, Skaar found sufficient acute toxicity tests conducted on three aquatic species found in Montana waters to identify LC50 values: Fathead Minnow, *Daphnia magna* (zooplankton), and *Ceriodaphnia dubia* (zooplankton). References for these studies are Mount et al. (1997), Tietge et al. (1997), Ingersoll et al. (1992), Dickerson et al. (1996), Meyer et al. (1985), Dwyer et al. (1992) and Forbes (2002).

Table 13. Summary of 48-hour LC50 values for *Daphnia magna* and *Ceriodaphnia dubia*, and 96-hour LC50 values for fathead minnows.

LC50 value	fathead minnow	<i>Daphnia magna</i>	<i>Ceriodaphnia dubia</i>
Mean (µS/cm)	6,080	5,499	3,246
Minimum (µS/cm)	413	1,560	1,797
Maximum (µS/cm)	20,266	11,466	5,130
Geometric mean (µS/cm)	4,204	4,843	3,128
N	18	14	20

To determine the “criterion maximum concentration”, EPA rules specify that one should take all the geometric means of genera in a waterbody, rank them, and then take the genus at the 5th lowest percentile (or 4th lowest genus if there are less than 60 genera), to determine a “final acute value”. This number is then divided by 2 to determine the “criterion maximum concentration”, a value that would assure no animals are killed by the resulting concentration. Using the table above (Table 13), the most sensitive species is *Ceriodaphnia*. The associated criterion maximum concentration is 1,564 µS/cm. Mount et al (1997) reported that this value is equivalent to concentration between LC0 and LC10.

Skaar also cited laboratory and field studies in which deleterious effects were measured relative to a control or to conditions judged to be unharmed. Koel and Peterka (1995) reported that Northern Pike (which are found in the Milk River) hatch success decline as salinity increased from 680 to 1,812 µS/cm. Mossier (1971) reported a decline in Northern Pike hatch success as salinity increased from 1,300 to 4,000 µS/cm. Hendrickson (1990) reported a decline in Northern Pike hatch rates as salinity increased from 950-3,050 µS/cm. Koel and Peterka (1995) showed moderate declines in hatch success of Walleye as conductivity rose from 680 to 1,812 µS/cm, and Mossier (1971) found a moderate decline in hatch success as levels rose from 500 to 1,300 µS/cm. Large declines in hatch success for

Walleye were seen by Hendrickson (1990) as conductivity rose from 1,100 to 3,200, by Mossier (1971) as conductivity rose from 1,300 to 4,000 $\mu\text{S}/\text{cm}$, and by Koel and Peterka (1995) as conductivity rose from 680 to 3,301 $\mu\text{S}/\text{cm}$. A field study done by Violett (1992) showed, circumstantially, that Northern Pike preferred, or were more successful at spawning in water of salinity near 1,000 $\mu\text{S}/\text{cm}$ than in water over 2,000 $\mu\text{S}/\text{cm}$.

Woodward et al. (1985) tested long-term effects of sodium and magnesium sulfate salts on aquatics. Fathead Minnows, which are relatively salt tolerant, showed a reduction in growth as conductivity rose from 480 to 1,680 $\mu\text{S}/\text{cm}$, and a slight reduction in survival as conductivity rose from 480 to 2,750 $\mu\text{S}/\text{cm}$. *Daphnia* reproduction was not affected at conductivities as high as 4,950 $\mu\text{S}/\text{cm}$, consistent with the high geometric mean in Table 13. Mayfly larvae survival was reduced as conductivity rose from 700 to 1,800 $\mu\text{S}/\text{cm}$.

Ecological studies that determine presence or absence of fish species in lakes of varying ionic concentrations can also be helpful in determining tolerance levels. Rawson and Moore (1994) studied the physicochemical conditions in 60 saline lakes in Saskatchewan and associated fish compositions. Table 14 lists associated ranges of TDS tolerated by fish according to the Saskatchewan study by Rawson and Moore as reported in a Confluence Consulting report (2003). Data indicate that Longnose Suckers, Longnose Dace, and Pearl Dace were not found in lakes with TDS greater than 1,000 mg/L. The absence of these species from lakes with greater than 1,000 mg/L TDS doesn't prove that concentrations greater than the values in the table are lethal, rather suggests that the species are suitable indicator species candidates (Confluence Consulting, 2003).

Table 14. Range of TDS tolerated by fish in saline lakes in Saskatchewan (Rawson and Moore, 1944).

Fish Species	Range of tolerable TDS (mg/L)
Lake Whitefish (<i>Coregonus clupeaformis</i>)	100-3,000
Bigmouth Buffalo (<i>Ictiobus cyprinellus</i>)	900-3,000
White Sucker (<i>Catostomus commersoni</i>)	200-8,000
Longnose Sucker (<i>Catostomus catostomus</i>)	200
Longnose Dace (<i>Rhinichthys cataractae</i>)	200-600
Pearl Dace (<i>Margariscus margarita</i>)	200
Emerald Shiner (<i>Notropis atherinoides</i>)	200-3,000
Fathead Minnow (<i>Pimephales promelas</i>)	200-15,000
Spottail Shiner (<i>Notropis hudsoniscus</i>)	200-4,000
Northern Pike (<i>Esox lucius</i>)	200-3,500
Yellow Perch (<i>Perca flavescens</i>)	200-8,000
Walleye (<i>Stizostedion vitreum</i>)	200-8,000
Iowa Darter (<i>Etheostoma exile</i>)	200-12,000
Brook Stickleback (<i>Culaea inconstans</i>)	200-17,000
Burbot (<i>Lota lota</i>)	200-3,000

Effects and potential impacts of TDS, SAR, EC, nutrients, and trace elements in irrigation water on potential receiving areas

General background on effects and potential impacts of TDS, SAR, and EC on vegetation and soils is outlined in Chapter 2. Specifically, salinities exceeding the previously described threshold values for native vegetation and crops (namely alfalfa) will result in reduced evapotranspiration, and ultimately in reduced plant growth and yields. Sodicity, particularly for soils with an SAR exceeding 12, will result in reduced soil infiltration rates, reduced hydraulic conductivities, increased surface runoff, and reduced plant-available water. Smectitic soils, commonly found in the Milk River basin, are particularly susceptible to sodic water.

Two studies were reviewed that addressed trace element concentrations within the refuge. “Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in Bowdoin National Wildlife Refuge and adjacent areas of the Milk River basin, northeastern Montana, 1986-87” was authored by Lambing et al., 1988. Summary statistics for trace element concentrations in water samples collected within Bowdoin NWR during this study are presented in Table 15.

Table 15. Summary statistics for trace element concentrations in water samples collected in 1986 by USGS staff on Bowdoin NWR (Lambing et al., 1988)

Constituent	n	Minimum (µg/L)	Maximum (µg/L)	Median (µg/L)
Arsenic	16	<1	47	2.5
Barium	16	27	100	78
Boron	16	<10	6,000	120
Cadmium	16	<1	3	<1
Chromium	16	3	<10	<10
Copper	16	<10	10	<10
Lead	16	<5	7	<5
Mercury	16	<0.1	0.3	<0.1
Molybdenum	16	<1	5	2
Nickel	16	1	9	2.5
Selenium	16	<1	1	<1
Silver	16	<1	<1	<1
Uranium	12	2.2	43	5.1
Vanadium	16	<1	51	2
Zinc	16	<3	56	14

Lambing et al. collected water in samples in 1986, which was a high water year. The authors were unable to determine the extent of dilution in 1986, thus making it difficult to determine threats from trace element concentrations in low water years. The maximum arsenic value recorded would exceed the current human health standard of 10 µg/L, but was well below current aquatic life standards of 340 µg/L acute and 150 µg/L chronic. The maximum

mercury concentration is greater than the human health surface water standard of 0.05 µg/L. The uranium human health standard of 30 µg/L has also been exceeded by the maximum value.

The study found highest trace element concentrations in the Dry Lake Unit. Arsenic (47 µg/L), uranium (43 µg/L) and vanadium (51 µg/L) concentrations were all significantly higher in the Dry Lake Unit compared to other lakes and inflows into the refuge. The study found that concentrations of most trace elements were not much greater than inflow waters from Dodson South Canal and irrigation drainage waters. Yet, as would be expected, there were increases in concentrations for some elements measured in the lakes compared to the inflow waters. Arsenic, boron, uranium, and vanadium had at least a two-fold increase in one or more of the lakes. With the exception of the Lakeside Unit, arsenic concentrations were several times larger than inflow concentration in all lakes. Nonetheless, arsenic concentrations were relatively small with the exception of a value of 47 µg/L measured in the Dry Lake unit. Boron concentrations were substantially greater at two sites measured in Lake Bowdoin compared to inflow water (890 and 1,000 µg/L). Possible sources of this increase are the numerous saline seeps along the shores of the lake, which contribute significant quantities of boron. Uranium concentrations (43 µg/L) and vanadium concentrations (51 µg/L) were substantially higher in Dry Lake as opposed to irrigation source water. Uranium and zinc concentrations were found to be substantially higher in the drains than in the canal. Data was insufficient to determine whether these increased levels were indicative of irrigation drainage to Bowdoin NWR.

In the same USGS study, trace element concentrations were also measured in bottom sediment. In almost all cases, concentrations were within baseline ranges of soils of the northern Great Plains. Dry Lake unit had the highest concentrations: chromium 99 µg/g, copper 37 µg/g, vanadium 160 µg/g, and zinc 37 µg/g were significantly greater than mean background levels. Selenium concentrations in bottom sediments ranged from 0.3 to 0.6 µg/g and were similar to mean background soil concentrations. The study also looked at concentrations of trace elements in biota. With very few exceptions, concentrations were less than levels known to be detrimental to growth or reproduction.

The second study reviewed on trace element concentrations within Bowdoin NWR was produced by the USFWS (DuBois et al., 1992). Monitoring took place between 1989 and 1991. Trace element concentrations were evaluated in many different contexts, including water, sediment, aquatic plants, aquatic invertebrates, water bird eggs, and water bird liver samples. Twenty-three trace elements (aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, cobalt, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, tin, vanadium, and zinc) were analyzed in 1991 at seven surface water monitoring stations and 14 monitoring wells. Table 16 lists trace element concentrations measured in filtered water samples collected in 1991 at the surface water sites. Except where indicated, all values are listed as micrograms per liter (µg/L).

None of the samples exceeded EPA criteria according to the 1986 guidelines. However, some values measured would exceed current standards published in the Montana Numeric

Water Quality Standards Circular DEQ-7. The current standards as of February 2006 are listed for each element in Table 16. Aquatic life standards are listed as “acute” and “chronic” while human health standards are listed as “human”. If nothing is listed then a standard has not been adopted.

Table 16. Surface water trace element concentrations (µg/L) measured in filtered water samples collected in 1991 by USFWP on Bowdoin NWR (DuBois et al., 1992). Aquatic life standards (acute and chronic) and human health standards (human) from DEQ-7, Feb. 2006.

Element	MT WQ Standards	S-1	S-6A	S-7	S-11	S-12	S-24	S-NC
Aluminum	750 acute, 87 chronic	445	120	367	296	193	395	867
Arsenic	340 acute, 150 chronic; 10 human	6.4	5.5	3.8	13.8	5.4	3.4	<2.2
Barium	2,000 human	91	250	69	44	59	47	92
Beryllium	4 human	2	<0.6	2	<0.6	<0.6	<0.6	1
Boron		129	675	148	147	123	97	88
Cadmium	0.52 acute, 0.097 chronic, both @25 mg/L hardness; 5 human	1	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Chromium	100 human	4	<3.3	<3.3	5	8	4	<3.3
Copper	3.79 acute, 2.85 chronic, both @25 mg/L hardness; 1,300 human	19	4	18	7	6	5	9
Iron	1,000 chronic; 300 secondary max contaminant level	222	<55.6	82	<55.6	<55.6	<55.6	577
Lead	13.98 acute, 0.545 chronic, both @25 mg/L hardness; 15 human	22	<5.6	<5.6	<5.6	<5.6	<5.6	16
Manganese	50 secondary max contaminant level	16	<2.2	18	27	29	19	27
Mercury	1.7 acute, 0.91 chronic; 0.05 human	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Molybdenum		<4.4	<4.4	<4.4	8	<4.4	<4.4	6
Nickel	145 acute, 16.1 chronic, both @25 mg/L hardness, 100 human	32	6	26	11	11	<5.6	22
Selenium	20 acute, 5 chronic; 50 human	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	4.6
Strontium	4,000 human	434	277	442	197	299	424	360
Vanadium		6	6	3	3	4	2	6
Zinc	37 acute, 37 chronic both @25mg/L hardness; 2,000 human	11	<4.4	8	14	10	11	<4.4

Twelve sediment samples were analyzed in 1989, and boron concentrations ranged from 43.6 to 151 µg/g dry weight. Selenium concentrations measured in sediment were also more than twice the US western geometric mean. Selenium values ranged from <0.3 to 1.33 µg/g dry weight with highest selenium concentrations in sediment samples from the west side of Lake Bowdoin and Teal pond. Drumbo and the east side of Bowdoin Lake did not have detectable concentrations of selenium. Trace element concentrations in sediment samples from the USFWS 1989 study were compared to concentrations reported in the 1986 USGS study. Sediment sample collection sites in the 1989 study were different than 1986 study sites but concentration levels were not significantly different with the exception of boron, which was more than ten times greater in the 1989 study than the 1986 study and more than twice the US western geometric mean (Shacklette and Boerngen, 1984).

Additionally, USFWS evaluated trace elements in sago pondweed and algae collected at eleven sites. Arsenic levels ranged from 1-14 µg/g with the exception of one sample from Patrol Road pond that contained 29 µg/g. Arsenic levels of 30 µg/g were reported to cause decreased growth rates in female mallard ducklings (Camardese et al., 1990). Boron levels exceeded 300 µg/g in four of the algae samples and nine of sago pondweed samples. Pondweed from Dry Lake Pond contained 1060 µg/g boron. Selenium ranged from <0.3 to 1.07 µg/g in aquatic plants, below levels known to cause reproductive problems in mallards. Selenium levels measured in these aquatic plants could not be correlated with levels measured within sediments of the same water units. Arsenic, boron, and zinc concentrations all were found to be greater than concentrations measured in the 1986 USGS study, while chromium levels were found to be lower. All other trace element concentrations in aquatic plants were similar to or below concentrations reported in the 1986 study.

Aquatic invertebrates sampled for trace element concentrations included *Daphnia*, amphipods, damselfly nymphs, waterboatmen, midge larvae, and aquatic beetle larvae. Geometric means of all element concentrations in invertebrates were less than known concentrations deemed harmful to waterfowl. The highest arsenic levels found in the invertebrates was from the Drumbo unit (7.1 µg/g), while the highest boron levels in invertebrate samples were found along the north and west shores of Lake Bowdoin. Elevated boron and selenium concentrations were also found in some water bird livers sampled.

In summary, the two studies indicate that while some trace element concentrations were elevated, there was not a significant exceedence of standards. However, with the lack of outflows from the Refuge, evapotranspiration will likely result in increased concentrations of these elements within the refuge over time.

Recommended in-stream water quality standards for EC and SAR in irrigation waters for receiving area

There are at least three rationales to defining an acceptable salinity and sodicity level of water below the mixing zone. Acceptable mixed, in-stream salinity and sodicity standards which are defined as 'protective' of current or future beneficial uses are likely to be

somewhat different than absolute salinity or sodicity thresholds which target species (fish) or other entities (irrigated crops, soils). Existing historic data was assessed including salinity and sodicity during the low and high flow periods for the irrigation and non-irrigation season. Tables 8-10, located at the beginning of this chapter, present this information. The data indicate the highest in-stream salinity and sodicity occurs between September and December. EC ranges from 878 to 1339 $\mu\text{S}/\text{cm}$ and the SAR averages approximately 4 during this time. Lowest EC values occur during the irrigation season when flows are greatest. EC ranges between 665 and 1084 $\mu\text{S}/\text{cm}$ and the SAR averages 3 during high flows. During the non-irrigation and proposed discharge period, the EC ranges between 843 and 1359 $\mu\text{S}/\text{cm}$ and the average SAR is 4.

Secondly, it is necessary to consider tolerance levels of the aquatics, native riparian plants, crops, and soils in the receiving area down gradient of the discharge point. Data presented in Table 13 indicate that *Ceriodaphnia* is the most sensitive aquatic species. The TDS criterion maximum concentration of *Ceriodaphnia* is approximately 1,000 mg/L (EC of 1,564 $\mu\text{S}/\text{cm}$). Alfalfa is the most salinity sensitive crop downstream of the discharge point. The EC of water applied to alfalfa should not exceed 1,300 $\mu\text{S}/\text{cm}$ (4% leaching fraction) to avoid reductions in yield. Red-osier dogwood is the most sensitive native species growing within the downstream receiving area. Threshold salinity for dogwood is 2,000 $\mu\text{S}/\text{cm}$ for saturated paste extract, which corresponds to applied water EC of 1,333 $\mu\text{S}/\text{cm}$ (based on the assumption that ECe equilibrates at 1.5 times EC applied water).

Potential impacts to soils from releases from Bowdoin NWR are specific to each soil series. In general, clay textured smectitic soils will be the most sensitive to increases in EC and SAR. The potential impact of mixed water releases on soils in the downstream receiving area should be determined by plotting a projected mixed water EC and SAR combination on the figure provided in Appendix D (Ayers and Westcot, 1976). The Ayers and Westcot figure defines reductions in infiltration based on the interaction between EC and SAR. Maximum allowable salinity standards can be identified through plant and aquatic tolerances, while sodicity standards can be determined through the corresponding sodicity below that which causes a reduction in infiltration. Literature suggests that the salinity threshold of both alfalfa and red-osier dogwood is approximately 1,300 $\mu\text{S}/\text{cm}$. Based on a threshold salinity of 1,300 $\mu\text{S}/\text{cm}$ and the EC/SAR interaction figure (Appendix D), the maximum allowable SAR resulting in no reduction in infiltration is approximately 5.

From a protective perspective, discharge of salt-rich water should not be any greater than that which would cause a 10-20% increase in ambient flow salinity and/or sodicity of the receiving stream during irrigation season. During non-irrigation season, the standard can be set somewhat higher, depending on other downstream uses. An appropriate discharge scenario from the Refuge might consist of salinity and flow combination that maintains resulting receiving stream salinity significantly below the standard or not more than 10-20% of the ambient, assuming the ambient is significantly below the standard at present. Inspection of existing water chemistry and lakebed sediment sample analyses suggests that neither nutrients nor trace elements will be an issue with discharges from Bowdoin NWR.

Bowdoin Refuge water release scenarios

To address potential releases from the Refuge to the Milk River, MSU-EWQ attempted to assess flow and salinity concentration combinations that could be released into the Milk River without adversely affecting downstream irrigators, aquatic values, or exceeding DEQ standards. Although the Montana DEQ has not set standards for EC or SAR for the Milk River or Beaver Creek, it is possible to speculate what in-stream numeric values would be appropriate as 'protective' of downstream beneficial uses.

The RWRCC presented MSU-EWQ with a hypothetical release scenario of 5 cfs at 5000 mg/L TDS from November 1 through February 28. Concern was expressed to MSU-EWQ regarding releases during four time periods including ice jam season, irrigation storage at Vandalia dam, the irrigation diversion period, and the irrigation season. Preferably, releases would occur outside of these seasons or have minimal effect on them. To determine if releases would occur during the ice jam period, the US Army Corp of Engineers Cold Regions Research and Engineering Laboratory (CRREL) Ice Jam Database was queried. According to CRREL, ice jam season in the Milk River typically occurs from February 15th through April 15th. Thus, releases scheduled from Nov. 1 to Feb. 28 would likely incur minimal impact or interference with ice jam season. Appendix E illustrates ice jam occurrences in the Milk River as a function of date. According to personal communication with Glasgow Irrigation District members, irrigation storage occurs from March 1st through July 31st, irrigation diversions occur from March 1st through August 31st, and the irrigation season generally begins May 1st and goes through October 15th. Therefore, the proposed release scenario would occur outside of irrigation related time periods.

Additionally, concern was expressed regarding bank storage of saline water and inadvertent dam storage of saline water. Review of stream flow data for Milk River USGS stations from Juneberg Bridge to Tampico indicate the Milk River gains groundwater in this section. Consequently, bank storage is unlikely and/or insignificant above Vandalia dam. To determine if reservoir storage of saline water is likely, a simple calculation can be conducted with some assumptions. Assuming 20% replacement efficiency of in-channel water, no bank storage, and no in-channel storage of significance, the estimated time for channel displacement of mixed water to reach Vandalia dam would be four to five days. An inflow replacement rate of 214 cfs into Vandalia dam (average February flow at Juneberg Bridge) would take one to two days for total replacement of resident basin storage behind Vandalia dam. At an inflow rate of 980 cfs (average March flow at Juneberg Bridge), replacement time would be less than one day. Assuming a discontinuation of discharge from the Bowdoin complex into the Milk River by February 28, it is likely that storage in Vandalia dam after March 7th to 10th would not be significantly or measurably impacted by discharges of 5 cfs at 5000 mg/l TDS from Dry Lake between November 1 and February 28.

To completely assess consequences of release of 5 cfs at 5000 mg/L TDS from the Bowdoin complex, a determination of the volume and concentration of mixed water passing through the Milk River channel below the Bowdoin discharge point was completed. This process involved several steps:

1. Create an equation that predicts EC within the Milk River based on flow within the Milk River. Analysis of the EC data collected within the Milk River revealed that EC values were not measured on each day of the year. Thus it was important to be able to predict EC in the Milk River on any given day. Therefore, EC was plotted as a function of flow. Predictably, flow was negatively correlated with EC. A correlation equation was developed for this data set and an R^2 value calculated. Regression correlations were developed for EC values at flows less than 1000 cfs. Flows greater than 1000 cfs represent flood conditions and are not representative of a worst-case scenario. This resulted in two equations to predict EC, one based on all flows, and another to predict EC when flows were less than 1000 cfs.
2. Average daily flow was calculated for each day of the year based on 16 years of flow data from the USGS station at Juneberg Bridge (1/1/90 – 9/17/06).
3. Non-mixed Milk River EC was calculated for each day of the year using equations developed for EC and average daily flows calculated for the Milk River.
4. Flow-weighted mixed water EC values were calculated for the Milk River and Bowdoin discharge (using the 5 cfs at 5000 mg/L TDS release scenario). These values were determined with a weighted calculation for two scenarios: flows less than 1000 cfs and for all flows. Figure 2 illustrates the results. According to the discharge scenario, discharges only occurred during the non-irrigation season, thus data from March 1 to Oct. 1 (between the two black vertical lines) do not represent mixed water. Increases in EC within the Milk River resulting from Bowdoin releases are illustrated from Jan. 1 to Feb. 28, and from Oct. 2 to Dec. 31. The difference between the mixed water EC (pink and blue lines) and the non-mixed water EC (green and teal lines) is apparent. The increase in EC resulting from Bowdoin releases of 5 cfs at 5,000 mg/L is approximately 200 $\mu\text{S}/\text{cm}$. The two horizontal lines (red and blue) delineate crop and aquatic thresholds. Because water is released from Bowdoin only during the non-irrigation season, the alfalfa threshold doesn't apply, and therefore no thresholds are exceeded with the 5 cfs, 5,000 mg/L scenario.

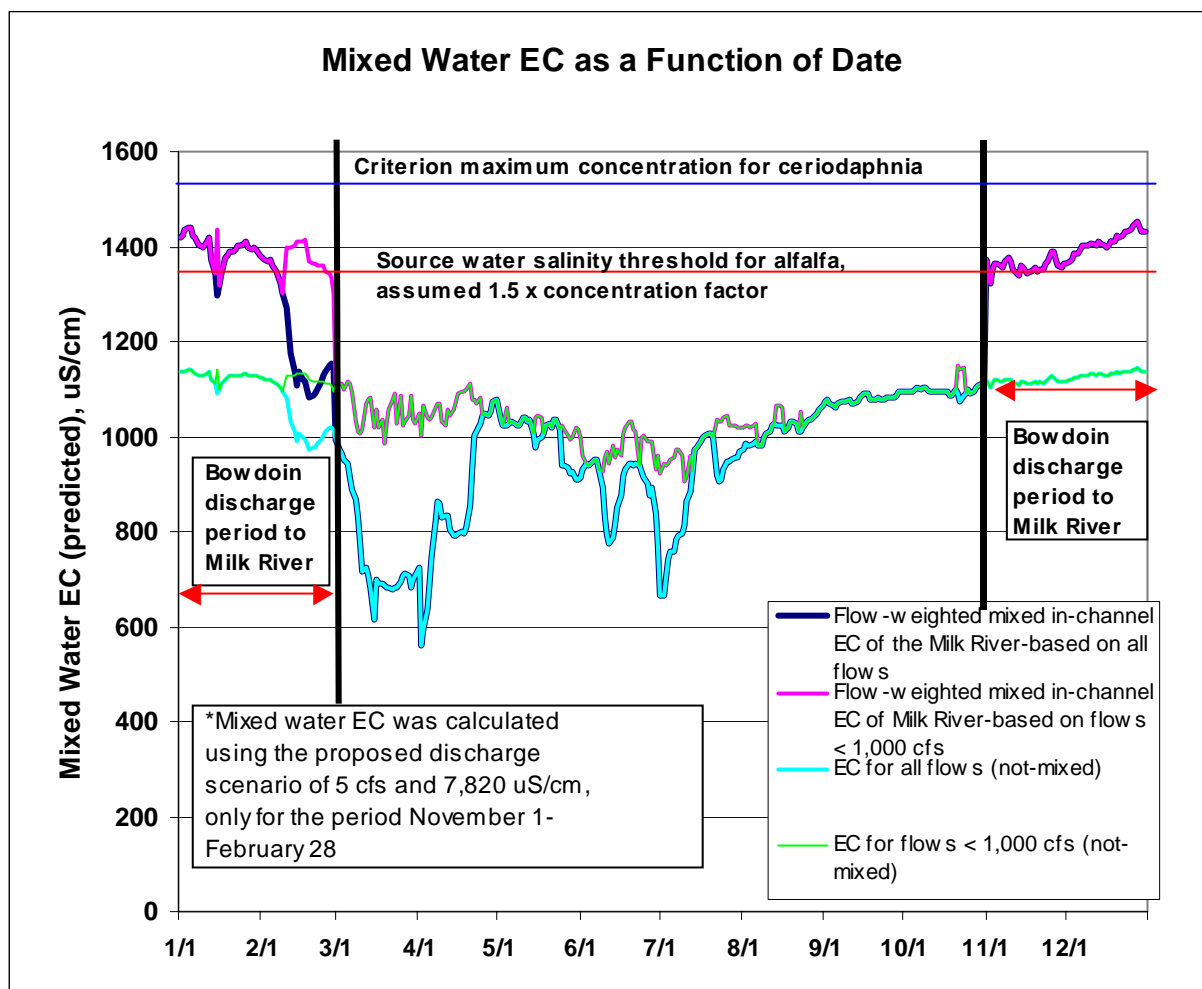


Figure 2. EC values of mixed and non-mixed water over a season based on two flow weighted calculations for stream flows less than 1,000 cfs and for all stream flows; mixed EC values represent projected EC of the Milk River when mixed with 5 cfs of Bowdoin release water at 5,000 mg/L TDS (7,820 μ S/cm).

Additionally, MSU-EWQ conducted calculations to determine volumes of water that could be released from Bowdoin Refuge to the Milk River without exceeding alfalfa and aquatic thresholds. Calculations are based on average flows within the Milk River and discharge from Bowdoin of 6,000 mg/L TDS water. During irrigation season, the allowable mixed EC (Bowdoin + Milk River water) was set 10% below the alfalfa threshold to provide protection. During the non-irrigation season, the allowable mixed EC was set 10% below the threshold for *Ceriodaphnia*. Figure 3 illustrates calculated allowable discharges from Bowdoin at 6,000 mg/L TDS based on flow within the Milk River, time of year, and crop and aquatic thresholds.

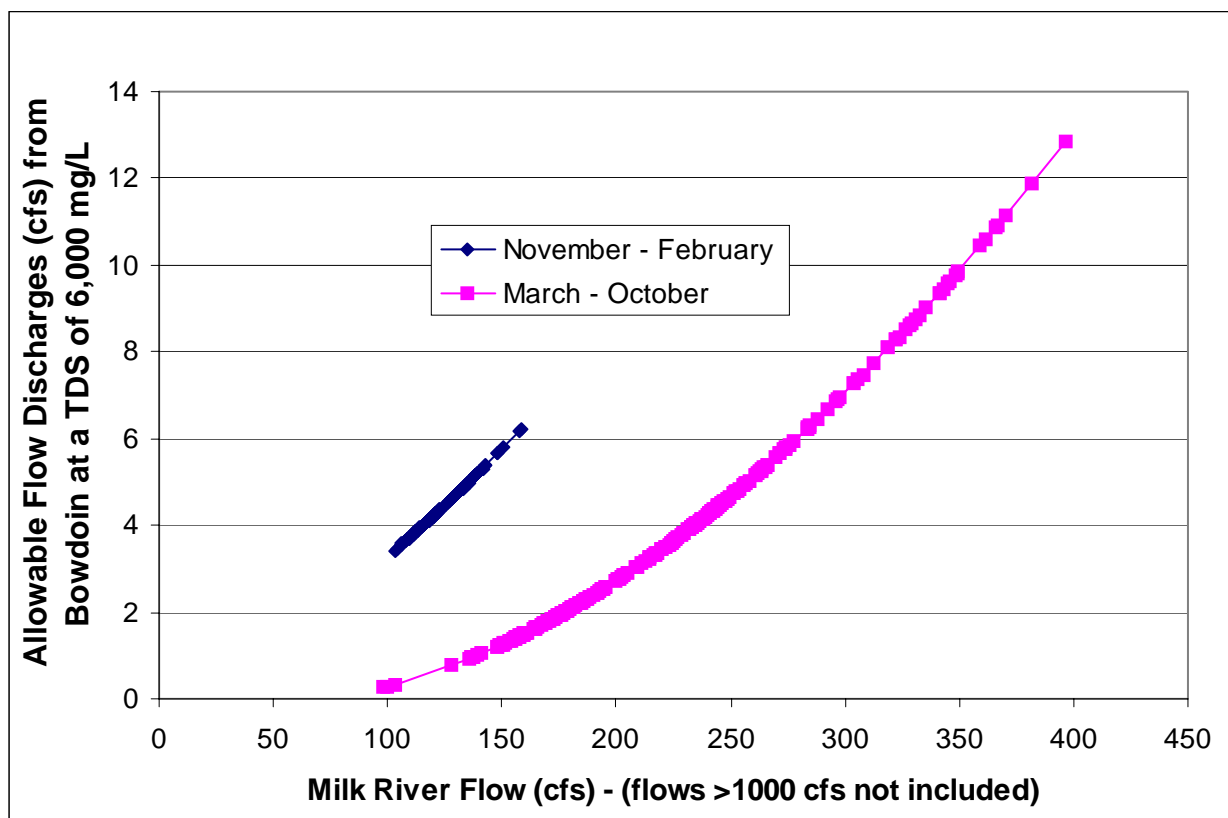


Figure 3. Projected allowable flow discharges from Bowdoin NWR as a function of flow in the Milk River. “Allowable” discharges deemed discharges that do not result in exceedance of aquatic and crop thresholds (minus 10% to provide protection).

In summary, analysis of the 5 cfs at 5,000 mg/L TDS scenario presented by the RWRCC team did not result in salinity threshold exceedances for *Ceriodaphnia* during non-irrigation season. However, these results are based on average flows for the Milk River and are very much a function of the dilution capabilities of the Milk River. At lower flows, the probability of exceeding salinity thresholds increases, suggesting that management of releases from Bowdoin NWR should be flexible and quickly adaptable.

Chapter 5 Accidental spills

Question: What are the likely impacts of accidental spills from Bowdoin NWR if salts are not released gradually?

Historically, Bowdoin NWR received flood water from Beaver Creek once every 3.35 years on average (67 years of record). In 1939 and 1979, the volume of flood water received was great enough to fill Lake Bowdoin and Dry Lake beyond their natural capacity. In 1978 Dry Lake and Lake Bowdoin were filled to dike level. While the frequency of Beaver Creek sourced flood water delivered to Bowdoin NWR has decreased in more recent years, it is possible that the Refuge will again fill beyond its capacity. Accidental spills of highly saline and sodic water from the Refuge have potential impacts to acreage in the Beaver Creek corridor downstream of the Refuge. Water levels and chemistry in Lake Bowdoin fluctuate and change over time and the nature and longevity of an accidental spill is unknown, therefore several scenarios must be assessed to illustrate a range of potential impacts. These scenarios are based on a number of assumptions regarding circumstances causal to flooding of the Refuge.

According to Refuge staff, full pool capacity of Lake Bowdoin is 20,649 acre-feet (Kathy Tribby, personal communication, 2006). Mike Dailey's water sample records from September 21, 2006 indicate that the TDS of Lake Bowdoin along the east shore was 12,297 mg/L. TDS of 12,297 mg/L likely represents a high-end value for the lake as fresh water from Dodson Canal enters on the west side. On September 21, the volume of water in Lake Bowdoin was 4,515 acre-feet. If it's assumed this represents salinity of the entire complex (to error towards worst case), the volume of water in the lake is static, and that saline water in Lake Bowdoin mixes uniformly with fresh water from Beaver Creek floods, the TDS of water that would accidentally spill from Bowdoin in an extreme flooding event can be calculated. Based on USGS data (Kendy, 1999), EC of Beaver Creek during high flows ranges from 200 to 300 $\mu\text{S}/\text{cm}$ (250 $\mu\text{S}/\text{cm}$ used for calculation). At 4,515 acre-feet pool level in Lake Bowdoin, it would take 16,134 acre-feet of Beaver Creek water to reach full pool capacity. Upon flooding, it is likely that Bowdoin flood water would be diluted further when mixed with Beaver Creek as flood water leaves the Refuge. The USGS Montana Flood Frequency and Basin-Characteristics Data website indicates that for the Beaver Creek below Guston Coulee near Saco, MT station (061660), annual peak discharge with a 20% annual exceedance probability is 1,160 cfs.

Salts in Bowdoin Refuge are typically sodium-sulfate salts, consequently it is necessary to consider sodicity and soil dispersion. The average SAR of sediment samples collected by Bauder and Hershberger from the Dry Lake bed in 2006 was 58.87. This likely represents the high end of SAR values in the refuge as the sample consisted primarily of crust-forming salts. Assuming some carbonate remains soluble in Bowdoin Lake and would resolublize if Dry Lake were flooded, 50 might be a reasonable SAR for calculation purposes. Using the

above conditions, assuming that chemical constituents of the Refuge and Beaver Creek are conservative, and assuming the SAR of Beaver Creek during flood conditions is two, a mixed SAR can be calculated.

TDS and SAR was calculated for six scenarios in which Lake Bowdoin fills to capacity and discharges at varying rates into Beaver Creek at two flow conditions: 1) Lake Bowdoin overflows at a 5 cfs rate into Beaver Creek flowing at 1,160 cfs; 2) Lake Bowdoin overflows at a 50 cfs rate into Beaver Creek flowing at 1,160 cfs; 3) Lake Bowdoin overflows at a 100 cfs rate into Beaver Creek flowing at 1,160 cfs; 4) Lake Bowdoin overflows at a 5 cfs rate into Beaver Creek flowing at 500 cfs; 5) Lake Bowdoin overflows at a 50 cfs rate into Beaver Creek flowing at 500 cfs; and 6) Lake Bowdoin overflows at a 100 cfs rate into Beaver Creek flowing at 500 cfs. The 500 cfs flow rate of Beaver Creek is meant to simulate spilling of Lake Bowdoin into Beaver Creek as flooding flows in Beaver Creek subside. Calculated TDS and SAR values for the six scenarios are summarized in Table 17. Threshold exceedance refers to salinity thresholds identified through literature review for alfalfa, *Ceriodaphnia dubia*, and red-osier dogwood (see Chapter 4).

Table 17. Calculated TDS, SAR, and EC values for six flooding scenarios for Bowdoin NWR.

Scenario	TDS (mg/L)	SAR	EC (µS/cm)	Threshold exceedance
1. Bowdoin 5 cfs, Beaver Cr. 1,160 cfs	171.41	2.05	268	None
2. Bowdoin 50 cfs, Beaver Cr. 1,160 cfs	269.62	2.43	421	None
3. Bowdoin 100 cfs, Beaver Cr. 1,160 cfs	370.76	2.83	579	None
4. Bowdoin 5 cfs, Beaver Cr. 500 cfs	186.26	2.10	291	None
5. Bowdoin 50 cfs, Beaver Cr. 500 cfs	401.27	2.96	627	None
6. Bowdoin 100 cfs, Beaver Cr. 500 cfs	602.48	3.75	941	None

Based on the six scenarios above, an accidental spill from the Refuge does not result in excess salinity or sodicity downstream of the Refuge. Salinity calculated for each scenario remains below exceedance thresholds for alfalfa, *Ceriodaphnia dubia*, and red-osier dogwood. However, if an event not represented by the above scenarios occurs, reduction in yield resulting from an accidental spill of Refuge water onto agricultural acreage along the Beaver Creek corridor will be dependent on climatic, flooding, and irrigation conditions following the flooding event. If little to no additional non-saline water is available shortly following the flood event, declines in crop yield are likely, but difficult to quantify. If additional water is available to leach salinity from the soil following the flood event, the soil can potentially be restored to its previous salinity. On a Bowdoin clay soil, with a pre-flood

EC of 4,000 $\mu\text{S}/\text{cm}$ (based on NRCS soil survey), it would take roughly 0.30 to 0.40 feet of water applied through sprinkler irrigation to reclaim two feet of soil to its previous salinity level (based on reclamation leaching described in Hanson et al., 1999). Reclamation of saline soil that might result from flooding of Bowdoin is possible and feasible. However, reclamation of sodic soils would be more difficult. Leaching, if possible, is unlikely to improve soil permeability and potentially results in worsened sodicity conditions as either the salinity is leached from the soil, or water pools on the soil surface eventually result in a saline site. Impacts to native vegetation and biota will also be a function of climatic and flooding conditions following the flood event. Again, if non-saline water is available following the flood event, impacts to biota and native vegetation should be minimal. Trace elements are unlikely to be a source of contamination in the event of a flood. From previous studies, summarized in Chapter 4, there is not a significant exceedance of trace element standards in the Refuge, and dilution associated with a flooding event would further reduce hazards associated with trace elements.

While the previous scenarios assume complete mixing of fresh water from Beaver Creek with salty water of the Refuge, analysis of landsat imagery provided by the RWRCC team indicate that complete mixing is unlikely. In the absence of mechanical dispersion, diffusion of salts into freshwater is a slow process. Landsat imagery indicates that previous floods may have flooded the Dry Lake unit entirely but mixed only with the eastern edge of Lake Bowdoin. Under this scenario, flood water enters the Refuge and solubilizes salt as it progresses across Dry Lake. The initial wave of flood water moving across the lakebed would likely pick up the greatest amount of salt as readily soluble salts quickly dissolve. This may create an initial wave of saline water exiting the Refuge upon overtopping the dike system. It is not possible to accurately quantify the salinity of the initial wave of flood water leaving the Refuge without reliable data. However, Hamilton, Roelle, and Schafer (1989) measured sampled soil EC of Dry Lake and found the salinity of the top 12 inches to be approximately 20,000 $\mu\text{S}/\text{cm}$. Associated flood water salinities would be less than soil salinities. Damage caused by flood waters exiting the Refuge is entirely dependent on the mixing of flood water with Beaver Creek that occurs following spill from the Refuge and dependent on the salinity of flood water following the initial surge of saline water. It is likely that flood tail-water and mixing with Beaver Creek could dilute and leach salinity to insignificant concentrations. There is the possibility of spreading of isolated and unmixed pockets of saline water that could cause considerable crop loss and/or soil dispersion in concentrated areas. In this scenario of incomplete mixing of flood water with Refuge water, less total salt is removed from the Refuge. In effect, the potential harm to downstream water users and growers is less than in previous scenarios with complete mixing, but the Refuge suffers from lack of flushing.

In a third scenario, accidental spills occur not from flooding of the Refuge but from structure failure due to human interference or rodent burrows. Under this scenario, no dilution of saline/sodic water occurs upon spilling from the Refuge. One time application of water with TDS of 12,297 mg/L (as assumed in first scenario) would likely result in severe crop loss, but could be mitigated with a supply of fresh water. Application of water with a SAR of approximately 50 could potentially result in moderate to severe soil dispersion. Salinity of

12,297 mg/L could temporarily offset a SAR of 50. However, leaching of the soil from irrigation or precipitation may eventually decrease soil salinity, but have little to no effect on soil sodicity, resulting in a permanently dispersed soil. This final scenario represents the most predictable and significant consequences to growers in the vicinity of the Refuge.

In summary, it is MSU-EWQ's professional opinion that the most significant short-term impacts of accidental spills are subsequent litigation (even if claims can't be substantiated) associated with claims of crop losses, soil quality deterioration, soil contamination due to trace elements, or crop losses due to salinization and flooding. It is likely that an accidental spill from Bowdoin would be greatly diluted by Beaver Creek water to levels below salinity thresholds. From an agronomic perspective, it is likely that many of the down-gradient soils above Nelson Reservoir are already salt-impacted, both in the shallow zones and below the root zone. Salinization is probably a common occurrence in the poorly drained, low-lying areas, which would be subject to flooding. It is likely that significant crop loss and long-term salinization currently occur in low-lying, poorly drained areas. In the event of an accidental saline spill lacking dilution from Beaver Creek, well-drained areas would likely experience temporary (1-2 years), but significant crop reductions. In areas of well-drained soils, once the water table receded and additional rainfall or irrigation water was applied, the salinity issue would become less significant. If flooding occurred on heavier, clay-dominated soils, there is a likelihood of relatively permanent dispersion. The mitigation option would be long-term subsidization or land-purchase.

Chapter 6

No action

Question: What are the hazards to Bowdoin NWR and downstream water users of doing nothing?

In order to address this question a number of potential hazards to the Refuge were addressed: 1) expanded footprint of the Refuge; 2) progressively increasing salinity through evapoconcentration; 3) risk of arsenic, selenium, trace element toxicity; and 4) progressive reduction in plant species population and diversity due to increasing salinity within the Refuge. Additionally, the no-action alternative will be addressed. Hazards to downstream water users if nothing changes at the refuge will also be discussed.

On-Refuge concerns

One concern that has been expressed is that the Refuge will increase in size if no changes in management are made. The entire Refuge encompasses 15,550 acres, including Lake Bowdoin (3,500 surface acres) and Dry Lake (1,300 surface acres). Currently the Refuge does not seem to be expanding, at least with respect to the size of lakes within the Refuge. In recent years the Refuge has been getting greater deliveries than the 3,500 acre-feet allotted. Yet, instead of increasing in size, Lake Bowdoin has actually decreased in size. It appears that all of the water being delivered to the Refuge through the Dodson South Canal is evaporating. In a draft report prepared by the Bureau of Reclamation (Esplin and Duberstein, 2000), the Refuge has an annual water deficit of 11,000 acre-feet in an average year and can have up to a 16,000 acre-foot deficit during a dry year. According to the Refuge manager, Carmen Luna, water levels have been too low in Bowdoin in the last 10 years to move water over to Dry Lake (personal communication, 2006). Thus, if no changes are made within the Refuge, it is not likely that the footprint of the Refuge will increase.

Another significant concern to the Refuge if no change in management is made, is progressively increasing salinity levels as a result of evapoconcentration. Kendy (1999) explains, "Water that evaporates from a lake is essentially devoid of salt. A consequence of evaporation is that the remaining lake water becomes more concentrated with salt owing to the decrease in water volume". Additionally, Kendy writes "salinity in the lakes--particularly those lakes that receive inflow primarily from other lakes--generally is higher than in source water owing to evapoconcentration". Kendy calculated a total lake average evaporation rate of 36.5 inches per year for Bowdoin Refuge from 1972 to 1997. Per Nimick (1997) in referring to Benton Lake, "If these pools were flooded continuously and no outlet were constructed, dissolved solids concentrations would be expected to increase as the water added each year evaporated". Lambing et al. (1998) writes about Bowdoin Refuge, "during years of limited water supplies, accumulations of salts and trace elements from surface and ground-water sources in the basin may potentially affect water quality especially during the water-deficient years when evaporation concentrates dissolved constituents". Because the

Refuge receives influxes of water from several sources, does not release water, and is not increasing in size, it is very apparent that evaporation is a key process occurring in the Refuge system. Thus, it is reasonable to conclude that salinity will continue to increase as a result of evapoconcentration if no changes are made in Refuge management.

The risk of arsenic, selenium, and trace element toxicity has also been expressed as a concern if nothing changes in Refuge management. A study done in the San Joaquin Valley of California on constructed evaporation ponds addresses this issue (Gao et al., 2005). In the San Joaquin Valley most agricultural drainage water is disposed of in evaporation ponds. The authors analyzed the fate of arsenic and selenium in these ponds and found that evapoconcentration resulted in increases of EC, alkalinity, chloride, sulfate, sodium, and magnesium. Arsenic concentrations were found to increase linearly with EC, but selenium levels actually decreased. The authors attributed the reduction in selenium to sink mechanisms causing reductions to elemental Se, organic Se, and selenite, which are sorbed by sediments.

A study done on Bowdoin Refuge (DuBois et al., 1992) reported that one algae sample collected had an arsenic concentration close to dietary levels found to be harmful to ducks. Additionally, a sago pondweed sample had a boron level known to cause reproductive problems in mallards. All other algae and pondweed samples had low trace element concentrations. Elevated selenium levels were measured in livers and eggs of some American avocets, eared grebes, and ruddy ducks, yet levels in eggs were not significantly high enough to cause embryonic deformities and mortality. The Lambing et al. (1998) USGS study of Bowdoin found more than two-fold increases in arsenic, boron, uranium, and vanadium in one or more of the lakes when compared to inflow water. These increases were considered a result of evaporation. The study occurred during a high water year, 1986, and found only a few exceedences of water quality targets/standards. This suggested to the authors that even if high concentrations of trace elements were found in low water years, periodic high-water conditions could dilute concentrations to non-harmful levels. The study concluded that trace element toxicity was not likely a persistent problem within the Refuge.

Another concern on the Refuge is changes in plant species as a result of increasing salinity. Hamilton, Roelle, and Schafer (1989) reported, "It is now apparent that salt accumulation on the refuge has lowered marsh productivity. The decline is especially evident in Dry Lake where cattails and round bulrushes have been replaced by alkali tolerant species. Submerged aquatics such as pondweeds and widgeongrass, which flourished during the 1950's, are nearly gone. Lake Bowdoin is showing signs of the same problems....cattails, which are less tolerant to salinity than bulrushes, have already nearly disappeared from Lake Bowdoin." DuBois et al. (1992) reported similar findings. They state "there are indications that historic cattail communities at Bowdoin NWR have been converted to alkali and hardstem bulrush as a result of salinization of refuge units over time." Johnson (1990) examined aquatic vegetation, salinity, aquatic invertebrates, and duck brood use at Bowdoin NWR. He found that salinity had impacts on aquatic macrophyte distributions and abundances within the refuge. His data trended toward a decreasing number of species with increasing salinity.

MSU-EWQ was also asked to address the no-action alternative. In the no-action alternative, future water deliveries would be the same as historical water deliveries, meaning deliveries of project water will be limited to 3,500 acre-feet per year. Some simple calculations can be made to address this management scenario based on a number of assumptions: 1) yearly evaporation (on average) will equal inflow water, i.e., lake level will stay about the same; 2) there are no flood related flushing or dilution events; 3) salt chemistry is conservative for sodium sulfate and close to conservative for calcium and magnesium with some loss due to precipitation for calcium and magnesium carbonates; 4) inflow water equals 3,500 acre-feet at a TDS of 565 mg/L (equivalent to Milk River at Juneberg Bridge average EC during the irrigation season of 883 μ S/cm); 5) Bowdoin Lake TDS at present equals 6,000 mg/L; and 6) existing water in Lake Bowdoin equals 4,000 acre-feet (approximate lake volume in September, 2006).

Based on these assumptions and using a simple flow-weighted calculation, Bowdoin Lake at 4,000 acre-feet, would experience an increase in TDS from 6,000 mg/L to 6,494 mg/L, an 8% increase in year one. Over time, TDS will continue to increase by 494 mg/L per year if there are no changes in inflows, but the percentage of increase will diminish. Keep in mind, these calculations do not account for any salt inflow or evaporation of return flow water and are likely a conservative estimate of salt accumulation within the Refuge. It is likely that evaporation is greater than 3,500 acre-feet per year. According to Refuge staff, the average capacity of Bowdoin Lake in 2006 was approximately 8,000 acre-feet of water from April through July. By September the lake capacity was approximately 4,000 acre-feet. So, the lake lost 4,000 acre-feet over the summer, not including any unaccounted for water the Refuge took in through return flows and precipitation. As one would expect, the no-action alternative would result in continued salinization of the Refuge.

Off-Refuge concerns

There are significant potential hazards to downstream water users if no action is taken at the Refuge. One of the most significant hazards would be an accidental spill as described in detail in Chapter 5. It seems reasonable to assume that if no changes in management of Refuge water are made, the progressively increasing salinity within the Refuge presents a greater hazard in the event of an accidental spill.

Without any change in Refuge management there is also the possibility that water will again be moved to Dry Lake, so as to evaporate saline water and blow the salts away. Under current management this appears the only way to rid the Refuge of salts. Hamilton et al. (1989) writes “alkali dust can cause problems for Refuge neighbors through deposition of alkali on agricultural lands, which lowers crop productivity. Alkali dust deposits are also a nuisance and inconvenience in the same way that blowing dirt is”. Impacts to downwind landowners are discussed in depth in Chapter 2.

Chapter 7

Salt diffusion

Question: Will salts presently stored in sediments of Dry Lake and/or Lake Bowdoin leach or diffuse out and contribute salts to Beaver Creek or Milk River due to subsurface flow?

It is MSU-EWQ's professional opinion that there is little likelihood of significant subsurface migration of lake water, leaching, or diffusion of salts from saturated lake bottom sediments of Lake Bowdoin or Dry Lake to either Beaver Creek or the Milk River. Correspondingly, there is little likelihood of significant increases in concentrations of salts in either the Milk River or Beaver Creek due to subsurface water movement from Lake Bowdoin or Dry Lake. The areas where salts are presently contained, including the geologic lake beds, lake bed sediments, and soils in low-lying, accumulating areas, are saline and a direct consequence of the lack of drainage or leaching over time. By all indications, the lake bottom sediments are relatively impermeable and thus do not drain.

Subsurface diffusion and leaching

In the absence of uncontrolled flooding or water release events, the overwhelmingly predominant mechanism for water removal from Lake Bowdoin and Dry Lake is evaporation. Net water flow is upward, into the atmosphere, due to evaporation - not downward due to drainage or leakage. Due to the particle dispersion driven by sodium-rich water, addition of fresh water (either via diversions from Dodson canal or from rainfall) to lakebed sediments likely causes lake bed soils to become progressively more impervious over time. There may be some flushing and loss of salts due to both flushing and diffusion, but sub-basement sediments will remain saline and essentially impermeable for an indefinite period of time.

This supposition is substantiated by Nimick (1997), wherein he states: "...likelihood is minimal that decreased concentration (referring to salts in surficial soils of Benton Lake) resulted from downward migration of salts induced by infiltration of rain." It is reasonable to assume that this theory holds true for Dry Lake as well and that minimal salt loss or deep seepage occurs due to drainage or significant downward movement below the Dry Lake bed. Nimick does acknowledge the potential for some migration of dissolved solids, although limited in magnitude and distance. Nimick cites Kadlec (1982), "Dissolved solids in pore water in lakebed sediment potentially could move vertically, either by movement of the pore water or by diffusion through pore water if hydraulic or concentration gradients were present." Both upward movement of salts (due to evaporation at the surface) and downward movement of salts (during wetting events following dry lakebed conditions) can occur. In the Benton Lake study, no estimates of net movement of salts in either direction were made.

Underlying the lakebeds of Dry Lake and Lake Bowdoin are unweathered glacial till remnants. Unweathered glacial till is poorly permeable. Although surficial weathering and soil-forming processes such as freezing and thawing, wetting and drying, biological activity, and movement of soil moisture tend to increase permeability of glacial till, this increase is only to the extent of weathering influence. Because these processes are most active at or near the surface, till permeability diminishes rapidly with depth. According to Meyboom (1967), unweathered glacial till is 1/10th to 1/100th times less permeable than surficially weathered till. For example, the hydraulic conductivity of glacial till at a pothole site in central North Dakota was determined by Meyboom et al. (1966). Values of hydraulic conductivity ranged from 0.02 to 0.002 foot per day at soil depths of 27 to 60 feet below the surface. Laboratory permeater tests of till core samples from depths of 11, 22, and 30 feet, respectively, gave an average hydraulic conductivity of about 0.0006 foot per day. This conductivity rate equates to a travel distance of approximately two feet per year. This also assumes a unit hydraulic head gradient, i.e. a driving force of substantial head differential.

Additional findings that support this presumption of very low hydraulic conductivities and limited migration of salts from lakebed sediments to either Beaver Creek or Milk River include specifics regarding the chemistry of lakebed salts and sediments. Both the findings of Nimick (1997) and chemistry of sediments and source water validate that precipitation of carbonate minerals during evapoconcentration results in the accumulation of carbonate minerals in lakebed sediments. This long-term, geologic precipitation of calcium carbonate progressively fills in fine pores in lake bottom sediments, resulting in extremely low pore water velocities. Additionally, high concentrations of sodium salts further contribute to low pore water velocities due to clay and silt particle dispersion.

The extent of downward and lateral water movement was qualified in USFWS report NERC 89/08 (Hamilton et al., 1989), which was based on a simulation model of water and salt balance at Bowdoin National Wildlife Refuge. It states that “Lateral ground-water flow from the lake into the soils marginal to the lake is significantly limited because soils in this basin are very fine in texture, are dispersed and already saturated, and are known to have very low hydraulic conductivity. It is likely that water from the lake will not be able to replenish (or flow laterally) the soil water deficit more than a few hundred yards (at most) from the lake.”

Surface water salt diffusion and leaching

With regard to the question of whether salts stored in sediments will “leak” out and increase concentrations of salts in outflow, the answer is ‘yes’, so long as there is a salt concentration differential between the inflowing water and soil pore water in the zone of wetting. This is substantiated by findings for Benton Lake (Nimick, 1997). Analyses of water samples and soil samples collected by Nimick and review of additional soil and water chemistry data about Benton Lake revealed that in circumstances where water was discharged into a dry lakebed of Benton Refuge, resultant salinity values of water in the lakebed were higher than inflow values and higher values occurred farthest from the inflow point. Per Nimick: “These higher values probably resulted from pre-existing water that was pushed by inflowing water

and from the initial dissolution of salts as the water was pushed over the dry lakebed. The general increase in specific conductance observed throughout the pool may have resulted from dissolution of salt crusts that had formed on the lakebed during the previous hot summer days.”

This observation has implications relative to Bowdoin Refuge. In the event that surplus water is discharged from Bowdoin Lake, other impoundments of the Refuge into Dry Lake, or flooding and flushing from Beaver Creek occurs, it is reasonable to expect that water exiting Dry Lake via drainways to Beaver Creek will be of significantly higher salinity than water entering Dry Lake. It is also reasonable to assume that the most saline water in Dry Lake will occur at locations farthest from inflow sources of flushing water and as the first flow exiting Dry Lake. This may have implications relative to ‘managed flushing’ events to reduce salts in Dry Lake, i.e., initial flushing may be most effective by minimizing flow volumes across the lakebed, thereby concentrating dissolved salts into smaller volumes for discharge down-gradient. With extended periods of repeated flushing, it is likely that salt concentrations in discharge water will diminish dramatically and reach an equilibrium condition of lesser salt concentration in time.

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APPENDICES

Appendix A: Milk River characteristics

Table 18. Minimum, maximum, and average EC ($\mu\text{S}/\text{cm}$), discharge at time of measurement (cfs), and date of measurement at Milk River USGS stations.

USGS Station	Minimum EC $\mu\text{S}/\text{cm}$, cfs, date	Maximum EC $\mu\text{S}/\text{cm}$, cfs, date	Average EC $\mu\text{S}/\text{cm}$, cfs
Milk River at Juneberg Bridge near Saco	200; 6,940; 12/13/77	2,020; 52; 2/27/86	1,030; 658
Milk River near Dodson	270; 12,900; 12/13/77	1,910; 0.31; 6/4/04	730; 585
Milk River near Harlem	190; 1,020; 3/7/90	1,500; 44; 5/6/93	610; 628
Milk River near Vandalia	220; 15,800; 3/5/86	1,940; 79; 1/5/84	1,040; 630

Table 19. Average monthly flow (cfs) for period of record at USGS stations of interest on the Milk River.

USGS Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Milk River near Dodson 9/28/82 – 9/30/05	83	128	449	174	171	214	159	59	116	185	97	71
Milk River at Juneberg Bridge 10/1/77-9/30/05	117	214	979	723	456	458	404	234	227	275	149	120
Milk River at Tampico 10/1/73 – 9/30/05	211	179	1035	733	550	568	475	194	162	183	217	152
Milk River at Nashua 10/1/39 – 9/30/05	144	244	1280	2137	981	953	648	301	269	300	209	156

Table 20. Average EC ($\mu\text{S}/\text{cm}$), TDS (mg/L), and associated flow (cfs) for the Milk River during irrigation season: April 1 – Oct 1. Data obtained from the DNRC.

Station	Average EC ($\mu\text{S}/\text{cm}$)	Average TDS (mg/L)	Average Flow (cfs)	n	Date Ranges
Milk River near Dodson	1,801	906	52	12	2003-05
Milk River at Juneberg Bridge	966	484	277	20	2003-06
Milk River near Hinsdale	951	475	578	20	2003-06
Milk River at Page Crossing	1,124	563	472	19	2003-06

Table 21. Average EC ($\mu\text{S}/\text{cm}$), TDS (mg/L), and associated flow (cfs) for the Milk River during non-irrigation season: Oct. 2 – March 31. Data obtained from the DNRC.

Station	Average EC ($\mu\text{S}/\text{cm}$)	Average TDS (mg/L)	Average Flow (cfs)	n	Date Ranges
Milk River near Dodson	1,313	662	309	12	2003-05
Milk River at Juneberg Bridge	1,330	667	293	18	2003-06
Milk River near Hinsdale	1,354	678	326	14	2003-06
Milk River at Page Crossing	1,436	722	282	18	2003-06

Table 22. Average EC ($\mu\text{S}/\text{cm}$), SAR, and associated flow (Q, cfs) for the Milk River during RWRCC potential discharge scenario period: October 1–Jan 31.

Station	Average EC ($\mu\text{S}/\text{cm}$)	Average SAR	Average Q (cfs)	n	Date Ranges
USGS 06155030 Milk River near Dodson	995	n/a	75	33	1982-89, 1991-2000, 2002-03
USGS 06164510 Milk River at Juneberg Bridge	1,327	4	133-EC data 143-SAR data	77-EC 49-SAR	EC: 1977-2005 SAR: 1977- 93
USGS 06155900 Milk River at Cree Crossing near Saco	1,157	n/a	51	6	2000-2004
USGS 06172000 Milk River near Vandalia	1,320	4	178-EC data 146-SAR data	46-EC 36-SAR	EC: 1969-73, 1982-85, 198 SAR: 1969-73
USGS 0617230 Milk River at Tampico	1,330	4	224-EC data 296-SAR data	45-EC 20-SAR	EC: 1973-77, 1987-2000, 1982 SAR: 1973-77
USGS 06174200 Milk River near Glasgow	1,352	4	152-EC data 140-SAR data	16-EC 8-SAR	EC: 1969-73 SAR: 1970-7
USGS 06174500 Milk River at Nashua	1,502	4	216-EC data 243-SAR data	92-EC 62-SAR	EC: 1960-64, 1967,1969, 1974-2004 1960-64, 1967, 1969, SAR: 1974-93, 1999-2001

Appendix B: Soil series descriptions

LOAMS

Attewan – deep well drained soils formed in alluvium; nearly level and gently sloping soil on fans and terraces; surface runoff is medium; wind and water erosion is moderate; suited to dryfarmed wheat, barley, oats, and wildlife habitat and range; Permeability: 0.6 – 2.0 inches per hour; Salinity: < 2 mmhos/cm; Shrink-swell potential: 0-4inches low, 4-14 in. moderate, 14-24 in. low.

Attewan-Beaverell complex – Attewan and similar soils: 50%, Beaverell and similar soils: 35%; Attewan - Surface layer texture: loam; Drainage class: well drained; Available water capacity: 5.2 inches; Beaverell – Surface layer texture: gravelly loam; Drainage class: well drained; Available water capacity: 2.7 inches; Landform: both on stream terraces and outwash plains.

Beaverell-Tinsley complex – Beaverell and similar soils: 60%, Tinsley and similar soils: 30%; Tinsley – Surface layer texture: gravelly loam; Drainage class: excessively drained; Available water capacity: 1.2 inches.

Bullhook – Landform: floodplains; Drainage class: well drained; Saline within 30 inches; Sodic within 30 inches; Available water capacity: 8.7 inches.

Cabbart-Delpoint complex – Cabbart loam – 45%, Delpoint Loam – 40%; Strongly rolling and hilly soils on uplands that are dissected by deep intermittent stream valleys; Surface runoff is rapid, the hazard of water erosion is moderate, and the hazard of wind erosion is severe; Cabbart – Permeability – 0.6-2.0 inches per hour; Available water capacity: 0.14-0.2 inches per inch of soil; Cabbart – Salinity: <4mmhos/cm; Shrink/swell potential: low; Delpoint – Permeability: 0.6-2.0 inches per hour; Available water capacity: 0.14-2.0 inches per inch of soil; Salinity: <4mmhos/cm; Shrink/swell potential: low.

Creed-Gerdrum complex – Creed and similar soils: 50%, Gerdrum and similar soils: 40 %; Creed – Surface layer texture: loam; Drainage class: well drained; Saline within 30 inches; Sodic within 30 inches; Available water capacity: 6.6 inches; Gerdrum – Surface layer texture: clay loam; Drainage class: well drained; Saline within 30 inches; Sodic within 30 inches; Available water capacity: 6.1 inches.

Degrad – Drainage class: well drained; Permeability: Moderate in the upper 23 inches, rapid below; Landform: stream terraces, outwash plains; typically in cropland; Available water capacity: 4.8 inches

Evanston – Landform: alluvial fans, stream terraces, and drainage-ways; Drainage class: well drained; Available water capacity: 10.1 inches; Surface layer texture: loam; Permeability: moderate; Salinity: 0-5in. <2mmhos/cm, 5-17in. <2mmhos/cm, 17-60in. 2-8 mmhos/cm.

Evanston-Lonna – Evanston loam – 50%, Lonna loam – 40%; undulating and gently rolling soils on uplands; surface runoff is medium, water erosion and wind erosion hazard is moderate; suited to dryfarmed wheat, barley, oats, hay, and pasture, also suited for range and wildlife habitat; Lonna – Permeability: 0.6-2.0 inches per hour; Available water capacity: 0.16-0.22 inches per inch of soil; Salinity: 0-11in.: <2mmhos/cm, 11-65in.: 2-4mmhos/cm; Shrink/swell: 0-11 in. – low, 11-65 in. – moderate.

Evanston-Marmarth – Evanston loam – 50%, Marmarth loam – 30%; undulating to strongly rolling soils on uplands; Surface runoff is medium, hazard of erosion by wind and water is moderate; Suited to dryfarmed wheat, barley, oats, and pasture.

Glendive-Havre – Glendive and similar soils: 60 percent; Havre and similar soils: 30 percent; Landform: flood plains; Glendive – Surface layer texture: loam; Drainage class: well drained; Available water capacity: 8.8 inches; Havre – Surface layer texture: loam; Drainage class: well drained; Available water capacity: 9.7 inches.

Havre – Surface layer texture: loam; Drainage class: loam; Available water capacity: 9.7 inches; Landform: floodplains.

Hillon – occupies moderately steep side slopes of small valleys on glaciated uplands; surface runoff and hazard of wind erosion is moderate, hazard of water erosion is severe; suited for range and wildlife habitat; Permeability: 0 in. – 0.6-2.0 inches per hour, 4-60 in. – 0.2-0.6 inches per hour; Salinity: 0-4 in. <2, 4-60 in. 2-8 mmhos/cm; Shrink-swell potential: 0-4 in. low, 4-60 in. moderate.

Hillon-Joplin – Hillon and similar soils: 50%, Joplin and similar soils: 35%; Hillon – Surface layer texture: cobbly loam; Drainage class: well drained; Landform: hills; Available water capacity: 9.7 inches; Joplin – Surface layer texture: cobbly loam; Drainage class: well drained; Landform: hills; Available water capacity: 9.0 inches.

Hillon-Telstad – Hillon loam: 50%, Telstad loam: 40%; strongly rolling soils on glaciated uplands; Surface runoff is medium or rapid; hazard of wind erosion is moderate, and hazard of water erosion is severe; soils are suited to range and wildlife and to a lesser degree, they are suited to dryfarmed wheat and barley.

Marmarth-Cabbart – Marmarth loam – 40%, Cabbart loam – 35%; gently rolling to hilly soils on uplands; Surface runoff is medium or rapid; wind erosion is moderate, hazard of water erosion is severe; suited to range and wildlife habitat; Marmarth – Permeability: 0.6-2.0 inches per hour; Marmarth – Available water capacity 0.12-0.20 inches per inch of soil; Salinity: 0-16 in.. <2 mmhos/cm; 16-35 in. 1-8 mmhos/cm.

Nishon – nearly level soil in small basins on glaciated uplands; surface runoff is slow or ponded; hazard of wind and water erosion is slight; suited to growing dryfarmed wheat, barley, oats, hay, pasture, range, and wildlife habitat; Permeability: 0-5 in. – 0.6-2.0 inches

per hour, 5-60 in. - <0.06 inches per hour; Salinity: 0-21 in. <2mmhos/cm, 21-60 in. 2 – 8 mmhos/cm; Shrink-swell potential: 0-5 in. – low, 5-60 in. – high.

Phillips – nearly level and undulating soil on glaciated uplands; surface runoff is medium and hazard of wind and water erosion is moderate; suited to growing dryfarmed wheat, barley, oats, pasture, and hay; also suited for range and wildlife habitat; Permeability: 0-5 in. – 0.6-2.0 inches per hour, 5-60 in. – 0.06-0.2 inches per hour; Salinity: 0-12in. <2mmhos/cm, 12-60 in. 2-8 mmhos/cm; Available water capacity: 0-5 in. - 0.14-0.20 inches per inch of soil, 5-12 in. - 0.12-0.16 inches per inch of soil, 12-60in. - 0.12-0.18 inches per inch of soil.

Phillips-Elloam – Phillips loam: 50%, Elloam clay loam: 25%, Thoeny loam: 15%; nearly level to gently rolling soils and glaciated uplands; surface runoff is medium, and the hazard of wind and water erosion is moderate; suited to growing dryfarmed wheat, barely, and oats, also suited for range and wildlife habitat.

Phillips-Nobe-Absher complex – Phillips loam: 40%, Nobe clay: 20%, Absher clay loam 20%, Thoeny loam: 15%; consists of nearly level and gently sloping soils on fans, terraces, and glaciated uplands; surface runoff is slow or medium, and the hazard of wind and water erosion is moderate; soils are suited to range and wildlife habitat

Phillips-Scobey complex – Phillips loam: 50%, Scobey clay loam: 30%; consists of undulating and gently rolling soils on glaciated uplands; surface runoff is medium, and hazard of wind and water erosion is moderate.

Redvale – nearly level and gently sloping soil on stream terraces and fans; surface runoff is slow, permeability is slow to a depth of about 30 inches and then rapid below, available water capacity is low, hazard of wind erosion is moderate, and hazard of water erosion is slight; suited to dryfarmed what, barley, oats, pasture, and hay; Salinity – 0-20 in. < 2 mmhos/cm, 20-30 in. 2-8 mmhos/cm, 30-60 in. <2 mmhos/cm; Shrink-swell potential – 0-6 in. – low, 6-20 in. – moderate, 20-60 in. – low.

Telstad – nearly level to gently rolling soil on glaciated uplands; surface runoff is medium, and the hazard of wind and water erosion is moderated; suited to dryfarmed wheat, barley, oats, hay and pasture, also suited to range and wildlife habitat; permeability is moderate to a depth of about 34 inches and slow below that depth. The soils are suited to dryfarmed wheat, barley, oats, hay, and pasture. Salinity – 0-34in. <2 mmhos/cm, 34-60in. <2 – 8 mmhos/cm; Shrink-swell potential: 0-8 in. –low, 8-16 in. – moderate, 16-34 in. – low, 34-60 in. – moderate; Available water capacity: 0.12-0.20 inches per inch of soil.

Telstad-Joplin – Telstad and similar soils: 50%, Joplin and similar soils: 35%; Telstad – Surface layer texture: loam; Drainage class: well drained; Landform: till plains; Available water capacity: 9.9 inches; Joplin – Surface layer texture: loam; Drainage class: well drained; Landform: till plains; Available water capacity: 9.3 inches.

Thoeny-Phillips – Thoeny loam: 55%, Phillips loam: 35%; consists of nearly level and undulating soils on glaciated uplands; surface runoff is medium, and the hazard of wind and water erosion is moderate; suited to dryfarmed wheat, barley, and oats; Thoeny – permeability is very slow the and available moisture capacity is high; Salinity – 0-13in. < 4mmhos/cm, 13-60 in. 4-15 mmhos/cm; Shrink-swell – 0-6 in. – low, 6-13 in. – high, 13-60 in. – moderate.

SANDY LOAM

Parshall – nearly level and undulating soil is on uplands; surface runoff is slow or medium; the hazard of wind erosion is severe, and the hazard of water erosion is slight; soil is suited to dryfarmed what, barley, oats, hay, and pasture; permeability is moderately rapid; Salinity <2 mmhos/cm; Shrink/swell potential is low; Permeability 2 –6 inches per hour; Available water capacity: 0.10-13 inches per inch of soil.

Tally – undulating soil on uplands; surface runoff is medium; hazard of wind erosion is severe, and the hazard of water erosion is moderate; suited to dryfarmed wheat, barley, oats, pasture, and hay; Salinity – 0-20 in. <2 mmhos/cm; 20-60 in. <2-4 mmhos/cm; Shrink-swell potential – low; Available water capacity– 0-20 in. - 0.10-0.16 inches per inch of soil, 20-60 in. - 0.04-0.08 inches per inch of soil.

Tinsley complex – Tinsley gravely sandy loam – 40%, Other soils that are deep and moderately deep loam and clay loams – 60%; consists of strongly sloping and moderately steep soils on side slopes of stream valley in uplands; surface runoff is rapid; hazard of wind erosion is moderate and the hazard of water erosion is severe; soils suited to rangeland and wildlife habitat; Tinsley – Salinity <2 mmhos/cm; Shrink-swell potential – low; Available water capacity <0.04 inches per inch of soil; Permeability 6 – 20 inches per hour.

SILTY CLAY LOAM

Harlem – nearly level soil occupies flood plains and low terraces along major streams; surface runoff is slow; the hazard of wind erosion is moderate, and the hazard of water erosion is slight; the soil is subject to rare flooding; suited to irrigated crops and dryfarmed crops; Salinity – 0-6 in. <2 mmhos/cm, 6-60 in. 2-8 mmhos/cm; Shrink-swell potential – 0-6 in. – moderate, 6-60 in. – high; Available water capacity 0.12-0.20 inches per inch of soil; Permeability – 0-6 in. -0.2- .6 inches per hour, 6-60 in. - 0.06-0.2 inches per hour.

Havre – nearly level soil on flood plans and stream terraces; surface runoff is slow; hazard of wind erosion is moderate, and the hazard or water erosion is slight; soil is subject to rare flooding; suited to growing irrigated and dryfarmed crops; Salinity – 0-8 in. <2 mmhos/cm, 8-45 in. – 2-8 mmhos/cm, 45-65 in. – 4-16 mmhos/cm; Available water capacity - 0.10-0.20 inches per inch of soil; Permeability – 0-8 in. - 0.2-0.6 inches per hour, 8-65 in - 0.6-0.2 inches per hour; Shrink-swell potential – 0-8 in. – moderate, 8-65 in. – low.

Havre-Glendive complex – Havre silty clay loam – 65%, Glendive loam – 25%; consists of nearly level and gently undulating soils on flood plains and stream terraces; surface runoff is slow, and the hazard of wind and water erosion is moderate; soils are subject to rare flooding; suited to irrigated wheat, barley, oats, corn silage, alfalfa and tame grass hay and pasture; Glendive – Salinity <2 mmhos/cm; Shrink-swell potential – low, Available water capacity – 0-8 in. – 0.12-0.20 inches per inch of soil, 8-60 in. – 0.10-0.13 inches per inch of soil; Permeability – 0-8 in. – 0.6-2.0 inches per hour, 8-60 in. – 2-6 inches per hour.

Kobase – Surface layer texture: silty clay loam; Drainage class: well drained; Landform: lake plains; Permeability: slow; Available water capacity: 9.7 inches.

CLAY LOAM

Elloam – level and undulating soil on glaciated uplands; surface runoff is medium or rapid, and the hazard of wind and water erosion is moderate; suited for range and wildlife habitat; Salinity – 0-6 in. – 2-6 mmhos/cm, 6-60 in. – 4-8 mmhos/cm; shrink-swell potential – 0-6 in. – moderate, 6-60 in. – high; Available water capacity – 0-6 in. – 0.12-0.18 inches per inch of soil, 6-60 in. – 0.10-0.14 inches per inch of soil; Permeability – 0.06-0.2 inches per hour.

Ethridge – Surface layer texture: clay loam; Drainage class: well drained; Landform: alluvial fans, stream terraces, and drainageways; Available water capacity: 9.8 inches; Salinity – 0-4 mmhos/cm; SAR – 16-60 in. – 1-5; Shrink-swell potential – 0-6 in. – moderate, 6-44 in. – high, 44-60 in. – moderate; Permeability – 0-6 in. – 0.20-0.60 inches per hour, 6-60 in. – 0.06-0.20 inches per hour.

Ethridge-Gerdrum – Ethridge and similar soils: 55%, Gerdrum and similar soils: 35%; Surface layer texture: clay loam; Landform: alluvial fans, stream terraces, and drainageways; Gerdrum – drainage class: well drained; saline within 30 inches; sodic within 30 inches; Available water capacity: 6.1 inches; Shrink-swell potential – 0-3 in. – moderate, 3-60 in. – high; Permeability – 0-3 in. – 0.20-0.60 inches per hour, 3-60 in. – 0.01-0.06 inches per hour; Salinity – 0-3 in. – 0-2 mmhos/cm, 3-12 in. – 1-8 mmhos/cm, 12-23 in. – 2-8 mmhos/cm, 23-60 in. – 8-16 mmhos/cm; SAR – 3-12 in. – 10-20, 12-23 in. – 13-20, 23-60 in. – 13-30.

Kevin – Sunburst – Kevin and similar soils: 55%, Sunburst and similar soils: 30%; Surface layer texture: clay loam; Landform: till plains; Drainage class: well drained; Kevin – Drainage class: well drained; Available water capacity: 9.2 inches; Salinity: 9-60 in. – 0-2 mmhos/cm; Shrink-swell potential: 0-6 in. – moderate; 6-9 in. – high; 9-60 in. – moderate; Permeability: 0-6 in. – 0.60-2.00 inches per hour, 6-33 in. – 0.2-0.6 inches per hour, 33-60 in. – 0.06-0.2 inches per hour.

Lallie – Surface layer texture: clay loam; Landform: oxbows; Drainage class: very poorly drained; Saline within 30 inches; Available water capacity: 7.7 inches; Salinity: 0-60 in. – 0-8 mmhos/cm; Shrink-swell potential: 0-16 in. – moderate, 16-60 in. – high; Permeability: 0.06-0.2 inches per hour.

Nishon – Surface layer texture: clay loam; Landform: closed depressions; Drainage class: poorly drained; Available water capacity: 9.3 inches; Salinity: 4-30 in. – 0-2 mmhos/cm, 30-60 in. – 2-4 mmhos/cm; Shrink-swell potential: 0-4 in. – moderate, 4-60 in. – high; Permeability: 0-4 in. – 0.2-0.6 inches per hour, 4-60 in. – 0.06-0.2 inches per hour.

Scobey – nearly level to gently rolling soil is on uplands; surface runoff is medium; hazard of water and wind erosion is moderate; suited to dryfarmed wheat, barley, oats, pasture, and hay; Salinity – 0-15 in. <2 mmhos/cm, 15-60 in. 2-8 mmhos/cm; Shrink-swell potential – 0-5 in. – moderate, 5-15 in. – high, 15-60 in. – moderate; Available water capacity: 0.12-0.18 inches per inch of soil; Permeability: 0-15 in. – 0.2-0.6 inches per hour, 15-60 in. – 0.06-0.2 inches per hour.

Scobey-Kevin – Scobey clay loam – 50%, Kevin clay loam – 35%; Landform: till plains.

Scobey-Sunburst complex – Scobey clay loam – 50%, Sunburst clay loam – 30%; consists of gently rolling to hilly soils on uplands; surface runoff is rapid; the hazard of wind erosion is moderate, and the hazard of water erosion is severe; suited to range and wildlife habitat.

Sunburst - strongly rolling and hilly soil on glaciated uplands and sides of valleys; surface runoff is rapid, hazard of wind erosion is moderate, and hazard of water erosion is severe; suited to range wildlife habitat; shrink-swell potential is moderate; Salinity – 0-4 in. <2 mmhos/cm, 4-60 in. 2-8 mmhos/cm; Available water capacity: 0.12-0.18 inches per inch of soil; Permeability: 0-4 in. – 0.2-0.6 inches per hour, 4-60 in. – 0.06-0.2 inches per hour.

Sunburst-Kevin complex – Sunburst gravelly clay – 50%, Kevin gravelly clay loam – 35%; Landform: hills.

Sunburst-Lisam complex – Sunburst clay loam – 40%, Lisam clay – 35%; strongly rolling and hilly soils on uplands; surface runoff is rapid, hazard of wind erosion is moderate, and the hazard of the water erosion is severe; suited to range and wildlife habitat; Lisam – Salinity: 1-15 mmhos/cm; shrink-swell potential: high; Available water capacity: 0.12-0.18 inches per inch of soil; Permeability: 0.06-0.2 inches per hour.

CLAYS

Nobe-Absher complex - nearly level and gently sloping soils on fans and terraces on uplands and in valleys. Approximately 50% Nobe clay, 40% Absher clay loam. Some Nobe clays have accumulation of salts on the surface and may have high salt concentrations. Surface runoff of the complex is slow to medium; hazard of water erosion is slight. Absher clay loam - seasonal water table greater than 6 in., Permeability: <0.06 inches per hour to 0.2 inches per hour; Salinity: <2-8 mmhos/cm 0-2 in., 8-16 mmhos/cm 2-14 in., >16 mmhos/cm 14-60 in. Nobe clay – seasonal water table greater than 6 ft. deep; Permeability: <0.06 inches per hour, 0-60 inches; Salinity: 4-8 mmhos/cm, 0-60 inches; high shrink-swell potential.

Bowdoin - deep, well drained soils that formed in alluvium and are found on flood plains and low stream terraces. Permeability is very slow, available water capacity is moderate, and reaction is moderately alkaline. These soils are used for range and irrigated hayland, pasture, wildlife habitat, and some irrigated small grain. When the soil is dry, 1-2" wide cracks occur.

Bowdoin clay - nearly level soil on flood plains and low stream terraces. Surface runoff from this soil is slow, hazard of wind and water erosion is slight. Bowdoin soils are subject to rare flooding and are used primarily for irrigated hay and pasture. This soil is best suited to pasture and hay. Seasonal water table > 6 feet; Permeability: <0.06 inches per hour; Salinity: 4-10 mmhos/cm; high shrink-swell potential.

Harlem series - deep, well-drained soils that formed in stratified, fine and moderately fine textured alluvium of mixed origin. The soils occupy flood plains and low terraces along the major streams and rivers. Permeability is slow, available water capacity is high. Reaction is mildly and moderately alkaline. These soils are primarily used for irrigated and dryfarmed crops. Seasonal water tables range from < 6.0 feet to 4-6 feet. Permeability ranges from 0.2 to 0.6"/hr. in upper horizons to 0.06 to 0.20"/hr. in deeper horizons. pH for the series ranges from 7.4 to 8.4. Salinities are <2 mmhos/cm in surface horizons to 4 to 15 mmhos/cm in wet clays with shallow water tables. The shrink-swell potential is moderate to high, predominately high.

Maria series - deep, well drained soils that formed in calcareous, fine-textured alluvium. The soils occupy uplands, fans, and terraces. Permeability is very slow. Reaction is moderately alkaline throughout. These soils are mainly used for dryfarmed crops. When the soils are dry, 1 to 2 inch cracks form in the upper soil layers. The soil is clay or silty clay and is 45 to 60 percent clay. Surface runoff is medium and hazard of water erosion is moderate. This soil is suited to dryfarming, range, and pasture. The seasonal water table is > 6.0 feet, permeability ranges from 0.06 to 0.2 inches/hr. The pH ranges from 7.9 to 8.4, salinity ranges from 2 to 4 mmhos/cm in upper layers and 2 to 8 mmhos/cm in lower layers. The shrink-swell potential is high.

Lisam-Dilts complex - rolling to hilly soil on uplands that are dissected by intermittent streams. The soils occur in an unpredictable pattern on the landscape. Some wet and saline areas are on narrow bottoms along the intermittent streams. Surface runoff is rapid, and hazard of water erosion is severe. These soils are suited to range and wildlife habitat. The seasonal water table is > 6.0 feet, permeability is 0.06 to 0.2 inches/hr., pH ranges from 6.6 to 8.4, salinities range from 1 to 15 mmhos/cm, and the shrink-swell potential is high.

Thebo - moderately deep, well drained soils that formed in material weathered from clay shale. The soils occupy uplands. Clay shale is at a depth of about 23 inches. Permeability is slow and the reaction is moderately alkaline. These soils are used mainly for range and wildlife habitat. The soil is 60 to 75 percent clay. The seasonal water table is > 6.0 feet, permeability is 0.06 to 0.2 inches/hr., pH ranges from 7.4 to 8.4, salinity ranges from 2 to 8 mmhos/cm, and the shrink-swell potential is high.

Thebo-Lisam - undulating to strongly rolling soils on uplands. About 50 percent of the soil is Thebo clay, and about 40 percent is Lisam clay. Surface runoff is medium or rapid, the hazard of water erosion is severe. Soils in this complex are suited to range and wildlife habitat. For Thebo clays the seasonal water table is > 6.0 feet, permeability is 0.06 to 0.2 inches/hr., pH ranges from 7.4 to 8.4, salinity ranges from 2 to 8 mmhos/cm, and the shrink-swell potential is high. For Lisam clays, the seasonal water table is > 6.0 feet, permeability is 0.06 to 0.2 inches/hr., pH ranges from 6.6 to 8.4, salinity ranges from 1 to 15 mmhos/cm, and the shrink-swell potential is high.

Lisam-Dilts-Rock outcrop complex - strongly rolling and hilly soils on uplands that are dissected by intermittent drainage ways. These soils occupy side slopes and foot slopes. Shale crops out on steep side slopes and rounded ridge tops. Surface runoff is rapid, and the hazard of water erosion is severe. This complex is suited to range and wildlife habitat. Some soils are saline. Properties of this soil are highly variable. In general, the seasonal water table is > 6.0 feet, permeability is 0.06 to 0.2 inches/hr., pH ranges from 6.6 to 8.4, salinities range from 1 to 15 mmhos/cm, and the shrink-swell potential is high.

Elloam gravelly clay - undulating and gently rolling soil on glaciated uplands. The soil has a thin surface layer that is mostly gravelly clay. Surface runoff is medium or rapid and the hazard of water erosion is moderate. Permeability of the soil is slow, reaction is mildly alkaline or moderately alkaline to about 6 inches, and moderately or strongly alkaline below. This soil is suited to range and wildlife habitat. The seasonal water table is > 6.0 feet, permeability is 0.06 to 0.2 inches/hr., pH ranges from 7.4 to 9.0, salinities range from 2 to 8 mmhos/cm in upper layers, and 8 to 16 mmhos/cm in lower layers, and the shrink-swell potential is moderate to high.

SILTY CLAYS

Havre-Harlem complex - nearly level soils on flood plains and stream terraces. About 50 percent of the complex is Havre silty clay, and 40 percent Harlem silty clay. The soil has a slowly permeable silty clay surface layer about 12 inches thick. Surface runoff is slow, the hazard of water erosion is slight. These soils are subject to rare flooding; are suited to irrigated and dryfarming and to range and wildlife habitat. Havre silty clays have a seasonal water table > 6.0 feet, permeability ranges from 0.2 to 2.0 inches/hr., pH ranges from 7.4 to 8.4, salinities range from < 2 mmhos/cm in surface layers and 4 to 16 mmhos/cm in lower layers. Harlem silty clays have seasonal water tables generally > 6.0 feet, permeability ranges from 0.06 to 0.2 inches/hr., pH ranges from 7.4 to 8.4, and salinities of < 2 mmhos/cm to 4 to 15 mmhos/cm.

Lallie - deep, poorly drained soils that formed in calcareous fine textured alluvium. The soils occupy oxbows, abandoned stream channels, and low terraces on flood plains along the major streams and rivers. The native vegetation is primarily Prairie cordgrass, Bluejoint reedgrass, Reed canarygrass, sedges, and some forbs. Permeability is slow, reaction is moderately alkaline. These soils are subject to flooding and ponding from stream overflow

and from excess irrigation water the runs off nearby irrigated fields. These soils are mainly used for pasture, range, and wildlife habitat. The seasonal water table depth is 0 to 1.0 feet, permeability is 0.06 to 0.2 inches/hr., pH ranges from 7.9 to 8.4, salinity ranges from 1 to 8 mmhos/cm, and the shrink-swell potential is high.

Vaeda - consists of deep, well-drained soils that formed in alluvium. The soils occupy fans and low terraces. Permeability is very slow. Vaeda soils have a high content of sodium which causes a dispersed condition and restricted water intake into the soil. Reaction is medium acid or strongly acid to a depth of 10 inches and neutral below that depth. These soils are mainly used for range and wildlife habitat. The season water table is > 6.0 feet deep, permeability is <0.06 inches/hr., pH ranges from 5.1 to 8.4, salinity ranges from 4 to 8 mmhos/cm, and the shrink-swell potential is high.

SILT LOAM

Lonna - deep, well drained soils that formed in alluvium. The soils occupy fans and uplands. Permeability is moderate, reaction is moderately alkaline throughout. These soils are used mainly for dryfarmed crops and some wildlife habitat. The seasonal water table is > 6.0 feet deep, permeability is 0.6 to 2.0 inches/hr., pH ranges before 7.9 to 8.4, and salinity is <2 mmhos/cm in upper layers and 2 to 4 mmhos/cm in lower layers. The shrink-swell potential is low to moderate.

Lonna-Marias complex - nearly level and gently sloping soils on uplands. About 50 percent is Lonna silt loam, and 45 percent Marias clay. Surface runoff is medium, the hazard of water erosion is moderate. Soils in this complex are suited to dryfarming, range, and wildlife habitat. The Lonna silt loam seasonal water table is > 6.0 feet deep, permeability is 0.6 to 2.0 inches/hr., pH ranges before 7.9 to 8.4, and salinity is <2 mmhos/cm in upper layers and 2 to 4 mmhos/cm in lower layers. The shrink-swell potential is low to moderate. The Marias clay seasonal water table is > 6.0 feet deep, permeability is 0.06 to 0.2 inches/hr., pH ranges from 7.4 to 8.4, salinity ranges from 2 to 8 mmhos/cm, and the shrink-swell potential is high.

FINE SANDY LOAM

Hanly - very deep, somewhat excessively drained soils that occupy flood plains and formed in alluvium. Permeability is rapid. Permeability ranges from 6.0 to 20.0 inches/hr., pH ranges from 6.6 to 8.4, reaction is slightly to moderately alkaline, and flooding of the soil is rare.

OTHER

Aquic Ustifluvents, saline - consists of deep, nearly level and gently sloping soils that formed in alluvium of flood plains, stream terraces, and fans in valleys. These soils occur along intermittent and perennial streams. The surface layers and underlying material are clay or clay loam. Soils are moderately well drained and somewhat poorly drained. These soils

are subject to common flooding. Surface runoff is slow, hazard of water erosion is slight. The soils are moderately to strongly saline. The seasonal water table is 40 to 60 inches deep during most of the growing season. Soil properties are too variable to be rated.

Typic Fluvaquents, gently sloping - consists of nearly level and gently sloping soils that formed in alluvium on flood plains, in oxbows, in abandoned stream channels, and on stream terraces. This unit is mainly along perennial and intermittent streams. The surface layer and underlying material range from loam to clay. The soils are mostly poorly drained. In some small areas, water stands on the surface. The depth to the seasonal water table is mainly 20 to 40 inches. Surface runoff is slow or the soil is ponded and flooding is frequent. Hazard of water erosion is slight. Soil properties are too variable to be rated.

Ustic Torrfluents, gently sloping - consists of soils that formed in recent deposits of alluvium on nearly level to gently sloping low terraces, bottom lands, and flood plains. Soils are mostly well drained and moderately well drained but are subject to common flooding. The soil is stratified loam to clay. Soil characteristics are extremely variable. Surface runoff is mainly slow or medium and the hazard of water erosion is moderate. The soils in this unit are suited to range and wildlife habitat.

Fluvaquentic Haploborolls, gently sloping - consists of nearly level and gently sloping soils that formed in alluvium on bottom lands and low terraces along intermittent streams. The soils are dark gray loam and clay loam in the surface layer and underlying material. These soils are dominantly somewhat poorly drained. The water table fluctuates between depths of 30 to 60 inches. Surface runoff is slow and the hazard of water erosion is slight. These soils are subject to common flooding and are suited to range, pasture, and wildlife habitat. Soil properties are too variable to be rated.

Appendix C: Crops and native vegetation

Table 23. Irrigated Crops for Phillips and Valley Counties, Montana, 2004 and 2005.
Adapted from USDA National Agricultural Statistics Service

Crop	Year	County	Planted All Purposes (acres)	Harvested (acres)	Yield (per acre)	Production (county total)
Winter Wheat All	2004	Phillips	900	700	60 bushel	42,000 bushel
Wheat Other Spring	2004	Phillips	3,300	3,300	64 bushel	212,000 bushel
Wheat Other Spring	2005	Phillips	2,700	2,600	58 bushel	152,000 bushel
Wheat All	2004	Phillips	4,200	4,000	63.5 bushel	254,000 bushel
Wheat All	2005	Phillips	3,200	3,000	57 bushel	171,000 bushel
Barley All	2004	Phillips	2,300	600	68 bushel	41,000 bushel
Hay Alfalfa (Dry)	2004	Phillips		17,500	2.8 tons	48,500 tons
Hay Other (Dry)	2004	Phillips		19,000	2 tons	38,000 tons
Hay All (Dry)	2004	Phillips		36,500	2.37 tons	86,500 tons
Wheat Durum	2004	Valley	900	900	86 bushel	77,000 bushel
Wheat Durum	2005	Valley	700	700	71 bushel	50,000 bushel
Wheat Other Spring	2004	Valley	5,000	4,800	58 bushel	279,000 bushel
Wheat Other Spring	2005	Valley	5,700	4,900	49 bushel	239,000 bushel
Wheat All	2004	Valley	6,500	6,100	62.6 bushel	382,000 bushel
Wheat All	2005	Valley	6,400	5,600	51.6 bushel	289,000 bushel
Corn for Silage	2004	Valley		1,600	20 tons	32,000 tons
Corn for Silage	2005	Valley		1,100	21 tons	23,600 tons
Barely All	2004	Valley	3,300	1,500	73 bushel	110,000 bushel
Beans Dry Edible	2005	Valley	1,600	1,300	1,120 pounds	14,500 hundredweight
Hay Alfalfa (Dry)	2004	Valley		30,000	3.8 tons	113,000 tons
Hay Other (Dry)	2004	Valley		4,500	2.4 tons	11,000 tons
Hay All (Dry)	2004	Valley		34,500	3.59 tons	124,000 tons

Table 24. Native riparian vegetation found along the Milk River and associated salt tolerances. Adapted from Jones (2003), CPHA (2002), Hanson et al. (1999), Warrence (2001) and NRCS PLANTS database.

Common name	Latin name	Salt tolerance	Comments (salt tolerance)
plains cottonwood	<i>Populus deltoides</i>	4,000 μ S/cm ECe	Acceptable upper limit salinity
narrowleaf cottonwood	<i>Populus angustifolia</i>	Low	Less than 3,000 μ S/cm
black cottonwood	<i>Populus balsamifera ssp. Trichocarpa</i>		
boxelder	<i>Acer negundo</i>	6,000 μ S/cm ECe	Acceptable upper limit salinity
peachleaf willow	<i>Salix amygdaloides</i>		
red-osier dogwood	<i>Cornus sericea</i>	2,000 μ S/cm ECe	Acceptable upper limit salinity
yellow willow	<i>Salix lutea</i>		
chokecherry	<i>Prunus virginiana</i>	2,000 μ S/cm ECe	Acceptable upper limit salinity
western snowberry	<i>Symphoricarpos occidentalis</i>	4,000 μ S/cm ECe	Acceptable upper limit salinity
Wood's rose	<i>Rosa woodsii</i>	None	
silver buffaloberry	<i>Sheperdia argentea</i>	Medium	3,000 to 8,000 μ S/cm
western wheatgrass	<i>Pascopyrum smithii</i>	High	Greater than 8,000 μ S/cm
thickspike wheatgrass	<i>Elymus lanceolatus</i>	High	Greater than 8,000 μ S/cm
Kentucky bluegrass	<i>Poa pratensis</i>	Low	Less than 3,000 μ S/cm
smooth brome	<i>Bromus inermis</i>	Low	Less than 3,000 μ S/cm
silver sage	<i>Artemisia cana</i>	Low	Less than 3,000 μ S/cm
saltgrass	<i>Distichlis spicata</i>	70,000 μ S/cm ECe	Max reported tolerance
three-square bulrush	<i>Schoenoplectus pungens</i>	Medium	3,000 to 8,000 μ S/cm
black greasewood	<i>Sarcobatus vermiculatus</i>	High	Greater than 8,000 μ S/cm
broadleaf cattail	<i>Typha latifolia</i>	17,500 μ S/cm ECe	Max reported tolerance
hardstem bulrush	<i>Schnoenoplectus acutus</i>	Medium	3,000 to 8,000 μ S/cm

Appendix D: EC x SAR interaction

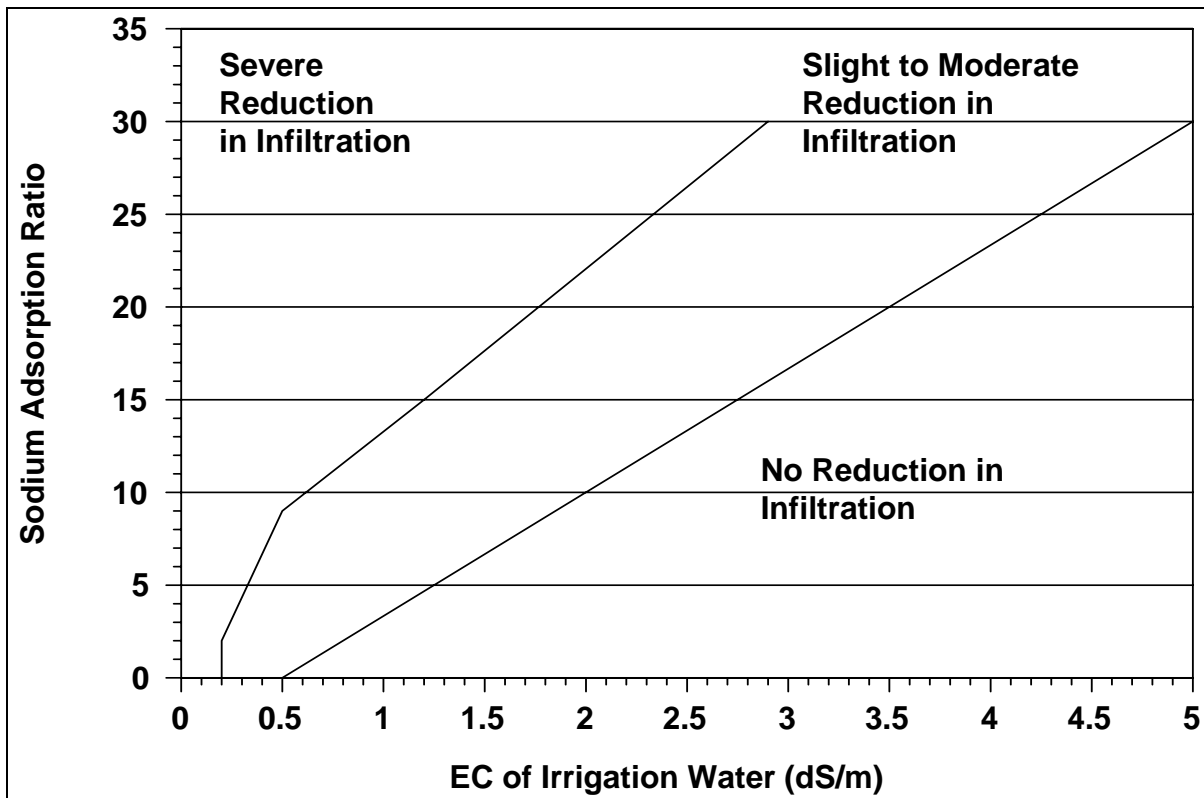


Figure 4. Reduction in soil infiltration as defined by the interaction between EC and SAR of irrigation water. (Source: Hanson et al., 1999)

Appendix E: Ice jams

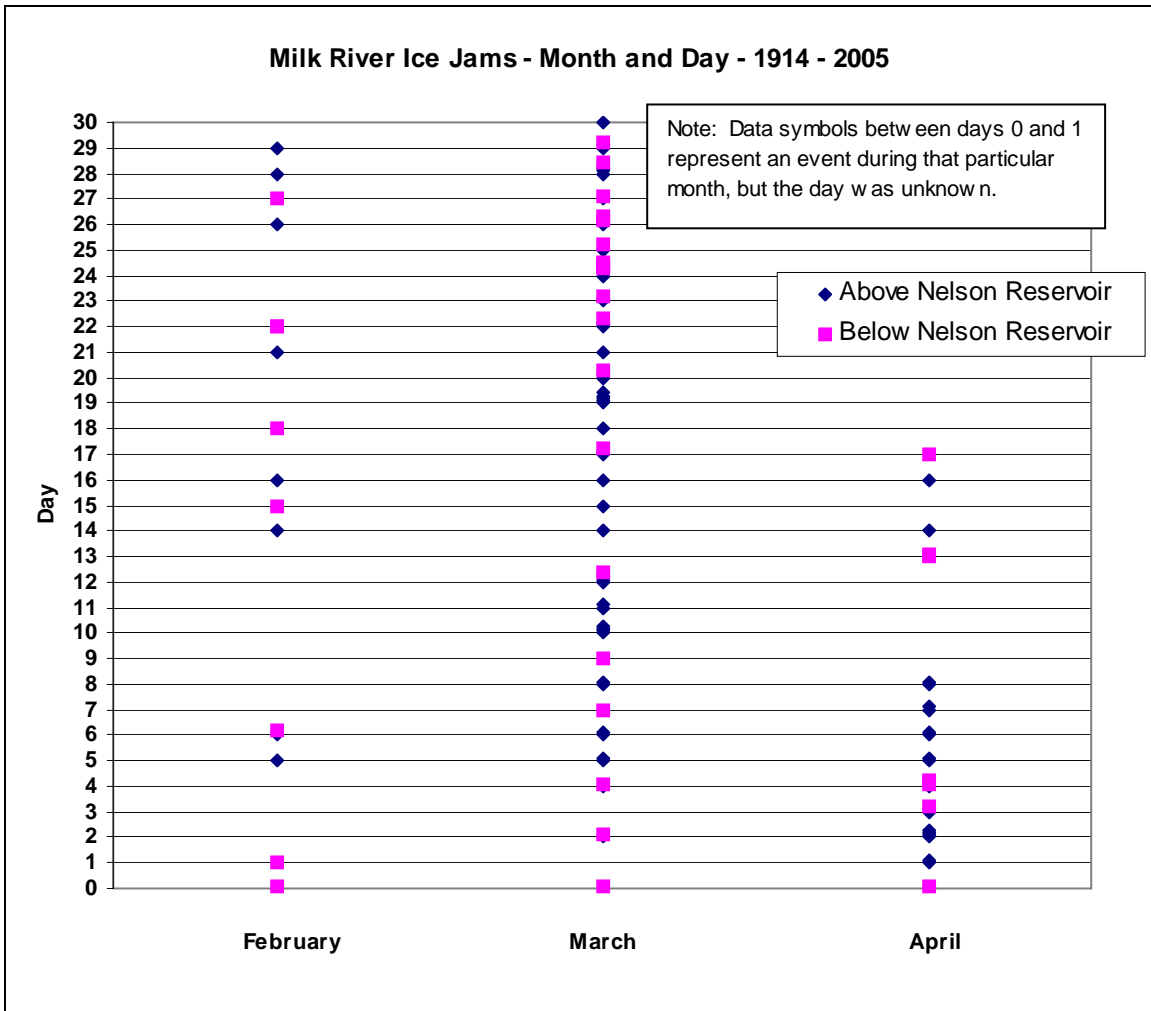


Figure 5. Ice jam occurrence and season for the Milk River above and below Nelson Reservoir from 1914 to 2005. Data obtained from Army Corp of Engineers CRREL Ice Jam Database.

Appendix F: Response to comments

In December of 2006, MSU-EWQ provided the RWRCC technical team with a draft version of this report. The technical team reviewed the report and following a public meeting, submitted comments and additional scenarios for consideration. MSU-EWQ has attempted to address RWRCC and public comments to the draft report below.

Comment #1:

Early on, RWRCC staff unilaterally ruled out the alternative of making systematic releases of saline water into Beaver Creek (except during flood events) to reach salt balance in the refuge. RWRCC's rationale was that upstream from of Nelson Reservoir, Beaver Creek is an intermittent stream, and downstream of the Reservoir, flows are small in volume and high in "background" salinity. If water from the Refuge is released into Beaver Creek, the lack of mixing flows would result in unacceptably high salinity levels, and due to the extremely shallow slope of the channel, a large volume of the brine would accumulate in the channel pool behind Vandalia Dam. Glasgow Irrigation District would be forced to delay springtime irrigation deliveries until natural spring runoff had time to push the brine downstream. However, the FWS is not ready to rule out Beaver Creek just yet, because they want to keep their options open as they embark on their CCP process. Does MSU-EWQ see any major problems with RWRCC's rationale? If so, under what kinds of conditions might releases to Beaver Creek become feasible? Would MSU-EWQ recommend further study?

MSU-EWQ Response #1:

During the proposed discharge season of saline water from the Refuge of November 1 through February 28, only the lower portion of the creek (east of Nelson reservoir) has any significant amounts of water. Montana DNRC has monitored four sites on Beaver Creek for flow and EC during the last several years. Two of the monitoring sites were located on upper Beaver Creek (south of Bowdoin NWR and Nelson Reservoir). Monitoring indicated this portion of the creek generally has little or no flow during this period. The other two stations on Beaver Creek were located to the east and downstream of Nelson Reservoir. The Beaver Creek near Saco monitoring site was monitored from 2005 and 2006 (n=7) had an average EC of 2,172 $\mu\text{S}/\text{cm}$ with a corresponding average flow of 10 cfs for November through February. Downstream of this site, a site identified as Beaver Creek near Hindsdale, has been monitored since 2003. The average EC at Beaver Creek near Hindsdale was 3,127 $\mu\text{S}/\text{cm}$ and the average flow was 13 cfs during 15 sampling events within the November 1 to February 28 period.

In general, salinities in the range of 2,000-3,000 $\mu\text{S}/\text{cm}$ are considered the upper range of acceptable salinity levels for plants. The ambient EC in Beaver Creek during the proposed discharge season (non-irrigation season) is already within this range. While the proposed discharge scenario presents little to no impacts to irrigated crops, native plants, aquatic

habitat, and bank storage must be considered, and any increase in ambient salinity needs to remain within reasonable confidence limits of the historic non-irrigation season.

To evaluate effects on Beaver Creek salinities, MSU-EWQ used average flows and EC values measured at DNRC Beaver Creek monitoring stations during the non-irrigation season to calculate mixed flow-weighted EC values based on a release of 5 cfs at 7,820 $\mu\text{S}/\text{cm}$ EC from Bowdoin/Dry Lake to Beaver Creek.

Beaver Creek near Saco: 10 cfs @ EC of 2,172 $\mu\text{S}/\text{cm}$ + 5 cfs @ 7,820 $\mu\text{S}/\text{cm}$ =
Flow-weighted EC of 4,055 $\mu\text{S}/\text{cm}$

Beaver Creek near Hindsdale: 13 cfs @ EC of 3,127 $\mu\text{S}/\text{cm}$ + 5 cfs @ 7,820 $\mu\text{S}/\text{cm}$ =
Flow-weighted EC of 4,431 $\mu\text{S}/\text{cm}$

These two scenarios present 29 to 46% increases in ambient non-irrigation season EC at Beaver Creek monitoring sites. The MT-DEQ non-degradation rule, which the MT-Board of Environmental Review adopted and applied to the standards for the Tongue, Powder Rivers and Rosebud Creek, indicates that the increase in salinity below the mixing zone cannot exceed the ambient by more than 10%. Thus, application of the non-degradation rule would preclude discharge from Bowdoin to Beaver Creek under the existing conditions.

Based on ambient non-irrigation season conditions within Beaver Creek, MSUEWQ concludes that Beaver Creek is not a viable option to receive releases of saline water from the Refuge, and see no need to research this alternative any further.

Comment #2:

In MSU-EWQ's analysis of potential downstream effects of a flood related spill, an assumption was made that the flood water would thoroughly mix with the saline water in the Refuge before passing downstream. I suspect the assumption, for all practical purposes, is valid. Please re-visit the assumption and comment on the following scenario (scenario based on analysis of landsat imagery of past Bowdoin flood event): Out-of-bank flows from Beaver Creek spilled into the Refuge at the east end of Lake Bowdoin, and then turned and flowed eastward through Dry Lake and back into Beaver Creek. Dry Lake was fully incorporated into the flood, and RWRCC suspects that any water that might have been held in Dry Lake before the flood was either mixed with the flood or pushed ahead as a surge on the front of the flood hydrograph. Lake Bowdoin, appears to have been pushed aside and bypassed by the flood. While some of the saline water might have drained into the floodwaters as the flood levels receded, much of it might have remained in the lake after the flood.

Another situation that might lead to an accidental discharge of water from the Refuge would be structure failure due to vandalism (e.g. pranksters removing flashboards) or dike failure due to rodent burrows. While the Refuge staff monitors the dikes pretty closely, but there is a remote chance it could happen.

MSU-EWQ Response #2:

Response to these questions and scenarios has been built into Chapter 5.

Comment #3:

According to John Lacey, the setting at Bowdoin appears to be similar to that in the Big Muddy Creek/Medicine Lake area. John suggested the report might be valuable and serve as a reference.

Response #3:

Review of the NRCS report mentioned by Mr. Lacey by MSU-EWQ revealed that, while the Big Muddy Creek/Medicine Lake situation is similar in many aspects to the Bowdoin Refuge situation, the report itself was not applicable to this report. Additionally, MSU-EWQ conducted a search for additional reporting on Big Muddy/Medicine Lake, and found no additional published articles or data. Thus, MSU-EWQ was unable to reference Big Muddy/Medicine Lake due to lack of published and/or reliable materials on Big Muddy Creek.