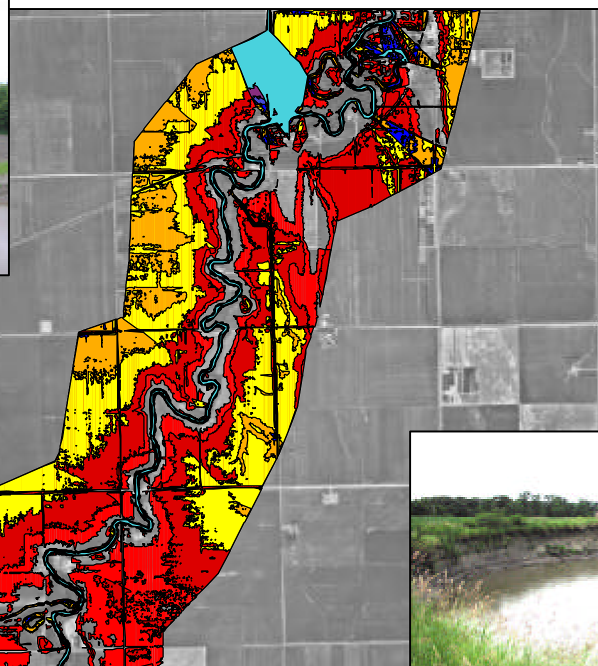
# Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives

## Sheyenne River Valley



***January 22, 2002***

**Prepared for:**

**ST. PAUL DISTRICT**
**UNITED STATES ARMY CORPS OF ENGINEERS**

Task Order Number: DACW37-00-D-004 (2;Partial Fullfillment))

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# EXECUTIVE SUMMARY

## BACKGROUND

Three outlet alternatives for reducing Devils Lake flooding problems are under consideration. Under the 300 cfs Constrained Outlet alternative, a constructed outlet would discharge Devils Lake water to the Sheyenne River between May and November whenever the level of Devils Lake exceeded 1441.6 fASL. Pumping would be constrained by; (1) a maximum pumping capacity of 300 cfs, (2) a maximum combined flow of blended Devils Lake/Sheyenne River water of 600 cfs at the point of insertion and (3) a maximum sulfate concentration in blended water of 450 mg/L. Under the 480 cfs Unconstrained Outlet alternative, Devils Lake water would be discharged via a constructed outlet during the same time period without constraint at a rate of 480 cfs any time the level of Devils Lake exceeded 1441.6 fASL. The No Action (natural spill) alternative) assumes that wet conditions will continue until water from the Devils Lake chain overflows naturally from Stump Lake through the Tolna Channel to the Sheyenne River.

There are three potential ways that the discharge of Devils Lake water could directly induce soil salinization problems along the Sheyenne River:

(1) Additional salt loading to affected floodplain soils could result from over-bank flooding with more saline, blended Devils Lake/Sheyenne River water.

(2) Salinization could result from raising watertables under floodplain and adjacent soils above a "critical depth", such that capillary action and evapotransiration would concentrate salts at the soil surface.

(3) Seepage outflow of mixed Devils Lake/Sheyenne River water could produce additional salt loading to adjacent floodplain soils during periods when the river is contained within the channel.

The impacts of these potential salinization mechanisms have been assessed based on; (1) projected changes in Sheyenne River water quality, (2) projected changes in the river' s stage and flow dynamics and (3) the effects of these changes on saline or salinizable soils within or adjacent to the floodplain of the Sheyenne River.

### Methods

### Sheyenne River Water Quality

The St Paul District, USACE developed Stochastic models to assess the environmental and economic impacts of the outlet alternatives, producing 10000 traces (or "futures") predicting flow and water quality estimates for the Sheyenne and Red Rivers under various climatic and outlet operational conditions. The "Wet7" trace was selected for analyzing the impacts of the outlet alternatives on potential salinization hazards along the Sheyenne River because it: (1) provides a conservative, "worst case" estimate of salinization hazards, (2) represents conditions that would require continued outlet operations for the projected 45-year life of the project, and (3) is a member of the "wet class" of futures that represents a continuation of the current pluvial (wet) period. Water quality traces for salinity (measured as total dissolved solids - TDS), sodicity (measured as sodium adsorption ratio - SAR), and associated water quality data were provided for each outlet alternative for five control points along the river. Datasets were tailored to facilitate the assessment of soil salinization hazards under the outlet alternatives. The effects of outlet operation parameters and the no-action "Natural Spill" alternative on salinity-related Sheyenne River water quality parameters were assessed by analyzing distribution statistics, exceedance plots and plots of TDS vs SAR overlaid onto the NSSL salinity/sodicity hazard classifications for irrigation water.

**Sheyenne River Stage and Flow**

The following resources were used to characterize the dynamics of river stages and flows along the Sheyenne River.

1. HEC 5Q model predictions used to assess daily variations in river stage, water quality, and flow were provided as a graphical user interface program for the Wet 7 climatic scenario.
2. Daily flow predictions provided by the St Paul District USACE for the Wet 7 climatic scenario were used to evaluate the flow dynamics for the Wet 7 scenario over the 45-year life of the project from initiation of pumping on May 1, 2005 to cessation of pumping November 30, 2050. Data are presented as percent exceedance graphs for the Cooperstown and Kindred control points.
3. Predictions of mean stage increases above long-term average base levels for May and August for USGS stage gauges at Warwick, Cooperstown, Valley City, Lisbon, Kindred, Horace, and West Fargo supplied by the St. Paul District, USACE.
4. Hydrographs from nearby water table wells developed by the United States Geological Survey (USGS) to determine the relationships between river stage and groundwater relationships with distance from the Sheyenne River.
5. Flooded area outlines calculated from Lidar digital elevation model (DEM) data.

**Soil Associations Along the Sheyenne River**

To characterize soils along the Sheyenne River, generic soil associations were developed based on Geographic Information Systems (GIS) data obtained directly from the Natural Resources Conservation Service (NRCS). Where available, Soil Survey Geographic (SSURGO) datasets were used. Where SSURGO datsets were unavailable, soils were hand digitized from scanned and geographically rectified soil survey map sheets. Only map units within a 1.5-mile buffer of the Sheyenne River and dominated by moderately well drained, somewhat poorly drained, poorly drained or very poorly drained soils within the valley floor were analyzed. The GIS was queried to determine acreages of soils in these drainage classes mapped along the valley floor within each soil survey area. Soils were then listed from most to least extensive on an acreage basis within the soil survey area and then placed in geomorphic context to define each Association.

**Soil-Attribute Database**

A relational soil attribute database was developed in Microsoft Access based on data from the NRCS Map Unit Interpretations Record (MUIR). MUIR contains virtually all of the soil attribute information included in a standard soil survey, including soil map unit composition, the percentages of major components and inclusions broken down by soil series, and physical, chemical, and interpretative data. The soil attribute database was used to; (1) develop descriptive soil legends, (2) determine major components and included soils of minor extent for each Association, and (3) evaluate important hydrological, morphological, and mineralogical characteristics important to evaluate salinization potential under the outlet alternatives. The result of this evaluation provided acreage estimates of all major, minor, and included soils mapped along the floor of the Sheyenne River Valley. Soil legends include descriptive data and the percentages of major and minor components by County Soil Map Unit. Natural Resources Conservation Service (NRCS) Official Series Descriptions (OSDs) of all soils identified along the Sheyenne River valley are also provided. The geomorphic settings for the soils were determined from the published soil surveys and from OSDs.

**Soil Salinization Hazard Classes**

Due to the imprecision of available data on existing soil salinity levels and ground water dynamics, a quantitative assessment of soil salinization hazards was precluded. Accordingly, salinity and salinization potential was qualitatively evaluated by placing potentially affected soils in their hydrogeologic setting and then estimating the effects of increased river stage, overbank flooding, and river water salinity under each outlet alternative. Four qualitative salinization hazard classes (i.e. None, Slight, Moderate, and Severe) were established based on; (1) soil drainage class and permeability, (2) seasonal high water tables, (3) flooding frequency and duration, (4) landscape setting and (5) existing soil/subsoil salinity and sodicity. Each soil series within each Association was ascribed a salinity hazard class. Acreages falling within each hazard class were compiled by Soil Association and for the Sheyenne River valley as a whole. Due to the limitations inherent in data on soils, water quality and river stage/flow, salinity hazards among the outlet alternatives were compared qualitatively. Most soils were placed in two classes (e.g. None to Slight) because broad ranges in landscape setting and soils physical and chemical characteristics preclude a more specific rating.

## RESULTS AND DISCUSSION

**Sheyenne River Water Quality**

***TDS and SAR Distribution Statistics***

There is a progressive increase in mean TDS values from baseflow conditions to the 300 cfs Constrained, the 480 Unconstrained, and the No Action (natural spill) alternatives. TDS values generally decrease with increasing distance from the point of insertion, most likely due to dilution from tributary and groundwater inflows and mixing in the Lake Ashtabula reservoir. Mean TDS values for the constructed outlet alternatives are uniformly below 1000 mg/l. When compared to the No Action (natural spill) alternative these values are quite close to baseline conditions. However, mean TDS values are much higher under the No Action (natural spill) alternative when compared to baseline, and are at or near 1000 mg/l throughout the reach of the Sheyenne River (ranging from 1600 (EC = 2.5 dS/m ) at Cooperstown to 1000 (EC = 1.5 dS/m) at Kindred).

Relationships between SAR, control point and alternative essentially mirror the relationships observed for TDS. Baseflow SAR values range from 1.5 to just over 2.0, with progressive increases in SAR due to increased proportions of Devils Lake water and decreasing distance from the point of insertion. Maximum mean SAR values reflect the additions of highly sodic

Stump Lake water in the No Action (natural spill) alternative along with proximity to the point of insertion for the Natural Spill. Thus mean SAR values are highest for Cooperstown (mean SAR of 6.98 for the No Action (natural spill) alternative), and decrease progressively downstream.

Mean SAR values under the constructed outlet alternatives range from just over 3.5 at Cooperstown to just over 2.5 at Kindred. Most irrigated soils in North Dakota do not experience sodicity-induced problems until the SAR goes above 5-6. SAR values under the constructed outlet alternatives are well below a SAR of 6. However, many soils periodocally flooded with Blended Stump Lake/Sheyenne River water under the No Action (natural spill) alternative may experience sodicity induced problems.

***Temporal Variability in TDS and SAR: Percentage Exceedance Curves***

Percentage exceedance graphs were used to assess the temporal variability in TDS and SAR values. Under the 480 cfs Unconstrained Outlet alternative, the outlet would operate about 65 percent of the time and blended water would be present in 69 percent of the daily predicted water quality values. Under this alternative, the outlet was not operating about 31 percent of the time because the predicted level of Devils Lake had dropped below 1441.6 fASL. While the 300 cfs Constrained Outlet alternative is limited by streamflow and sulfate concentrations at the point of insertion, outlet operation is essentially continuous over the entire period considered in this study. While the 480 Unconstrained Outlet and No Action (natural spill) alternatives result in poorer quality water, there would be more periods when baseflows prevail. Under the No Action (natural spill) alternative, natural overflow would occur only about 23 percent of the time over planning period. During the remainder of the planning period, no natural overflow would occur and water quality in the Sheyenne River is that of baseflow. While the natural spill from Stump Lake would occur for only a portion of the planning period, TDS and SAR values would be very high and would persist continuously for several years.

Regardless of alternative, when considered across the entire planning period, there are significant periods of time during the growing season where TDS and SAR are similar to baseflow values. These periods, generally at the higher percentage-exceedance ranges, are separated by only a few hundreds of mg/l or 0.5 SAR units for the upstream control points and less than this in the control points located along the Red River.

***NSSL Irrigation Water Salinity Hazard Classifications***

Since overbank flooding is the essentially the equivalent of intermittent irrigation, Sheyenne River water TDS and SAR data were plotted on National Soil Salinity Laboratory (NSSL) graphs of salinity/sodicity hazard classes for irrigation water. Base values for all control point locations along the Sheyenne River fell into the high end of the C2-S1 and the low end of the C3-S1 categories, indicating low to medium salinity water with low sodicity under natural conditions. Under the 300 cfs Constrained Outlet and 480 cfs Unconstrained Outlet alternatives, salinity and sodicity levels were progressively higher. However, the projected increases were not sufficient to change the NSSL hazard class from baseflow conditions. Under the No Action (natural spill) alternative, TDS and SAR values for river water at Kindred, Lisbon and Valley City move well into the C4-S2 and C4-S3 categories. For the Cooperstown control point upstream of Lake Ashtabula and closer to the point of insertion, TDS and SAR values for the No Action (natural spill) alternative move into the extremes of the C4-S3 category. Very high salinity and high sodicity are represented by the C4 and S3 categories, respectively. Soils regularly to intermittently inundated or exposed to water in the C4 and S3 categories would experience significant salinization- and sodification-induced problems.

## Sheyenne River Stages and Flows

### *HEC 5Q GUI predictions of daily stage and flow dynamics for the Wet7 Scenario*

Hydrographs showing predicted flow and stage data for a representative 5-year period (April 1, 2015 to March 2020) were developed based on HEC 5Q output provided by the St. Paul District, USACE. This period was chosen to represent a time where a natural spill was occurring from Stump Lake in order to compare stage and flow data among all of the outlet alternatives. The hydrographs show the following:

1. An expected large rise resulting from spring snowmelt is evident for all years. Outlet operations generally start May 1 after the spring flood has declined to levels below peak flood stage. Outlet operations under the 300 cfs Constrained alternative would not begin until floodwaters have receded to the point that the Sheyenne is within the banks at the point of insertion. This constraint on outlet operation would limit the impacts of overbank flooding. Regular spring flooding with base condition floodwater would also tend to leach salts that may have accumulated prior to the flood event.

2. Under the 480 cfs Unconstrained alternative, spring flooding would be aggravated because outlet operations would begin even during periods of overbank flooding at the point of insertion. The effects would be mitigated somewhat by the fact that the additional water added during outlet operation is a small portion of the spring flood volume, and may be diluted to some degree. In addition, even though outlet operations under the 480 unconstrained alternative are not limited by channel flow capacity, the beginning of outlet operations on May 1 ensures that the introduction of Devils Lake water into the Sheyenne will occur after the majority of spring flooding has passed.

3. Average stage increases during normal, in-bank flows vary between 2.5 to 3.5 feet for the 300 cfs Constrained and the 480 cfs Unconstrained alternatives, respectively.

4. Mean flows and stage under the No Action (natural spill) alternative are generally well under the flows and stages associated with the constructed outlet alternatives but will consist of more saline/sodic blended water for the duration of the flood event.

5. Flow and stage decline dramatically upon cessation of pumping on November 30.

6. Winter stages and flow in the Sheyenne River are maintained at generally higher levels under the No Action (natural spill) alternative due to continuous discharge from Stump Lake.

### *Average Stage for May and August*

Projected mean increases in the stage of the Sheyenne River as a result of adding 300 and 480 cfs to mean May and August flows were provided by the St. Paul District, USACE. These results are consistent with the observations made using HEC5Q data. The data show stage increases for May (higher flows) of 1 to 2.5 feet and 1 to 3.5 feet for the 300 and 480 cfs alternatives respectively. The data also show stage increases for August (lower flows) of 1 to 3 feet and 1 to 4 feet for the 300 and 480 cfs alternatives respectively.

### *Percentage exceedance graphs for HEC5Q predicted flows at Cooperstown and Kindred*

Percentage exceedance graphs developed for the 45-year planning period using HEC5Q data for Cooperstown and Kindred show that flooding in excess of 1000 cfs for the period of constructed outlet operations will be relatively rare. Flows above 1000 cfs for Cooperstown (representative of upstream conditions) can be expected for only approximately 2-5% of the growing season, primarily associated with the recession of spring flooding. Flows above 1000 cfs for Kindred (representative of downstream conditions) will be above 1000 cfs for approximately 2-5% of the growing season, again occurring primarily during spring. A comparison of this data to the HEC 5Q flow predictions again suggests that natural spring flooding would largely be over in most years before the annual discharge of Devils Lake water into the Sheyenne River.

### *USGS Monitoring Wells*

The USGS has provided interim water table well hydrograph data showing water table responses to controlled and uncontrolled increases in Sheyenne River stage. Wells were set perpendicular to the river at distances varying from 25 feet to over a thousand feet. Large stage changes in the Sheyenne River were generally in concert with changes in water table elevations in wells up to 800 feet from the river. However, the effects of minor stage changes were "dampened" even in fairly close wells. Wells emplaced at 1000 feet distant from the river showed only minor correspondence with stage levels in the Sheyenne. Based on this data, it appears that significant increases in river stage appear to create bank storage or backflow conditions that can affect watertables in nearby floodplain soils.

### *Flooded Area Outlines*

HEC-RAS predicted flooded area outlines at 1000, 1500, 2000, and 3000 cfs were used to estimate the potential flooding along the Sheyenne River. These models are based on accurate 1999-2000 Lidar digital elevation models (DEM) data. Extensive overbank flooding would occur at flow rates above 1000 cfs in the upper reaches of the Sheyenne River (i.e. above Lake Ashtabula). However, flow rates up to 3000 cfs in the deeply entrenched portions of the Sheyenne River below Baldhill Dam are essentially confined within the banks of the Sheyenne River and adjacent abandoned meanders and oxbows.

## SOIL SALINIZATION HAZARDS BY ASSOCIATION AND OUTLET ALTERNATIVE

### Acreage Breakdown of Soil Salinization Hazards by Soil Association

Six generic soil associations were developed for use in analyzing soil salinity hazards. The Lamoure-LaDelle-LaPrairie-Ryan and LaDelle-Ludden-Wahpeton Associations lie within the Till Plain reach of the Sheyenne River upstream of Lake Ashtabula between river miles 460 and 277. The LaDelle-Nutley and Fairdale-LaPrairie-LaDelle Associations lie within the Till Plain reach of the Sheyenne River but are downstream of Baldhill Dam between river miles 259 and 94. The Fairdale-LaDelle-Wahpeton-Delta association is dominated by the Sheyenne Delta between river miles 94 and 63. The Fairdale-Fargo Association lies on the Lake Plain reach between river miles 63 and the Sheyenne River's confluence with the Red River at river mile 0. Soil associations upstream of Lake Ashtabula are characterized by a shallowly entrenched river channel, a broad active floodplain and extensive areas of poorly and very poorly drained soils. Due to these characteristics, the majority of the existing saline soils along the Sheyenne River lie upstream of Lake Ashtabula. Soil associations downstream of Baldhill Dam are characterized by a much more deeply entrenched river and dramatically reduced acreages of poorly and very poorly drained soils. Saline soils are much less extensive downstream, being restricted largely to recently abandoned meanders on the active floodplain. The Fairdale-Fargo Association lies within the Red River Valley, which represents the former bed of Glacial Lake Agassiz. In this reach, the Sheyenne River valley is essentially confined to the entrenchment itself and several geomorphic settings immediately adjacent to the river. Again, saline or salinizable soils represent a minor component of this association.

The following table summarizes the acreages of soils in each hazard classification within each soil association.

**Acreage Summary of Soil Salinization Hazard Classes by Soil Association.**

| Soil Association | None | None-to-Slight | Slight-to-Moderate | Moderate-to-Severe | Not Rated | Grand Total |
|---|---|---|---|---|---|---|
| **Soil Associations Upstream of Lake Ashtabula** | | | | | | |
| Lamoure-LaDelle-LaPrairie-Ryan | 627 | 2803 | 3036 | 7674 | 172 | 14312 |
| LaDelle-Ludden-Wahepeton | 1515 | 510 | 4923 | 2366 | 50 | 9364 |
| ***Subtotals (acreage)*** | ***2142*** | ***3313*** | ***7959*** | ***10040*** | ***222*** | ***23676*** |
| ***Subtotals (percent)*** | ***9.0*** | ***14.0*** | ***33.6*** | ***42.4*** | ***0.9*** | ***100.0*** |
| **Soil Associations Downstream of Baldhill Dam** | | | | | | |
| LaDelle-Nutley | 3006 | 3038 | 752 | 502 | 41 | 7339 |
| Fairdale-LaPrairie-LaDelle | 139 | 5002 | 7991 | 357 | 18 | 13507 |
| Fairdale-LaDelle-Wahpeton-Delta | 1884 | 2255 | 2676 | - | 17 | 6832 |
| Fargo-Fairdale | 6169 | 2144 | 5201 | 228 | - | 13742 |
| ***Subtotals (acreage)*** | ***11198*** | ***12439*** | ***16620*** | ***1087*** | ***76*** | ***41420*** |
| ***Subtotals (percent)*** | ***27.0*** | ***30.0*** | ***40.1*** | ***2.6*** | ***0.2*** | ***100.0*** |
| **Grand Totals (acreage)** | **13340** | **15752** | **24579** | **11127** | **298** | **65096** |
| **Grand Totals (percent)** | **20.5** | **24.2** | **37.8** | **17.1** | **0.5** | **100.0** |

The vast majority of soils in the Slight-to-Moderate hazard classification are occasionally flooded LaDelle and frequently flooded Fairdale soil series. Little is known regarding the hydrologic connection between groundwater in Fairdale and LaDelle soils and the Sheyenne River. Groundwater recharge can be assumed during flooding events when the soils are inundated. However, groundwater discharge from upslope may maintain elevated levels in the interim between flooding events. In most cases the dominant groundwater movement is towards the Sheyenne River. Thus Fairdale and Ladelle soils that are not directly flooded with blended water may be unaffected because groundwater movement would be towards the river. Increases in the average depth to groundwater may present a salinization hazard for LaDelle soils, especially upstream of Baldhill Dam.

## Effects of the Outlet Alternatives on Soil Salinization

*300 cfs Constrained Outlet Alternative.*

The 300 cfs Constrained Outlet alternative would generally generate the lowest salinization hazard due to constraints on outlet operation. As compared to the 480 cfs Unconstrained Outlet alternative, the 300 cfs Constrained Outlet alternative will generate lower discharges, less overbank flooding, and smaller mean watertable increases adjacent to the river. Under the 300 cfs Constrained alternative, the highest potential salinity hazards would exist in the shallowly entrenched Till Plain reach of the Sheyenne River compared to the more deeply entrenched reaches below Baldhill Dam. The Till Plain reach is nearest the point of discharge, has the highest levels of mean salinity/sodicity in blended water and has extensive areas where the Sheyenne River is shallowly entrenched with adjacent poorly and very poorly drained soils. Many of these soils are already saline (e.g. Ryan and Lamoure saline), are near or have included saline soils, or have substantial amounts of subsoil salinity (e.g. Rauville and Ludden soils). Problems would not necessarily be limited to the poorly and very poorly drained soils. Moderately well drained Fairdale and LaDelle soils that are in low positions may also have increased salinization hazards in response to raised water tables and more frequent flooding with blended water.

Downstream of Baldhill Dam salinity hazards would be substantially reduced because the Sheyenne River is more deeply entrenched. Many areas of the floodplain downstream of the dam apparently do not flood regularly. Poorly and very poorly drained soils that are susceptible to salinization are largely confined to abandoned meanders and channeled areas. These soils may be affected by increased mean watertables and possible groundwater intrusion from the Sheyenne River during outlet operation.

*480 cfs Unconstrained Outlet Alternative.*

Salinization hazards would increase somewhat under the 480 cfs Unconstrained alternative because of increased watertables resulting from higher mean river stages and additional flooding. However, increases in hazards due to poorer water quality would likely be insignificant because the TDS and SAR values associated with both constructed outlet alternatives are very similar.

Salinization hazards associated with increased river stages under the 480 cfs alternative would be most significant in the Lamoure-LaDelle-LaPrairie-Ryan and LaDelle-Ludde-Wahpeton associations along the Till Plain reach of the Sheyenne River. In these associations, poorly and very poorly drained soils would experience an additional mean increase in watertables of approximately 0.5 feet over the 300 cfs Constrained alternative. The increase of mean river stage combined with greater overbank flooding under the 480 cfs Unconstrained alternative would result in increased watertable rise and additional salinzation hazards. The most susceptible soils would be the poorly and very poorly drained Ryan, Lamoure, Ludden, and Rauville series that are fine textured, slowly permeable, and already have high levels of subsoil salts. It is expected that the increased salinization hazard will be due more to raised watertables than to differences in water quality between the 300 cfs Constrained and the 480 cfs Unconstrained alternative.

Downstream of Baldhill Dam in the LaDelle-Nutley, Fairdale-Laprairie-LaDelle, Fairdale-LaDelle-Wahpeton-Delta, and Fairdale-Fargo associations the differences in stage between the 300 cfs Constrained and the 480 cfs Unconstrained alternatives are approximately one foot and would be essentially confined to the river channel due to the deep entrenchment of the Sheyenne River. With such minor differences in stage and water quality, the 300 cfs Constrained and 480 cfs Unconstrained alternatives have approximately equivalent soil salinization hazards downstream of Baldhill Dam. Any additional salinization hazards would be experienced in channeled areas and abandoned menaders with poorly drained soils whose water level is influenced by the stage of the Sheyenne River. These settings form a minor component of the soils in the subject associations.

*No Action (natural spill) Alternative*

Salinity and sodicity of blended Devils Lake/Sheyenne River water is much greater under the No Action (natural spill) alternative than it is under either of the constructed outlet alternatives. Mean TDS and SAR values vary by control point and are highest for the Cooperstown control point (1616 mg/L and 7, respectively) and are lowest for the Kindred control point (972 mg/L and 4.37, respectively). Maximum values in TDS and SAR are 2886 mg/L and 11 for Cooperstown, respectively. Maximum values in TDS and SAR for Kindred are 1894 mg/L and 8.5, respectively.

In contrast, TDS and SAR values for the constructed outlet alternatives and are well below the maximum TDS and SAR values recommended for most irrigated soils in North Dakota. TDS and SAR values associated with the No Action (natural spill) alternative would be sufficiently elevated that they would exceed recommended levels for many soils. Accordingly, salinization hazards under the No Action alternative are the most extreme of the alternatives considered.

Most of the productive agricultual soils along the floodplain of the Sheyenne River are fine to medium textured, moderately well drained soils that would be placed in Irrigibility Subgroups 4A (e.g. LaDelle, Fairdale, LaPrairie soils) and 3B (Wahpeton). Such soils would have recommended TDS and SAR maximums of 1460 mg/L or less and SAR values of 6 or less, respectively. These recommended maximum values would be exceeded regularly in blended water under the No Action (natural spill) alternative, suggesting that significant soil salinization/sodification hazards would result in soils affected by regular flooding or by groundwater intrusion. Effects would be worse for fine textured, poorly drained soils with existing high levels of surface or subsurface salinity such as the Lamoure, Ludden, and Rauville soils.

Most soils potentially affected by flooding or groundwater intrusion under the No Action (natural spill) alternative would have Moderate to Severe hazards, indicating that the effects would adversely affect land use, soil conditions, and salt-intolerant vegetation. Again, the effects of the No Action alternative would be influenced by the floodplain morphology of the

Sheyenne River. More severe salinization hazards would be expected upstream of Lake Ashtabula where regular overbank flooding would be a more common occurrence and saline or salinizable soils are more extensive. Downstream of Baldhill Dam, the effects of the No Action (natural spill) alternative would be severe, but would likely be confined to channeled and regularly flooded areas adjacent to the river and to abandoned meanders and oxbow lakes.

Under the No Action (Natural Spill) alternative, discharges could continue year round over a multi-year period and spring floodwaters could be quite saline. Extensive salinization/sodification of susceptible soils higher on the floodplain could result. In contrast, pumping under the constructed outlet alternatives would begin May 1 after much of the serious flood potential has passed in most years.

## Mitigation

### *Constructed Outlet Operation*

Under the constructed outlet alternatives, the only available operational mitigation measure appears to be managing the initiation of outlet operations to begin after the recession of spring flooding. Based on the broad range of spring flooding events observed at various control points, the initiation of outlet operations would normally be delayed by about two weeks in most years.

### *Measures Applicable to Potentially Affected Lands*

A variety of site-specific mitigation measures can be applied to manage salinity and sodicity problems on affected lands. These include: (1) performing detailed site-specific assessments of soil texture, drainage class, and existing in-situ salinity/sodicity to identify problem areas, (2) increasing minimum tillage or no-tillage, (3) increasing the area of forages, pastures, and tree crops, (4) using crops that are more salt-tolerant in rotations, (4) and ensuring adequate drainage.

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# 1. INTRODUCTION

## 1.1. BACKGROUND

Devils Lake is a large (greater than one hundred thousand acres) closed basin that has been filling since the early 1990s in response to pluvial conditions in the upper Midwest. The lake has risen approximately 24 feet between 1993 and 1999. Problems with infrastructure (e.g. roads) and the flooding of residences farm fields and pastures have become worse as the lake rises. The lake would discharge through a natural outlet from Stump Lake to the Sheyenne River if lake water reaches 1459 feet above sea level (fASL). Salinity is variable depending upon lake stage and position within the lake chain. Salinity is highest in Stump Lake, which is the lowest in elevation of the Devils Lake chain of basins. Lake water and bottom sediment salinity is generally lowest in West Bay, and is intermediate in the intervening bays. Solution chemistry is dominated by sodium sulfate.

Options to mitigate the ongoing Devils lake flooding have been legislatively mandated at the national level. The US Army Corps of Engineers, St. Paul District (USACE) is assessing environmental impacts of alternative management approaches through the preparation of an Environmental Impact Statement. The following report examines salinization hazards associated with the discharge of Devils Lake water to the Sheyenne River under two constructed outlet alternatives and a No Action alternative that assumes a natural spill from Devils Lake to the Sheyenne River.

## 1.2. ALTERNATIVES BEING CONSIDERED

Currently there are two general approaches being considered to reduce the impacts of Devils Lake flooding: (1) enhancing storage in the upper basin watershed (Upper Basin Storage Alternative), and (2) removing water from the lake through a created outlet (Outlet Alternatives). The outlet alternatives would, under two operating scenarios, release 300 and 480 cfs of Devils Lake water (extracted from West Bay) through a constructed outlet to the Sheyenne River. This study addresses the outlet alternatives and evaluates them in the context of a third alternative (the No Action (natural spill) alternative). The No Action (natural spill) alternative assumes that continued wet conditions will result in progressive increases in the stage of Devils Lake to the natural overflow point from Stump lake through the Tolna Channel to the Sheyenne River.

### 1.2.1. Alternative 1: 300 cfs Constrained Outlet

Releases of Devils Lake water to the Sheyenne River under the 300 cfs Constrained Outlet alternative will be constrained by five factors:

1. The outlet would be operated whenever the level of Devils Lake exceeded 1441.6 fASL.

2. Outlet operation could occur during a 7-month May-November window.

3. Maximum pumping capacity will be 300 cfs.

4. Combined flow of Sheyenne River and outlet water will not exceed 600 cfs at the point of insertion on the Sheyenne River.

5. The release rate will not cause the blend of river and outlet water to exceed 450 mg/L sulfate.

Pumping under the Constrained Outlet alternative will cease whenever the combined flow and sulfate limits in (4) and (5), respectively, are exceeded or the outlet operation is successful in lowering the level of Devils Lake below 1441.6 fASL. Previous work has indicated that the Constrained Outlet alternative will not result in overbank flooding during pump operation and normal stages of the river. However, during natural flooding periods blended water could overtop the banks and flood adjacent soils.

### 1.2.2. Alternative 2: 480 cfs Unconstrained Outlet

The 480 cfs scenario (Unconstrained Outlet Alternative) represents an unconstrained flow limited only to the 7-month May through November operation window. The outlet would be operated whenever the level of Devils Lake exceeded 1441.6 fASL. Computer modeling performed by the St. Paul District USACE has indicated that the Unconstrained Outlet can be effective at lowering the level of Devils Lake below the 1441.6 elevation; thus outlet operation could be more intermittent when compared to the 300 cfs Constrained Outlet alternative.

### 1.2.3. Alternative 3: Natural Spill from Stump Lake to the Sheyenne River through the Tolna Channel, the No Action (natural spill) Alternative

Alternative 3 assumes that continued wet conditions result in increases in the level of Devils Lake to the point where the lake naturally drains through Stump Lake and the Tolna Channel to the Sheyenne River. The No Action (natural spill) alternative has essentially the same distribution of soil salinization hazards as those associated with the 300 cfs Constrained and 480 cfs Unconstrained Outlet alternatives. However, the magnitude of the associated salinization hazards is greater because of the high levels of salinity associated with Stump Lake water discharged through the Tolna Channel. Again, computer simulations have indicated that a natural spill would not result in continuous discharge of Devils Lake water to the Sheyenne River. Outflow would be intermittent depending upon the climatic conditions used in the modeling run. Significant soil salinization hazards would essentially be confined only to periods of Stump Lake overflow; however, the effects could be persistent during no flow periods.

In the present report, the No Action (natural spill) alternative will be assessed using the same procedures associated with the constructed outlet alternatives.

# 2. METHODS

## 2.1. DETERMINATION OF CHEMICAL CHARACTERISTICS OF A REPRESENTATIVE WATER QUALITY TRACE

Stochastic models developed to assess the environmental and economic impacts of the Alternatives produced 10000 traces (or "futures") predicting flow and water quality estimates for the Sheyenne and Red Rivers under various climatic and outlet operational conditions. The original set of 10000 traces was developed to statistically evaluate the economic impacts of the proposed alternatives; however, a statistical analysis employing all 10000 traces is not indicated for this study due to time, data and methodology constraints. A subset of these traces has been used by the USACE and its contractors to assess applicable environmental concerns. The development of water quality parameters and traces for representative scenarios is discussed in detail in the USACE report Water Quality Effects: Devils Lake Water Quality Simulations, Sheyenne and Red Rivers (USACE, St Paul District, No Date).

The assessment of soil salinization hazards along the Sheyenne River Valley that are associated with overbank flooding and groundwater intrusion under the outlet alternatives depend upon TDS and SAR characteristics of the mixed Sheyenne River/Devils Lake water, combined with physical and chemical characteristics of soils available from National Resources Conservation Service (NRCS) databases and county soil surveys. A detailed evaluation of the TDS and SAR characteristics of mixed Sheyenne/Devils water in a conservative yet representative climatic scenario is necessary to assess soil salinization hazards associated with the outlet alternatives and the No Action (natural spill) alternative.

This report will utilize the "Wet7" trace in further analyses of the impacts of the outlet alternatives on potential salinization hazards associated with soils along the Sheyenne River. The Wet7 trace has advantages for detailed study because it:

1. Represents a conservative, "worst case" estimate of salinization hazards,

2. Represents conditions that would result in a continuation of outlet operations for the projected 45-year life of the project, and

3. Is a member of the "wet class" of futures that represents a continuation of the current pluvial (wet) period.

Water quality traces for TDS, SAR, and associated water quality data for selected control points along the Sheyenne River were provided by the St. Paul District for use in the current study. Data representing the Wet7 trace for control points (CP) at Warwick (CP1408), Cooperstown (CP1317) Valley City (CP1253), Lisbon (CP1162), and Kindred (CP1068) along the Sheyenne River were provided (**Figure 1**). For the rest of the report we will refer to the Control Point locations by their city description.

(Insert Figure 1 here)

### 2.1.1. Modifications to the Original TDS and SAR Dataset

Original TDS and SAR data as supplied by the Corps include: (1) daily values for the entire 365-day year and extending from November 1, 2000 through September 30, 2050, and (2) baseline data reflecting natural conditions (same climatic conditions as the Alternatives, but with no Devils Lake inputs). Several modifications were made to the dataset to make it more applicable to the assessment of soil salinization hazards under the outlet and no action alternatives.

1. The dataset as supplied was reduced to the period extending from May 1 through September 30, which approximates the growing season during which water appropriation by irrigators would occur. We are using the same time period for this report. The addition of the November 1 through November 30 period will not affect the data or the interpretations made from them.
2. The entire 50-year planning period represented by the original dataset begins November 1, 2001 and extends through September 30, 2050. However, outlet operations do not begin until May 1, 2005. In order to limit the dataset to only that period during which outlet operations would occur, all data from November 1, 2000 through May 1, 2005 were removed from the dataset.
3. Under all outlet alternatives the TDS and SAR datasets for the period May 1 through September 1 includes several periods during which baseflow conditions dominate due a lag in downstream movement of the mixed water after insertion, or because outlet operations cease because the level of Devils Lake dropped below the 1441.6 fASL elevation. Inclusion of these values under the Wet7 scenario would result in a dilution of the TDS and EC values for the given alternative dataset when running distribution statistics. In order to account for this dilution effect, only values representing mixed Sheyenne River/Devils Lake water having greater than 1 unit of dye tracer were used to statistically describe the data for the alternatives.

## 2.2. ESTIMATING THE EFFECTS OF THE ALTERNATIVES ON SHEYENNE RIVER STAGE AND FLOW

An estimate of temporal changes in river stage (both magnitude and duration) that potentially affected soils will be experiencing under the alternatives is an important but difficult-to-quantify component of the analysis. Soils not flooded by the river and not in landscape positions that receive groundwater originating as blended Sheyenne River/Devils Lake water will experience normal hydrologic conditions. Thus, they will not be influenced by the outlet alternatives. Conversely, soils that flood regularly and are close enough to the river to receive blended Sheyenne River/Devils Lake water as “backflow” from bank storage episodes could be affected. Impacts could be due to either the addition of salts originating as Sheyenne River water or mobilization of existing salts in the soil profile.

A quantitative assessment of groundwater impacts induced by Sheyenne River stage variations under the outlet alternatives is beyond the scope of the present report. A qualitative examination of flooding and water quality predictions provided by the St. Paul District USACE can generally represent the effects of expected flooding dynamics under the alternatives on the salinity of potentially affected soils. The following resources were used to assess the dynamics of flooding along the Sheyenne that may affect soil salinization.

6. HEC 5Q model predictions used to assess daily variations in river stage, water quality, and flow were provided as a graphical user interface program for the Wet 7 climatic scenario.
7. Daily flow predictions provided by the St Paul District USACE for the Wet 7 climatic scenario. These data were used to evaluate the flow dynamics for the Wet 7 scenario over the 45-year life of the project from initiation of pumping on May 1, 2005 to cessation of pumping November 30, 2050. Data are presented as percent exceedance graphs for the Cooperstown and Kindred control points.
8. Predictions of mean stage increases above long term average base levels for May and August for USGS stage gauges at Warwick, Cooperstown, Valley City, Lisbon, Kindred, Horace, and West Fargo supplied by Dennis Holme of the St. Paul District, USACE.
9. Hydrographs from nearby water table wells developed by the United States Geological Survey (USGS) to determine the relationships between river stage and groundwater relationships with distance from the Sheyenne River.
10. Flooded area outlines calculated from Lidar digital elevation model (DEM) data.

## 2.3. DETERMINATION OF SOIL ASSOCIATIONS

Soils along the Sheyenne River represent a very small component of the soils on a county-wide basis. Accordingly, few soil associations are available in the county soil surveys that describe in detail the distribution of alluvial soils within the Sheyenne Valley in relation to their geomorphic setting. To better characterize the soils mapped along the Sheyenne River, generic soil associations describing the main soils and their more important inclusions were developed. These associations were based on Geographic Information Systems (GIS) data obtained directly from the Natural Resources Conservation Service (NRCS) as Soil Survey Geographic (SSURGO; USDA-NRCS, 1995) datasets or hand digitized from geographically rectified map sheets scanned from the hard copy published soil survey. Soil associations provided in this report follow soil survey area boundaries due to differences in mapping and associated soil descriptive legends for each area. However, the soil associations as described here are generally similar due to the similarities in depositional environments along the floodplain of the Sheyenne River. Significant geomorphic differences are generally associated with areas outside of the valley floor and will be discussed within the respective association description.

### 2.3.1. Determination and Digitization of soils

Digitized soils along the full length of the Sheyenne River Valley and adjacent terraces were restricted to moderately well drained, somewhat poorly drained, and very poorly drained soil map units contained with the valley floor. Soil positions were compared to landform and elevations by reviewing Lidar digital elevation models (DEMs) provided by the St Paul District, USACE. Well drained to excessively drained soils are associated with elevated terraces, steep slopes along the valley walls, and the summits of the valley escarpment itself and would not be affected by alterations in stage and flooding dynamics under the outlet alternatives. However, moderately well, somewhat poorly, poorly, and very poorly drained soils on the valley floor and the active floodplain could be subject to overbank flooding and increased water tables induced by the outlet alternatives.

Digital data were available for Griggs, Ransom, and Cass counties. Digital soil maps for these counties were downloaded from the NRCS SSURGO web site and were converted to the UTM NAD83 meters coordinate system. Digital soil polygons for the entire county were clipped using GIS methods to include only the soils within a 1.5 mile buffer of the Sheyenne River. The clipped polygons were then further reduced to include only map units dominated by moderately well drained, somewhat poorly drained, and poorly drained soils within the valley floor. All digital soil polygons are attributed with the soil survey area identifier and the map unit symbol.

Digital SSURGO data were not available for Benson, Wells, Nelson, Barnes, Steele, or Richland counties. To digitize these soils, map sheets for each survey area that included the Sheyenne River were scanned and geo-referenced to the UTM NAD83 meters coordinate system. Map units including moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained soils were then hand digitized from the boundaries present on the georeferenced map sheets. All digitized polygons were attributed with the soil survey area ID and the respective map unit symbol.

In conjunction with a map query in Arcview, acreages of all moderately well, somewhat poorly, poorly, and very poorly drained soils mapped along the valley floor were determined by soil survey area. This list was ordered by acreage from the most extensive to the least extensive soils in the county and/or associated soil surveys. The soil associations described in Section 4.2.2 are the result of placing these soils in their geomorphic settings within the county or counties of interest.

### 2.3.2. Creation of a Soil-Attribute Database

The NRCS has developed the Map Unit Interpretations Record (MUIR: USDA-NRCS, 1994) database that contains virtually all of the soil attribute information included in a standard soil survey, including soil map unit composition, the percentages of major components and inclusions broken down by soil series, and physical, chemical, and interpretative data. Digital MUIR soil attribute information obtained on a county basis via internet download was condensed into a database to be used for this project and others involving soil salinization hazards under the outlet alternatives.

The resulting spatial and attribute datasets were joined with a relational database (Microsoft Access) in order to; (1) develop a descriptive soil legend, (2) determine major components and included soils of minor extent, and (3) evaluate important hydrological, morphological, and mineralogical characteristics important to evaluate salinization potential under the outlet alternatives. The result of this evaluation provided acreage estimates of all major, minor, and included soils mapped along the floor of the Sheyenne Valley by soil survey.

### 2.3.3. Determination of Geomorphic Settings

The geomorphic settings for the soils were determined from the published soil surveys and from Official Series Descriptions (OSDs) available from the NRCS. The database also permitted the development of a soil legend by individual soil survey area to be used in conjunction with the Arcview digitized soils map of the area covered by this report.

#### 2.3.4. Limitations

The reader should be aware of the limitations of the standard county soil survey for determining soil properties at large or small scales. Soil surveys used in the present report were mapped at a scale of 1:20000, and range in date of publication from the mid 1970s to the late 1990's. Soil survey technology and practice have been in a constant state of change and geomorphic concepts applicable to one survey and survey period may not apply to another. The problem is most obvious when matching soils surveys across counties where map units do not correspond. Map units can mysteriously stop at county borders. Frequently the same soil polygon will be mapped differently in each county. There are several examples of this in the dataset. In addition, some soil surveys represent a detailed analysis and map numerous polygons of consociations (one dominant and related similar soils) while others are less detailed and rely on complexes (two or three dissimilar soils related by landscape position mapped as one Map Unit). In one county analyzed in this report, nearly the entire Sheyenne River valley is essentially considered one map unit, with listed major and minor components. County soil surveys also may treat inclusions differently. Usually the incorporation of listed inclusions increases the accuracy of acreage estimates of soils of interest. However, including inclusions can also result in the incorporation of soils that are not of interest or are out of place.

Notwithstanding these limitations, this assessment of soil map units and their salinization potential under the outlet alternatives is based on the most detailed, current soils information available.

### 2.4. APPLICABLE SOIL SALINITY AND SODICITY ISSUES AND CONCEPTS

#### 2.4.1. Soil Salinity

Soluble salts in general are the products of rock and soil weathering processes (Bresler et al., 1982). In the Northern Plains the interaction of near surface pore water and constituents in surficial sediments results in unique groundwater chemistries dominated by sulfates of calcium, magnesium and sodium (Groenewald et al., 1983; Hendry et al., 1986). Soil salinity in the Sheyenne Valley area is associated with sodium and magnesium sulfates released through the weathering of shale and dolomite rock constituents of the local glacial sediments. Evapotranspiration can concentrate the constituents to high levels in soils, especially under conditions of inadequate drainage and the presence of naturally high watertables.

Soluble salts are defined as salts more soluble than gypsum ($CaSO_4 \cdot 2H_2O$), which has a solubility of approximately 2 grams per liter. There are eight ions commonly associated with soluble salts. Cations consist of calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), whereas anions consist of alkalinity (carbonate, $CO_3$; bicarbonate, $HCO_3$, and carbonic acid; $H_2CO_3$), sulfate ($SO_4$) and chloride (Cl). *Soil salinity* is essentially the sum total of soluble salts in the soil, generally limited to the root zone, and is operationally defined by the electrical conductivity of a soil saturation-paste extract (ECspe), expressed in deci-Siemens per meter (dS/m). Other units for describing salinity in soils and water are described in Section 2.5.1.1 below. Elevated salt content in the rooting zone of a soil reduces crop yields by competing with plants for water (Bresler et al., 1982).

A *salinity hazard* is generally associated with landscape positions characterized by groundwater discharge and shallow water tables (Seelig and Richardson, 1991; Franzen et al., 1994). Soil salinity can be described by the interaction between soil-specific "critical depth" and "critical salinity" parameters. *Critical depth* is generally defined as the maximum amount that watertables with a given salinity can rise without resulting in salinization of the soil surface. *Critical salinity* is defined as the minimum amount of salt content that near-surface groundwater can have without resulting in salinization of the soil surface, regardless of the watertable depth (Maianu, 1981). Specific critical depth and critical salinity values have not been developed for North Dakota Soils; however, the concepts explain soil salinization in the presence of shallow watertables (Seelig et al., 1987).

A *salinity risk* is the probability that a salinity hazard will become a problem (Bui et al., 1996). Areas at risk of salinization after alteration of watertable dynamics are those areas where stored salt is likely to be remobilized and redeposited by rising groundwater tables. Assessing the risk of salinization requires an estimate of preexisting hydrology/salinity and the effects of the altered hydrology induced by elevated watertables.

### 2.4.2. Soil Sodicity

*Soil sodicity* is defined by the concentration of monovalent sodium relative to the concentrations of divalent calcium and magnesium on both the soil cation-exchange complex (yielding an exchangeable sodium percentage, or ESP) and in the soil solution (yielding a Sodium Adsorbtion Ration, or SAR). SAR is defined in more detail in Section 2.5.1.2 below.

Elevated concentrations of sodium disrupt soil structure resulting in a "gumbo" type soil. Sodium-affected soils are hard and massive when dry. When wet, sodium-affected soils are structureless and dispersed, with reduced hydraulic conductivity, poor seed germination, and limited root penetration and distribution through the soil. Nutrient uptake can be affected as well as water availability to the plant due to limited root distribution (U.S. Salinity Laboratory Staff, 1954; Bresler et al., 1982).

Salinity and sodicity frequently coexist, resulting in sodic-saline soils; however, the deleterious effects of sodium are mitigated somewhat at high levels of salinity. Many areas of sodic and saline-sodic soils may be associated with groundwater discharge through underlying Pierre shale or through tills with high shale contents. The deleterious effects of both sodicity and salinity are also associated with texture, with fine textured soils being more severely affected than coarse textured soils (U.S. Salinity Laboratory Staff, 1954; Seelig and Richardson, 1991).

Salinity and sodicity are naturally occurring conditions along the Sheyenne River, especially in the shallowly entrenched upper reaches. The presence of high, relatively saline watertables adjacent to the Sheyenne results in the discharge of water to the rooting zone in response to evapotranspration, which concentrates salts to high levels.

### 2.4.3. Soil Salinization Processes

Soil salinity and sodicity are predictable soil characteristics. Natural salt accumulation in North Dakota is associated with specific hydrogeologic settings generally associated with groundwater discharge, shallow groundwater depths, and infrequent ponding (Seelig and Richardson, 1991); for example, areas adjacent to semipermanent wetlands and broad, low-relief flats (Arndt and

Richardson, 1989; Holm and Henry, No date). Dissolved salts move with saturated and unsaturated groundwater flow. Areas of persistent groundwater recharge are leached, whereas areas of persistent groundwater discharge can have a range of salinity depending on the salinity and depth of the groundwater in question (Lissey, 1971; LaBaugh, 1988; Arndt and Richardson, 1989; Knuteson et al., 1989; Seelig and Richardson, 1994; van der Kamp and Hayashi, 1998). Salts accumulate in the vadose (i.e. unsaturated) zone when unsaturated flow brings groundwater containing dissolved salts into the rooting zone. The attendant evapotranspirative withdrawal of pure water leaves the salts to accumulate. Although saline soils are the product of long term hydrogeologic conditions, salts are readily mobilized when groundwater hydrology changes (LaBaugh, 1988; Steinwand and Richardson, 1989; Arndt and Richardson, 1993a and 1993b).

## 2.5. SALINITY AND SODICITY CLASSIFICATION OF NORTH DAKOTA SOILS AND WATERS

Salinity and Sodicity classifications of North Dakota Soils are the same as those used by the Natural Resources Conservation Service and are based on ECspe and SAR. Non-saline soil series have an ECspe <4 dS/m. Saline phases of soil series have ECspe between 4 and 16 dS/m. Saline soil series have a ECspe > 16 dS/m. Natric or soils mapped as sodium affected will have SAR values in saturation extract pastes generally > 13. However, the dispersive effects of sodium on susceptible soils can be noticed at SAR values approaching 5 (Springer et al., 1999), and many soils that are mapped as sodic based on soil morphology in the field have SAR values < 13 (J.L. Richardson, Pers. Comm.).

### 2.5.1. Important Chemical Properties of Water Affecting Soil Salinization

The primary chemical characteristics that characterize salinity and sodicity in soil and water are the Electrical Conductivity (EC) and the Sodium Adsorption Ratio (SAR).

#### *2.5.1.1. Electrical Conductivity and Total Dissolved Solids (TDS) Conversions*

The ability of solutions to conduct electricity is directly proportional to the number of ions in solution, which can also be expressed as total dissolved solids. Both TDS and EC are commonly used when assessing soil and water salinity; however, the relationship between them is not direct, and interpretations using one unit must be converted when available data utilize the other. EC can be expressed a number of ways dependent upon the units used. The following are most commonly seen in the literature:

millimhos per centimeter (mmhos/cm),

deci-Siemens per meter (dS/m) or

micromhos per centimeter (umhos/cm)

where:

1000 mmhos/cm = 1 mmho/cm = 1 dS/m

Most of the soil salinity literature uses EC units of umho/cm or dS/m because there is a close numeric relationship between EC expressed as umho/cm and chemical analyses that provide TDS values as parts per million (ppm) or milligrams per liter (mg/l). The relationship deviates somewhat dependent upon the type of solute species involved. However, in sulfate dominated systems the following relationship has been used.

$$TDS = 0.65 * EC \text{ (EC in umho/cm)} \qquad \text{Equation 1}$$

$$TDS = 650 * EC \text{ (EC in dS/m)} \qquad \text{Equation 2}$$

The relationship between TDS expressed as mg/l and EC as umho/cm or dS/m was used in previous reports (Downstream Surface Water Users Study, Barr Engineering, March 1999a) and is in common use in North Dakota Soil Testing Laboratories. However, the NRCS soil survey uses units of dS/m in saturation past extracts to estimate salinity in soils. We will follow this convention when evaluating soil salinity in this report.

For the purposes of interpretation, NSSL salinity/sodicity hazard ratings that use EC ranges (umho/cm) will be converted to TDS values using equation 1. When applicable, parenthetical reference will be made to the EC equivalent as dS/m.

#### *2.5.1.2. Sodium Adsorption Ratio (SAR)*

The influence of sodium on soil properties depends on the relative amount of monovalent sodium cations with respect to divalent calcium and magnesium cations. The adverse effects of sodium on dispersing soil structure are mitigated by the presence of divalent cations that help hold soil particles together. The most accepted method of comparing sodium to calcium and magnesium is by calculating the sodium adsorption ratio (SAR). The SAR may be determined for soil extracts or ground and surface water.

The concentrations of calcium, magnesium and sodium must be determined or estimated in a soil extract of water sample. After analysis, the SAR can then be calculated using the following formula:

$$SAR = \frac{Na+}{\sqrt{\frac{[Ca^{2+}]+[Mg^{2+}]}{2}}} \qquad \text{Equation 3}$$

where:

$Na^+$ is the concentration of sodium in milliequivalents per liter of soil extract or meq/liter of surface or groundwater.

$Ca^{2+}$ and $Mg^{2+}$ are the concentrations of calcium and magnesium, respectively in meq/liter of soil extract or surface or groundwater.

A saturated-soil extract with an SAR of greater than 13 is usually an indication of sodium hazards. More detailed analyses of SAR can incorporate mineral equilibria between carbonate, sulfate, and calcium species in solution yielding an adjusted SAR; however, the resulting modifications to SAR and salinity/sodicity interpretations are minor. For the purposes of the present report, SAR as estimated by relative concentrations of Ca, Mg, and Na in the HEC5Q water quality analyses will be used. The derivation of the HEC5Q TDS and SAR estimates are discussed in more detail in Section 2.1.1 above.

Texture also modifies the effect of SAR relative to management. Although an SAR of 13 indicates significant clay dispersion in both a clay loam and sandy loam soil, the actual effect of the dispersion on soil properties is less in the sandy loam. Soils with a relatively low SAR may become dispersed depending on the amount of clay particles held together in part by the attraction of calcium to other clay particles and the dispersing action of sodium which counteracts the aggregation process. Recent research in the Northern Plains has indicated that sulfate dominated soils may have sodium-induced dispersion problems at SAR values > 5 (Springer, 1999).

#### *2.5.1.3. Salinity Designations of Blended Water:*

The United States Salinity Laboratory (NSSL) rates water salinity/sodicity hazards in terms of a scale from C1-C4 (**Figure 2**, after Richards, 1954). Soil scientists make frequent use of these designations to evaluate the salinity of soils in saturation paste extracts as well.

(Insert Figure 2 here)

The definitions of the scale are described below.

C1 — (Low-salinity water, < 250 umho/cm; 160 mg/l TDS) Little likelihood that soil salinity will develop or exists. Some leaching may be required for mitigation, but not more than normal leaching from standard irrigation practices unless the soils are extremely low in permeability.

C2 — Medium-salinity water, 250 – 750 umho/cm EC (160 – 490 mg/l TDS) Water can be used if a moderate amount of leaching is used. Plants with moderate tolerance to salinity can be grown without special practices for salinity control.

C3 — High-salinity water, 750 – 2250 umho/cm (490 – 1460 mg/l TDS) Cannot be used on soils with restricted drainage. Special management is required even with good drainage. Plants with good salt tolerance must be selected.

C4 — Very high-salinity water, > 2250 umho/cm (> 1460 TDS) Not suitable for irrigation except under very special conditions which include permeable soils, adequate drainage, excess water for leaching and very salt-tolerant crops.

#### *2.5.1.4. Sodium Hazard Designations:*

The sodium level in the soil in relation to calcium and magnesium (sodicity), as well as the sodium content of Sheyenne River water applied to soil in overflow and as groundwater intrusion water is important to assess existing and potential salinization hazards.

Richards (1954) further defines sodicity in terms of a scale from S1-S4. The definitions of each class are described below. SAR ranges are not provided because the classification reflects the fact that sodium hazards are indirectly related to salinity. Thus, for a given level of sodicity, the hazard is greater in less saline water. See Figure 2 for ranges.

S1 — (Low sodium water) Can be used on nearly all soils with little danger of sodium buildup to the soil, although levels may still be high enough to injure sodium sensitive plants.

S2 — (Medium sodium water) May present a potential sodium buildup on fine-textured soils with low permeability especially if available calcium levels are low. Class S2 water is suited to irrigate coarse textured soil with good permeability.

S3 — (high sodium water) May cause sodium buildup in most soils and requires special management, including providing for good drainage, applying excess water for leaching and organic matter additions. Soils with very high levels of free calcium may not develop problems. Chemical additions (e.g. gypsum or more soluble calcium salts) may be required to replace soil sodium. Chemical additions may not be practical if salinity is high.

S4 — (very high sodium water) Unsuitable for irrigation water except if the water is low or medium salinity (C1 or C2). With irrigation waters low in salinity, addition of soluble calcium salts to the irrigation water may make use of S4 water possible.

## 2.6. DETERMINATION OF ASSOCIATED SOIL SALINIZATION HAZARDS

Soil salinity in the Sheyenne River Valley has developed under a complex, interrelated hydrologic regime involving Sheyenne River water, flooding, and resulting effects on groundwater. This regime consists of a balance between additions, deletions, transformations and translocations of salt (Richardson et al., 1994). Salts are added to the soil profiles by groundwater discharge or overbank flooding and removed by groundwater recharge or leaching of water back to the river. A portion of the added salt is converted into salts of limited solubility (e.g. Calcite and Gypsum) and is stored in the soil profile. The salinity (EC as dS/m) and calcium carbonate and gypsum contents (weight basis expressed as a percentage) of the soils reflect the long-term dominance of the accumulation/leaching processes involved (Arndt and Richardson, 1988, 1989, 1992; Richardson et al., 1991; Seelig and Richardson, 1994; Skarie et al., 1986). Soils that receive more water than they yield build up salts in their profiles due to evaporative concentration of soluble constituents. Such soils frequently have higher salinity as dS/m and contain calcium carbonate or gypsum. Overbank flooding and infiltration of relatively fresh water can leach soluble salts concentrated in the surface soils to the subsoil, resulting in soils with low surface salinity and absent calcium carbonate and gypsum, but with subsoils higher in these constituents. Leached soils will be non-saline and will have little or no calcium carbonate or gypsum in their profiles. Well and moderately well drained soils can have the accumulated salts leached into the subsoil, where they accumulate depending upon the relative intensity of the leaching processes and groundwater relationships. Somewhat poorly drained, poorly drained, and very poorly drained soils can be strongly saline or not, again depending upon the relative intensity of the leaching process and dominant water movement. Poorly drained soils in elevated positions that receive relatively fresh floodwaters would leach salts deeply and be non-saline, in spite of their poorly drained status. Conversely, poorly drained soils that receive water as groundwater discharge or overbank flooding but have limited leaching can build up salts to a high level.

A quantitative estimate of soil salinization processes is precluded by the complex geochemical processes described above versus the limited nature of the available data. County soil surveys provide very broad ranges in surface and subsoil salinity, with the breaks being 4 dS/m (higher levels indicate a saline phase of an existing soil), and 16 dS/m (higher levels indicate a saline soil). Similarly gypsum and calcite contents are provided in broad ranges (e.g. 0-2%, 2-15%). In other words, the salinization hazards induced by the outlet alternatives will be strongly influenced by the existing salinity of the affected soils. However, the existing salinity of those soils is not sufficiently known to estimate the local effects.

Even if more detailed salinity data were available, groundwater relationships in the Sheyenne River Valley are still not sufficiently understood to quantify the soil-salinization effects of the outlet alternatives. Duration, season of occurrence, and depths for the seasonal high water table, flooding, and ponding characteristics are available in the MUIR database for specific soils. However, again the data are provided for very broad ranges (e.g. ponding brief, occasional, or frequent; seasonal high water table depths ranging from +0.5 to 2.0 feet). Notwithstanding their imprecision, the hydrologic data are important because they provide information regarding the hydrologic setting of the soil in question. Soils listed as never flooding will generally be above the floodplain of an adjacent river. Soils listed as having a perched seasonal high water table varying from 2 to 3 feet in depth will not be hydrologically connected to a nearby river, but will receive water as fresh runoff. Selected hydrologic data for all soils will be provided in tables at the end of this report.

### 2.6.1. Salinization Hazard Classes

Our approach to evaluating the salinity and salinization potentials is to place the moderately well drained to very poorly drained soils in their proper hydrogeologic setting in cross section, and then estimate the effects of increased river stage, overbank flooding, and river water salinity under the given hydrogeologic setting using certain principles and best professional judgement. Certain soils will have a significant hazard of salinization, while other soils will not.

In general, the following criteria were used to place soils into hazard classes that range from none through severe. Most soils were placed into two classes given the imprecision in known chemical, physical, hydrologic, and landscape position characteristics.

1. **None**. Soil map units, major components, and inclusions that are; (1) well drained, (2) in positions above the active floodplain that rarely if ever flood or receive groundwater originating from the Sheyenne River, or (3) associated with landforms that would not receive floodwater or groundwater originating from the Sheyenne River. Soils with a salinity hazard of **None** are not expected to experience adverse impacts under the alternatives.

2. **Slight**. Moderately well-drained soils that are; (1) occasionally flooded, (2) lack significant subsoil salinity as indicated by ECspe < 2, (3) have low amounts of calcite and/or gypsum in the surface soils and subsoils, and (4) have listed seasonal high watertables greater in depth than 4 feet. Soils with a salinity hazard of **Slight** are generally not expected to experience adverse impacts under the alternatives. However, soils in this category are in positions that could periodically receive floodwater containing blended Sheyenne River/Devils Lake water or could be affected by potential groundwater rises under the alternatives. Because of landscape setting, drainage, texture, or permeability relationships the effects are expected to be transitory and would be unlikely to significantly affect use or condition of the soils.

3. **Moderate**. Moderately well drained soils that are; (1) frequently or occasionally flooded, (2) poorly developed Fluvents, (2) have higher existing salinity as indicated by ECspe > 2 dS/m, and (3) potentially have both Gypsum and Calcite in the soil profile. Due to landscape setting, drainage, texture, or permeability relationships, soils with a salinity hazard of

Moderate may incur limited or transitory salinization. The use and conditions of the soils may be affected sufficiently to require mitigation.

4. **Severe**. Poorly and very poorly drained soils near the Sheyenne River that are; (1) frequently to occasionally flooded, (2) have significant amounts of subsoil salinity (ECspe > 4), (3) are fine textured and slowly permeable, (4) are in positions to have their mean watertable levels increased under the outlet alternatives and (5) in a position to receive groundwater originating in the Sheyenne River. Soils with a salinity hazard of **Severe** are expected to have significant impacts due to either the effects of frequent overbank flooding under the alternatives, expected significant increases in water table depths, and/or mobilization of high levels of subsoil salinity. Soils in the **Severe** Category are either soils that are already saline or soils that because of the presence of potentially high levels of subsoil salinity combined with their landscape position are likely to become saline under the alternatives. Soils with a salinity hazard rating of **Severe** are likely to experience salinization sufficient to adversely affect use and condition of the soils.

In some instances soils were ascribed to a different class than criteria would suggest by inspection of landscape setting in the GIS and using best professional judgement. An example is the placement of LaDelle soils into the Slight-to-Moderate category in the upper reaches of the Sheyenne River above Baldhill Dam where they have a significant chance of being occasionally flooded, but into the None-to-Slight category downstream of Baldhill Dam where HEC-RAS predicts that most flood stages will remain within the channel and adjacent low abandoned meanders.

Acreage estimates of potentially salinized soils by hazard class under the outlet alternatives will be provided; however, this estimate is not quantitative. These estimates indicate the acreage that may be subject to salinization under the outlet alternatives but not the degree of salinization. Similarly, a quantitative estimate of the effects of the individual outlet alternatives is not possible using the data available. The effects of the outlet alternatives will be examined at the conclusion of the discussion associated with each Soil Association.

In the discussion of potential soil salinization hazards that follows in Section 4.2.2, each soil association will be represented by a figure including the following items.

1.0 A section of the soil map showing the cross-section location on a hillshaded Lidar basemap to provide topographic context.

2.0 Where available, flooded area outlines of the Sheyenne River at 1000, 1500, 2000, and 3000 cfs. These products were provided by the St. Paul District, USACE and are presented in the figures to provide a context for potential overbank flooding. The St. Paul District has indicated that, in general, the 1000 cfs contour represents the "typical" flooded area outline for the upper reaches above Baldhill Dam. The 1500 cfs flooded area outline better represents the typical flooded area outline for the Sheyenne River below Baldhill Dam.

3.0 A cross section profile showing the distribution of major and minor soils identified by landscape position and expected salinity.

4.0 When available, a typical EM-38 transect providing salinity across a representative landscape (not from the location of the cross-section profiles in C.)

5.0 A typical landscape photo (not from the location of the cross section profiles).

Tables will be provided for each soil association that include:

- *Soil series name*
- *Acreage in the association*
- *Taxonomic classification*
- *Drainage class*
- *Depth and duration of the seasonal high water table*
- *Timing and duration of flooding*
- *Landscape position*
- *Salinity and sodicity characteristics (range in EC as dS/m, SAR)*
- *Salinity hazard under the outlet alternatives, and reason for classification*

In addition, a descriptive soil legend including descriptive data and the percentages of major and minor components by County Soil Map Unit along with Official Series Descriptions of all soils identified along the Sheyenne River Valley in support of this project will be provided.

# 3. EXISTING AND PROJECTED CONDITIONS RELATING TO SOIL SALINITY

As a prelude to the Results and Discussion, this section provides background information on; (1) the geology of the Sheyenne River Valley, (2) projected TDS and SAR in Sheyenne river water under the outlet alternatives, (3) projected salinity and sodicity hazard classes of Sheyenne River water under the outlet alternatives, (4) projected Wet7 stage and flow dynamics under the outlet alternatives, and (5) existing soil salinity and sodicity in the Sheyenne River Valley. All of the elements serve as input into the analysis of projected soil salinity and sodicity hazards.

## 3.1. GEOLOGY OF THE SHEYENNE RIVER VALLEY

Although an exact location for the point of insertion for the constructed outlet alternatives has not been decided, the most feasible areas are near the confluence of Peterson Coulee and the Sheyenne River (river mile 459) in Benson County, North Dakota (see Figure 1). The focus of the assessment of soil salinization hazards is downstream of this confluence. Downstream of the confluence with Peterson Coulee the Sheyenne River flows through east through southern Benson County, northern Eddy County and southern Nelson Counties, whereupon it turns and flows south through Griggs and Barnes counties. It enters the northeast portion of Ransom County, flowing in a south-to-east-to-north loop through Ransom and Richland counties. The Sheyenne then enters southeastern Cass County, and flows generally north until its confluence with the Red River north of Fargo near the town of Harwood, North Dakota. The total river mile length of the Sheyenne river covered in this report is approximately 459 miles with rivermile zero at the confluence of the Red and Sheyenne rivers (see Figure 1).

The Sheyenne River was a major glacial spillway during the end of the Pleistocene receiving water from Glacial Lakes Souris, Cando, and Devils Lake. The Sheyenne River delivered water to Glacial Lakes Agassiz and Dakota. The release of large amounts of glacial meltwater resulted in a classic underfit stream one to two miles wide flowing through a deep meltwater trench of glacial origin incised 100-200 feet into the surrounding till plain. The trench was cut in a relatively short period of time when it carried large amounts of glacial meltwater from Glacial Lake Souris. However, Aronow (1957) and Callendar (1968) documented 6 major spillways that also delivered glacial meltwater from Devils Lake to the Sheyenne River. The largest and most developed spillway is the Tolna Coulee, which is the natural outlet for the Devils Lake chain of Lakes. During a natural spill from Devils Lake, water from Stump Lake flows through the Tolna Coulee until its confluence with the Sheyenne at river mile 374. Devils Lake is a at present landlocked; however, there is evidence that Devils Lake has overflowed via the Tolna Coulee into the Sheyenne River several times in the past few thousand years during particularly pluvial (wet) times (Bluemle, 1988, Wiche and Pusc, 1994)

The Sheyenne River is characterized by three distinctly different reaches based on major geomorphologic and lithologic differences. Each reach has its own implications for soil salinity along the active floodplain occupying the valley floor. Local topography and stratigraphy further segregate the reaches into subreaches that have distinctly different soil distributions associated with the active floodplain and adjacent terraces.

### 3.1.1. Till Plain Reach

The portion of the Sheyenne River covered in this reach begins at river mile 459 and extends to river mile 154 near Lisbon. The geology of the area is covered by several North Dakota Geological Survey Bulletins (Bluemle, 1965, 1973, 1975, 1979; Kelly and Block, 1967). Throughout this area the river is incised primarily into glacial till. Abandoned terraces relict from glacial outwash events are visible 40 to 80 feet above the present floodplain in many places. Occasional outcrops of Pierre shale can also be observed, and are more prevalent downstream. Some terraces along the valley floor are shallow to glacial till, and occasional till inclusions are evidenced by the presence of small inclusions of till soils. The river gradually increases flow downstream due to tributary inflows and groundwater discharge, though most of the rivers flow is due to runoff from the surrounding till plain (Barr Engineering, 1999b). The Sheyenne is influent (receiving groundwater) throughout most if not all of its total reach; however, the actual amount of groundwater inflow is limited in the upper reach by the low permeability of the upland tills and the underlying Pierre Shale (Scott Parkin, NDSWC, Pers, Comm.). Borings performed by the NDGS and the NDSWC indicate that 0 to 40 feet of recent alluvial sediments are underlain by deposits of sands and gravels relict from the Late Wisconsin glaciation. The recent alluvium consists of relatively fine-grained deposits of silt and clay. Thin lenses of fine to coarse sand are present locally. Usually the alluvium is thickest near the center of the valley and thins out along the edges.

#### *3.1.1.1. Till Plain Subreach 1: Eddy, Benson, and Nelson Griggs, and Steele Counties*

In the area of Eddy, Benson, Griggs and Steele counties the Sheyenne consists of a small underfit stream meandering through a large valley deeply incised into the surrounding till plain. Abandoned terraces relicts from glacial outwash events are visible 40 to 80 feet above the present floodplain in a few places. Occasional outcrops of Pierre shale can be observed in places. There are few perennial tributaries in the upper reach. In extremely dry or cold weather the river stops flowing entirely. The river is shallowly entrenched in the area, with an apparent active floodplain extending across much of the valley floor. Portions of the upper reach are meandered; however, significant portions are relatively straight, especially in the upper portion. Typical landscapes of the upper reach are in **Figure 3**.

(Insert Figure 3 here)

#### *3.1.1.2. Till Plain Sub-reach 2: Barnes and Ransom Counties*

The separation between the upper and middle reaches is not clearly defined; however, the portion of the river beginning around river mile 352 is more meandered and deeply entrenched than the upper reach. The active floodplain is narrower, and mixed alluvial/colluvial deposits become more common at the valley edge. Abandoned meanders, oxbow lakes, and deeply channeled, dissected lands resulting from downstream movement of meanders are much more evident (**Figure 4**). Sediments tend to be a little coarser (fine silty and fine loamy as opposed to fine) in the upland and natural levees. Abandoned meanders that lie at varying elevations on ascending terraces are common. Abandoned meanders vary from somewhat poorly drained depressions in cropland and pasture to permanently water-filled oxbow lakes. Natural levees are more developed and tend to be better drained than much of the immediately surrounding area. The middle reach extends downstream to the beginning of the Lake Aggasiz beaches and the Sheyenne Delta in Ransom County.

(Insert Figure 4 here)

#### *3.1.1.3. Till Plain Subreach 4: Western Ransom County*

At its maximum extent, Glacial Lake Agassiz laid down shoreline and lacustrine deposits in the area of western Ransom County. Differences in geomorphology have resulted in slightly different landforms in western Ransom County that are actually intergrades between the deeply incised river characteristic of the till plain and shallower valley characteristic of the Sheyenne Delta. The steep portion of the valley deeply incised into the surrounding till plain gradually becomes less deeply incised in western Ransom County as the river flows into an area near Lisbon where the geology is dominated by collapsed lake sediments and mixed shoreline deposits near Lisbon. Colluvial/alluvial deposits become less common at the edges of the valley.

### 3.1.2. The Sheyenne Delta

Glacial Lake Agassiz was subject to dynamic lake stage fluctuations with significant rises and declines in stage during the Late Wisconsin glaciation resulting in a series of ascending strandlines described in Arndt (1977). During high water phases the Sheyenne River built up a significant sand delta into the lake. During low water phases which lasted for several hundreds of years the glacial Sheyenne River entrenched itself into the delta. Reflooding resulted in the creation of an estuary (i.e. a drowned river mouth). The resulting complexity is much in evidence in the Sheyenne Delta proper. Inspection of the Lidar elevation data provided by the St. Paul District, USACE indicates the presence of several oxbow lakes occupying positions on terraces that can be significantly higher than the active floodplain. When Lake Aggasiz finally emptied; the Sheyenne River further entrenched itself into the delta, abandoning the oxbows and meanders of the upper terraces. Groundwater discharge is a significant feature of the toe-of-slope positions in the delta portion of the Sheyenne delta, and supplies water to several of the elevated abandoned meanders in the Delta. The Sheyenne River is strongly effluent in the Sheyenne Delta, and receives a considerable flow of water from groundwater discharge and the addition of water from small tributary streams (Paulson, 1964). Because the surrounding uplands are dominantly coarse textured sediments with high infiltration rates and permeability to water, groundwater recharged in the uplands relatively rapidly is discharged at the breaks in slope at the foot of the valley walls. These springhead seeps and discharge areas may be extremely fresh, or can be quite saline. They are frequently 10 to 20 feet above the active floodplain, and would not be affected by the outlet alternatives under consideration because they are hydrologically upgradient from the river (Barr Engineering, 1999b)

### 3.1.3. The Lake Agassiz Plain

The Sheyenne River flows from the Delta onto the Lake Agassiz plain at river mile 69. The geology of the area is covered in Klausing (1968) and Baker (1967). The edge of the delta consists of a distinct low rise and a break from fine-textured lacustrine clays and clay loams of the Red River Valley to the coarser textured alluvial and aeolian sands of the Delta proper. It is also noted that extensive saline flats that result from the discharge of water recharged in the delta are found at the transition from the Delta to the Lake Agassiz Plain (see **Figure 5**) (Thompson and Joos, 1975)

(Insert Figure 5 here)

The Sheyenne River in the Lake Agassiz plain has a distinctive morphology created by the flatness of the terrain, the presence of very fine textured sediments, and the periodic overtopping of the banks during extensive flooding. The Red River valley portion of the Sheyenne River is deeply incised into the Lake Plain due to the competence of the fine textured lake sediments. During flooding periods the energy (speed) of the floodwater decreases very rapidly as the water overtops the banks of the river and flows diffusely across the lake plain. The decreased energy of the water results in the rapid settling of the coarser particles held in suspension, resulting in distinctive natural levees (Thornbury, 1969) that are actually the driest portions of the surrounding landscape. Modeling of river flood stages indicates that these natural levels are the last to flood, and actually rarely are covered with water (**Figure 6**). During flooding events breakouts of the river occur through these natural levees through a series of splays. Groundwater flow is generally to the river, with the surrounding soils being somewhat poorly to poorly-drained. Surface drainage has resulted in the development of very productive farmland; however, several areas of saline soils are located near the river and throughout the valley generally.

(Insert Figure 6 here)

## 3.2. EFFECTS OF ALTERNATIVES ON SURFACE WATER TDS AND SAR FOR THE WET7 TRACE

The quality of mixed Sheyenne River/Devils Lake water is strongly affected by outlet alternatives, outlet operation, and downstream distance from the point of insertion. In order to assess the effects of outlet operation parameters and the no-action "Natural Spill" alternative on Sheyenne River water quality and soil salinization hazards, distribution statistics (Table 1, Table 2), exceedance plots (Appendix A1), and plots of TDS vs SAR overlaid onto the NSSL salinity/sodicity hazard classification (Appendix A2) were developed for the Wet7 scenario provided by the St. Paul District, USACE. TDS (in parts per million or mg/l) will be considered equivalent to 0.65*EC (umho/cm) or 650*EC (dS/m) for the purposes of this report (see Section 2.5.1.1).

### 3.2.1. TDS and SAR Distribution Statistics

Variability in the TDS and SAR of blended water is important to assess soil salinization hazards of susceptible soils by overbank flow and groundwater intrusion. The following analysis of distribution statistics describes the distribution (mean, median, standard deviation, maximum, minimum, range, and count) of TDS and SAR for baseflow and mixed Sheyenne River and Devils Lake waters by control point.

Distribution statistics for TDS and SAR, Wet7 Climatic Scenario for all alternatives are provided for representative control points along the Sheyenne River in Tables 1 and 2, respectively. Graphs of mean TDS and SAR values for the same data are presented in **Figure 7** and **Figure 8**, respectively. Warwick data are absent for the No Action (natural spill) alternative because the natural spill of Devils Lake through the Tolna Channel is downstream of the Warwick Control Point. It is emphasized that TDS and SAR values for the alternatives represent only samples with mixed Sheyenne River/Devils Lake water. Base flows were removed from this dataset to represent only the periods where TDS and SAR values were above base-flow values. The data show the following.

(Insert Table 1 here)

(Insert Table 2 here)

(Insert Figure 7 here)

(Insert Figure 8 here)

*<u>3.2.1.1. TDS</u>*

1. There is a progressive increase in mean TDS values from Baseflow, the 300 cfs Constrained, the 480 Unconstrained, and the No Action (natural spill) alternatives for each control point (see Figure 7). This increase represents; (1) increasing proportions of Devils Lake water drawn from West Bay between the 300 and 400 cfs alternatives, and (2) significant amounts of more saline water from Stump Lake in the No Action scenario.

2. Exclusive of Warwick (for which the No Action (natural spill) alternative does not apply) TDS values generally decrease with increasing distance from the point of insertion, most likely caused by the influence of dilution from tributary and groundwater inflows and mixing in the Lake Ashtabula reservoir. TDS values for control points along the Sheyenne fall into two groups: Warwick and Cooperstown have the highest values, and TDS values for Valley City, Lisbon, and Kindred are quite similar because of proximity and the fact that they are downstream of Lake Ashtabula.

3. Mean TDS values for the 300 and 480 cfs outlet alternatives are uniformly below 1000 mg/l. When compared to the No Action, natural spill alternative these values are quite close to baseline conditions. However, mean TDS values are much higher under the No Action (natural spill) alternative when compared to baseline, and are at or near 1000 mg/l throughout the reach of the Sheyenne River (ranging from 1600 (EC = 2.5 dS/m )at Cooperstown to 1000 (EC = 1.5 dS/m) at Kindred).

TDS distribution statistics for the alternatives under the Wet7 scenario graphically illustrate a strong relationship to alternative and control point. These relationships will become important in the discussion of soil salinization hazards that follows in the Results and Discussion section. However, soil salinization responds to fairly broad ranges in TDS, and many soils and much of the near-surface groundwater associated with moderately well, somewhat poorly, poorly, and very poorly drained soils in North Dakota have TDS values in the range of 1000 mg/l or higher (EC = 1.5 dS/m and greater).

#### *3.2.1.2. SAR*

As expected, relationships between SAR, control point and alternative (see Figure 8), essentially mirror the relationships examined in detail for TDS, above. Baseflow SAR values range from 1.5 to just over 2.0, with progressive increases in SAR due to increased proportions of Devils Lake water and decreasing distance from the point of insertion. Maximum mean SAR values reflect the additions of highly sodic Stump Lake water in the No Action (natural spill) alternative along with proximity to the point of insertion for the Natural Spill. Thus mean SAR values are highest for Cooperstown (mean SAR of 6.98 for the No Action (natural spill) alternative), and decrease progressively downstream.

Again, SAR distribution statistics for the alternatives under the Wet7 scenario indicate strong relationships to alternative and control point location that are important in the discussion of soil salinization hazards. However, soil salinization responds to fairly broad ranges in both TDS and SAR, and near surface groundwater and subsoil saturation extracts of soils along the Sheyenne Valley can have SAR values in the range of less than 1 to well over 16. Mean SAR values under the constructed outlet alternatives range from just over 3.5 at Cooperstown to just over 2.5 at Kindred. Most irrigated soils in North Dakota do not experience sodicity-induced problems until the SAR goes above 5-6 (Franzen et al., 1996; Springer et al., 1999). SAR values under the constructed outlet alternatives are well below a SAR of 6. However, many soils periodically flooded with Blended Stump Lake/Sheyenne River water under the No Action (natural spill) alternative may experience sodicity induced problems.

### 3.2.2. Temporal Variability in TDS and SAR: Percentage Exceedance Curves

The operational parameters of outlet alternatives result in considerable temporal variability in the TDS and SAR values of Sheyenne River water. Most of the variability would occur during the growing season. In order to assess the temporal variability in TDS and SAR values, percentage exceedance graphs plotting the percentage of time that TDS or SAR exceed a given value were developed for each Alternative and control point using data for the Wet7 climatic scenario. These graphs are presented for the Warwick, Cooperstown, Valley City, Lisbon, and Kindred control points in Appendix A1, Figures A1-1 through A1-10, respectively.

Percent exceedance curves are the reverse of percentage accumulation curves commonly used to assess patterns and relationships in datasets. Several patterns in the exceedance curves provided in Appendix A1 relate to outlet operation characteristics and are consistent from control point to control point.

1. A break in the curve to steeper curve slopes for the 480 cfs Unconstrained Outlet alternative at about 65 percent exceedance represents the period of time where the outlet was in operation under this alternative. An analysis for the presence of Devils Lake dye tracer for the growing season data indicates that blended water was present in 69 percent of the daily predicted water quality values. Under the 480 cfs Wet7 scenario there are

significant periods of time (i.e. 30 percent) where the outlet is not operated because the predicted level of Devils Lake has dropped below 1441.6 fASL.

2. A similar break in the No Action (natural spill) alternative at about 25 percent represents the period of natural overflow of Stump Lake water. An analysis for the Devils Lake dye tracer showed that blended water was present for only 23 percent of the daily growing season values. Natural overflow occurs for only approximately 23 percent of the time under the Wet7, No Action (natural spill) alternative. During the remainder of the time no natural overflow occurs and water quality in the Sheyenne River is essentially baseflow.

3. The percentage of time the outlet is operating differs between the 300 cfs Constrained and the 480 cfs Unconstrained Outlet alternatives. Even though the 300 cfs Constrained Outlet alternative is limited by streamflow and sulfate concentrations at the point of insertion, outlet operation is essentially continuous over the entire period considered in this study. While the 480 Unconstrained Outlet and No Action (natural spill) alternatives result in poorer quality water, there are more periods where natural baseflows prevail.

4. When considered across the entire period beginning with outlet operation May 1, 2005 and extending through the remainder of the planning period, there are significant periods of time during the growing season where TDS and SAR for the alternatives are similar to baseflow values. These periods, generally at the higher percentage-exceedance ranges, are separated by only a few hundreds of mg/l or 0.5 SAR units for the upstream control points and less than this in the control points located along the Red River.

5. Timing is an important consideration, especially under the No Action (natural spill) alternative. The Wet7 climatic scenario predicts that a natural spill from Stump Lake will occur for only a portion of the planning period. However, the data indicate that TDS and SAR values are very high for the natural spill, and that these values would persist continuously for several years during which the natural spill is occuring.

The percentage exceedance curves presented in Figures A1-1 through A1-10 as well as the tabular data that they graphically represent reflect TDS/SAR relationships for the entire growing season during the planning period but after outlet operation was initiated.

Under the No Action (natural spill) alternative Stump Lake discharges to the Sheyenne River for only 23 percent of the WET7 climatic scenario growing season values, but during that time the water is highly saline and sodic. However, during the long period when Devils Lake is not overflowing water quality is essentially at baseflow conditions. From the standpoint of the full plan period, water under the No Action (natural spill) alternative seems quite favorable; however, there is a significant, multi-year period where soils in the Sheyenne Valley that are susceptible to salinization would be receiving saline/sodic water. Similar but much more moderate patterns are evident in the Wet7 480 cfs Unconstrained Outlet alternative trace.

### 3.2.3. NSSL Salinity Hazard Classifications for Wet7 TDS and SAR data

TDS and SAR data are plotted on graphs that include NSSL salinity/sodicity hazard classifications (Richards, 1954) in Appendix A2. Graphs present data from the HEC5Q model for the Warwick, Cooperstown, Valley City, Lisbon, and Kindred control points in Figures A2-1 through A2-5, respectively. The NSSL salinity hazard classifications are described in detail in Section 1.4.1.3 above. NSSL hazard classifications based on EC have been converted to TDS values applicable to the HEC5Q dataset. Pertinent characteristics of the data by control point and alternative include the following.

1. Base values for control point locations along the Sheyenne River falls into the high end of the C2-S1 and the low end of the C3-S1 categories indicating low to medium salinity water with low sodicity.

2. In general, salinity/sodicity hazard increases with increasing amounts of Devils Lake water added to Sheyenne River water; thus hazards are least under the 300 cfs Constrained Outlet alternative, intermediate under the 480 cfs Unconstrained Outlet alternative, and greatest under the No Action (natural spill) alternative. However, it should be noted that for the purposes of NSSL salinity hazard classification, river water under the 300 cfs Constrained and the 480 cfs Unconstrained outlet alternatives have essentially the same hazard classification for any control point. From the standpoint of the classification of river water salinity hazards, the constructed outlet alternatives are very similar.

3. In general for any given alternative, salinity/sodicity hazards in river water are greater nearer the point of insertion and decrease downstream.

4. Baseflow TDS and SAR data for the Warwick, Cooperstown, Valley City, Lisbon, and Kindred control points straddle the border between the C2-S1 and C3-S1 groups.

   Category C1 indicates medium-salinity water that can be used for irrigation without a salinity hazard if soils are moderately leached. Category S1 indicates low sodium water that can be used on nearly all soils with little danger of sodium buildup in the soil.

5. The mixing of progressively larger amounts of more saline and more sodic Devils Lake water with Sheyenne River water under the 300 cfs Constrained and 480 cfs Unconstrained outlet alternatives results in a movement of water quality further into the C3-S1 category. Several datasets show values approaching C3-S2 and C4-S2 categories.

   Category C3 indicates high salinity water that may be detrimental in soils with restricted drainage. However, C3 water may be used for irrigation under high levels of management and may require planting crops with good salt tolerance. Category S2 indicates medium sodium water that may present a sodium hazard on fine-textured soils with low permeability, especially in soils that lack free calcium (e.g. lack free calcium carbonate). Most groundwaters that are used for irrigation in North Dakota are in the C2 to C3 salinity range and the S1 to S2 sodium hazard range (Scherer et al., 1996).

6. Under the No Action (natural spill) alternative, TDS and SAR values for river water at Kindred, Lisbon and Valley City move well into the C4-S2 and C4-S3 categories. For the Cooperstown control point upstream of Lake Ashtabula and closer to the point of

insertion, TDS and SAR values for the No Action (natural spill) alternative move into the extremes of the C4-S3 category.

Category C4 indicates high salinity water that cannot be used on soils with restricted drainage. Special management is required even with good drainage, and crops with good salt tolerance must be selected. Categories S2 and S3 indicate medium and high sodium waters, respectively. S2 water will present an appreciable sodium hazard in fine textured soils with restricted drainage. High sodium (S3) water can present an appreciable sodium hazard (loss of structure, poor plant-water characteristics) on most soils unless they are gypsiferous (contain high levels of soluble calcium). Valley soils regularly flooded with such water that are hayed or cropped will require special management.

#### *3.2.3.1. General Implications of Water Quality for Soil Salinization Hazards*

Overbank flooding with blended Sheyenne River/Devils Lake water essentially amounts to the very intermittent irrigation of affected floodplain soils, generally delivered prior to the growing season. The NSSL salinity/sodicity data examined above indicates that few problems should be expected with the periodic flooding of irrigable, moderately well drained, occasionally flooded soils on the floodplain under the constructed outlet alternatives. Flooding will be intermittent and will be with water in essentially the same salinity category (C2-S1 and C3-S1) as base conditions. Furthermore, the flooding of moderately well drained soils on occasional or rarely flooded portions of the floodplain will be extremely rare after the recession of the spring flooding.

However, flooding of soils immediately adjacent to the river that are listed as being frequently flooded could be expected at any time during outlet operations, especially under the Wet7 climatic scenario that is based on a continuation of pluvial conditions that are much wetter than historic wet periods in North Dakota. Accordingly, soils next to the river that are listed as frequently flooded may be more susceptible to salinization. However, the accumulation of salts in these soils would be mitigated somewhat by leaching and flushing of the accumulated salts back into the river during early spring flooding prior to outlet operations. Poorly drained and very poorly drained soils in depressions, swales, abandoned meanders and oxbow lakes have the most severe hazard due to their position relative to the mean water table, the typical presence of elevated levels of subsoil salinity, relatively fine textures, and negligible leaching potential. These soils could be affected by the addition of more saline/sodic water under the outlet alternatives, and additionally would be susceptible to rises in mean watertables that would mobilize additional salt.

Based on river water quality only, salinization hazards appear to be greatest under the No Action (natural spill) alternative. As shown below, spring flooding under the No Action alternative will be initiated with more saline sodic water because the overflow from Stump Lake could continue year round. Accordingly, the hazards mentioned above will become more extreme under the No Action alternative, and could result in salinization of soils affected by flooding, mean increase in river stage, and groundwater intrusion occurring from backflow of Bank storage. The effects would be greatest on the poorly to very poorly drained soils adjacent to the river, as well as those soils adjacent to the river that are frequently flooded. The mitigating effects of leaching would not be as important as spring flood flows could be quite saline.

### 3.3. SHEYENNE RIVER STAGE AND FLOW: IMPLICATIONS FOR SOIL SALINIZATION

#### 3.3.1. HEC 5Q GUI predictions of daily stage and flow dynamics for the Wet7 Scenario

Outlet operations will have a significant effect on the salinization hazards associated with the introduction of blended Sheyenne River/Devils Lake water on soils adjacent to the upper Sheyenne subject to frequent spring flooding. The effects will be particularly noticeable in the upper reaches near the point of insertion because of a characteristically low channel capacity and a broad active floodplain.

Hydrographs showing predicted flow and stage data for a representative 5-year period beginning April 1, 2015 and extending through March 2020 are presented in **Figures 9 and 10** for the Cooperstown and **Figures 11 and 12** for the Kindred control points, respectively. The period presented was chosen to represent a time where a natural spill was occurring from Stump Lake in order to compare stage and flow data among all of the outlet alternatives. The hydrographs show the following:

1. An expected large rise resulting from spring snowmelt is evident for all years. However, 2015 and 2016 also represent periods where summer rainfall also produces some significant stage increases. This said, outlet operations generally start May 1 after the spring flood has declined to levels below peak flood stage. Outlet operations under the 300 cfs Constrained alternative would not begin until floodwaters have receded to the point that the Sheyenne is within the banks at the point of insertion. This constraint on outlet operation would limit the impacts of overbank flooding with blended Sheyenne River/Devils Lake water on potential soil salinization of adjacent soils that are regularly flooded during spring. Regular spring flooding with base condition floodwater would also tend to leach salts from the soils that accumulated under the alternatives prior to the flood event.

2. Under the 480 cfs Unconstrained alternative, spring flooding would be aggravated because outlet operations would begin even during periods of overbank flooding at the point of insertion. The effects would be mitigated somewhat by the fact that the additional water added during outlet operation is a smaller portion of the spring flood volume, and may be diluted to some degree. In addition, even though outlet operations under the 480 unconstrained alternative are not limited by channel flow capacity, the beginning of outlet operations on May 1 ensures that the introduction of Devils Lake water into the Sheyenne will occur after the majority of spring flooding has passed.

3. Average stage increases during normal, in-bank flows vary between 2.5 to 3.5 feet for the 300 cfs Constrained and the 480 cfs Unconstrained alternatives, respectively.

4. Mean flows and stage under the No Action (natural spill) alternative are generally well under the flows and stages associated with the constructed outlet alternatives. With the exception of the year 2019, flow and stage under the No Action (natural spill) alternative are just slightly over the flows associated with base conditions. However, spring flooding under the No Action (natural spill) alternative will consist of more saline/sodic blended water for the duration of the flood event. Under spring flood conditions, soils adjacent to the river that are

subject to regular spring flooding will receive more saline/sodic water during the entire flood event.

5. Flow and stage decline dramatically upon cessation of pumping on November 30. A river stage minimum is expected during winter when there are essentially no precipitation and runon inputs. However, the decline in stage observed during winter represents a period where watertables maintained at higher elevations during outlet operation would similarly decline. The overwinter decline in watertable elevation provides a mechanism for salts added to adjacent soils during outlet operation to be discharged back to the river. This would "set the stage" for a more aggressive leaching of salts during the portion of the spring flooding that occurs prior to outlet operation but after the frost leaves the ground.

6. Winter stages and flow in the Sheyenne River are maintained at generally higher levels under the No Action (natural spill) alternative due to continuous discharge from Stump Lake. Over long periods of time this could result in additional salinization as the saline blended water diffuses outward from the river itself. The effects would be primarily to the adjacent poorly drained soils associated with low floodplains and abandoned meanders. The effect may be mitigated by the effluent nature of the Sheyenne; however, transient flow reversals associated with stage variations in the river resulting in bank storage and backflow would be a normal occurrence.

(Insert Figure 9 here)

(Insert Figures 10 here)

(Insert Figure 11 Here)

(Insert Figure 12 here)

### 3.3.2. Average Stage for May and August

Mean increases in the stage of the Sheyenne River as a result of adding 300 and 480 cfs to mean May and August flows were provided by Pat Foley of the St. Paul District, USACE. These results are consistent with the observation made using HEC5Q data in 3.5.1, above. The data show stage increases for May (higher flows) of 1 to 2.5 feet and 1 to 3.5 feet for the 300 and 480 cfs alternatives respectively. The data also show stage increases for August (lower flows) of 1 to 3 feet and 1 to 4 feet for the 300 and 480 cfs alternatives respectively. Higher stage increases were associated with Horace and West Fargo gauge station where the river is quite narrow.

Mean stage increases of 1 to 1.5 feet in upstream locations where the river is shallowly entrenched (see data for Warwick and Cooperstown, Table 3) would increase the salinization hazards for soils in low areas adjacent to the river that have high watertables and are poorly drained. Salinization hazards could be associated with both additional salt due to overbank flooding, groundwater intrusion, or, more importantly, mobilization of existing salt under mean stage increases. Downstream where the river is deeply entrenched, increases of the order of 1 to 4 feet are not expected to significantly affect soils above the entrenchment because of the depth to which the river is entrenched and the rapidity with which adjacent soils would drain.

(Insert table 3 here)

### 3.3.3. Percentage Exceedance Graphs for HEC5Q Predicted Flows at Cooperstown and Kindred

Percentage exceedance graphs developed for the 45-year planning period using HEC5Q data, Wet7 climatic scenario for Cooperstown and Kindred show that flooding in excess of 1000 cfs for the period of constructed outlet operations beginning May 1 through September 31 will be relatively rare (**Figures 13 and 14**). Flows above 1000 cfs for Cooperstown (representative of upstream conditions) can be expected for only approximately 2% of the growing season, primarily associated with the recession of spring flooding. Flows above 1000 cfs for Kindred (representative of downstream conditions) will be above 1000 cfs for approximately 5% of the growing season, again occurring primarily during spring. Comparing this data to the HEC 5Q flow predictions again suggests that significant spring flooding associated with the larger flows will be prior to the introduction of blended water into the Sheyenne River.

(Insert Figure 13 here)

(Insert Figure 14 here)

### 3.3.4. USGS Monitoring Wells

The USGS has provided interim hydrograph data that shows water table responses to controlled and uncontrolled increases in Sheyenne River stage in water table wells set perpendicular to the river at distances varying from 25 feet to over a thousand feet. Large stage changes in the Sheyenne River were generally in concert with changes in water table elevations in wells up to 800 feet from the river, suggesting that the stage of the Sheyenne River can affect watertables elevations at some distance from the river. Wells emplaced at 1000 feet distant from the river showed only minor correspondence with stage levels in the Sheyenne River, and minor stage changes in the level of the Sheyenne River were dampened even in fairly close wells.

These interim data have yet to be analyzed by the USGS in detail and have not been placed in a topographic, hydrologic, or stratigraphic context. Most of the wells were installed within 250 feet of the river. Much of the flooding response appears to be the direct result of the impact of overbank flooding on the adjacent wells and the effects of bank-storage resulting in an increase in well levels. This increase was attributed to groundwater discharge in typically effluent areas being decreased by the presence of significant-but-transient groundwater mounds developing at the river' s edge in response to stage increases. However, the implications that stage variations in the Sheyenne River can influence groundwater tables at distances up to several hundred feet perpendicular from the river are apparent in a few well hydrographs. The impact to soil salinization of this increase will depend upon the watertable depth at the specific location, the magnitude of the stage change in the river, and any overbank flooding that would occur. Water quality data collected by the USGS suggest that stage increases were not the result of riverwater intrusion or backflow into the soils. This information comports well with other studies that show that effects of stage variations in areas of the Sheyenne that receive groundwater discharge are confined to areas generally close to the river (Strobel and Radig, 1997, Barr Engineering, 1999b).

The conclusion drawn is that significant increases in river stage create bank storage or backflow conditions that can affect watertables in nearby floodplain soils. It is expected that the soils most affected will be poorly-developed, frequently flooded Udifluvents that are on the active floodplain in channeled lands and regularly flooded soils in low positions adjacent to the river generally. The reader is directed to Doug Emerson of the USGS for more information on their interim study (Doug Emerson, USGS North Dakota Office, Phone 701.250.7402).

### 3.3.5. Flooded Area Outlines

HEC-RAS predicted flooded area outlines at 1000, 1500, 2000, and 3000 cfs were provided by the St. Paul District USACE for use in estimating the potential flooding along the Sheyenne at varying flow rates. Their models are based on extremely accurate Lidar digital elevation models (DEM) data created during 1999 and 2000. The data show that extensive overbank flooding will occur at flow rates above 1000 cfs in the upper reaches of the Sheyenne River (generally above Baldhill Dam). However, the data show that flow rates varying from 1000 to 3000 cfs in the deeply entrenched portions of the Sheyenne River below Baldhill Dam are essentially confined within the banks of the Sheyenne River and adjacent abandoned meanders and oxbows. Data showing a comparison of the distribution of saline soils with HEC-RAS estimated flooded area outlines for the shallowly entrenched upper reaches and the deep entrenched lower reaches of the Sheyenne are in **Figures 15 through 16**, and **17 through 18**, respectively. Soils have been color coded to indicate (1) existing mapped consociations of saline soils, (2) soils with major saline components, and (3) soils with listed saline inclusions.

(Insert Figure 15 here)

(Insert Figure 16 here)

(Insert Figure 17 here)

(Insert Figure 18 here)

The effects of shallow entrenchment and high watertables on existing salinity are evident. The areas where extensive flooding at 1000 cfs is expected have extensive to common saline soils due to the low entrenchment and higher water tables resulting in the concentration of salts by evapotranspiration. In areas where the entrenchment essentially confines flow up to 3000 cfs, mapped saline soils are rare or totally absent, reflecting the presence of moderately well drained soils with deeper watertables not within the influence of the root zone or areas of the soil profile that are subject to evapotranspiration. It is expected that moderately well drained mollisols occupying higher portions of the floodplain in this area will be rarely flooded and will not have a significant salinization hazard unless those soils are close enough to the river to be affected by mean increases in river stage.

### 3.3.6. Summary: Implications of Flow, Stage and Duration Data for Soil Salinization Hazards along the Sheyenne River Floodplain

1. During significant flooding events when overbank flooding persists past the initiation of outlet operations, low areas on the active floodplain could be flooded with blended Sheyenne River/Devils Lake water that has increased levels of salinity and sodicity. However, the Devils Lake water introduced to the Sheyenne River during spring flood conditions would be diluted by the relatively fresh runoff.
2. Overbank flooding is minimized under the 300 cfs scenario because of the constraint of not exceeding 600 cfs in the channel at the point of insertion.
3. The addition of 300 cfs Devils Lake water under the Constrained alternative and 480 cfs Devils Lake water under the Unconstrained alternative increases both predicted stage and flow. Comparing stage elevations after the recession of spring flooding, it is apparent in the HEC 5Q output that overall stage increases of normal in-bank flows will be approximately 2 feet higher under the 300 cfs Constrained alternative, and that normal flows will be proportionately higher at approximately 2.5 feet under the 480 cfs Unconstrained alternative. These are overall averages estimated from a comparison of HEC 5Q output for various Control Points. It should be noted that this generalized assessment of stage rises in response to the addition of 300 cfs and 480 cfs of Devils Lake water varies considerably between control point, time, and the morphology of the river channel. However, the data comport quite well with predicted mean stage increases supplied by the St. Paul District, USACE and discussed under section 3.2.2 above.
4. During the majority of the May 1 – November 30 operating period for the constructed outlet alternatives, flows in the Sheyenne River will be in-bank. Soils potentially impacted by salinization during in-bank conditions will be poorly and very poorly drained soils adjacent to the river in shallowly meandered areas that may experience more frequent flooding and increased groundwater levels responding to a mean rise in river stage. Impacts are expected in channeled and frequently flooded zones characteristic of the lowest portion of the floodplain that are dominated by Udifluvents.
5. Moderately well drained soils that are only occasionally flooded would not be expected to have a substantive salinization hazard under these conditions, especially in locations distant from the river where watertables are deep. However, areas close to the river could be affected if watertables rise to within the rooting zone.

Given the frequency and duration of flooding, with most of the spring flooding occurring prior to the initiation of outlet operations, the flooding of adjacent soils is the equivalent of the infrequent application of irrigation water to these soils. While having a lower TDS and SAR quality compared to base conditions, water quality under the constructed outlet alternatives is still acceptable for most irrigation purposes, and many of the moderately well drained floodplain soils are irrigible soils with high thresholds for both TDS and SAR (see PEC Report Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives: Irrigation, dated October 10, 2001).

## 3.4. SOIL SALINITY AND SODICITY ALONG THE SHEYENNE RIVER VALLEY IN NORTH DAKOTA

Significant acreage of saline and potentially saline soils presently exists along the Sheyenne River. Saline/sodic soils are primarily associated with low, poorly drained positions immediately adjacent to the river upstream of Lake Ashtabula. However, other soils have potential salinization problems if hydrologic regimes are altered sufficiently to mobilize and concentrate existing salts. Specific details regarding the determination of salinity and sodicity are discussed below and provide the background necessary to understand salinization hazards associated with the outlet alternatives along the Sheyenne River.

### 3.4.1. Important Topographic and Soil Properties Affecting Soil Salinity in the Sheyenne River Valley

This analysis has been limited to the effects of the outlet alternatives on soils in the Sheyenne Valley that are moderately well, somewhat poorly, poorly, and very poorly drained soils that are characteristic of floodplain and terrace positions potentially affected by the alternatives. Well-drained soils at the periphery of the valley do not flood and are high enough above the water table that they would not be affected under the outlet alternatives.

Saline soils are common along the Sheyenne River, especially in the upper reaches above Lake Ashtabula, and are typically associated with geomorphic positions related to the active floodplain and associated terraces. Sodic soils are less common, but occur occasionally on the floodplain, on Lake Plain inclusions, and in soils that are shallow to shale. Salinity and sodicity are recognized in the soil survey, and ranges in ECspe and SAR are provided for surface soils (A-horizons) and subsurface soils (B- and C-horizons). Non-saline soils have saturation extract EC (ECspe) less than 4 dS/m. Non-sodic soils have SAR values < 13.

The following list of soil properties represent the most important soil characteristics to evaluate the impacts of the outlet alternatives on soil salinization along the Sheyenne River valley.

#### *3.4.1.1. Landscape Setting*

Soils in the Sheyenne River Valley have developed under a hydrologic regime consisting of a balance between water sources, including surface floodwaters, groundwater associated with stream stage and flooding dynamics, infiltrated precipitation and runoff.

Landscape position is the most important factor regarding the current salinization status of soils associated with the Sheyenne River because landscape position drives the hydrologic regimes under which the soils developed. Some soils flood regularly, but are in positions where accumulated salts can leach. Other soils are in positions that are intermittently to continuously wet and do not leach, permitting evapotranspiration to concentrate salts to high levels. Virtually all of the soils identified in this report are associated with the Sheyenne River and adjacent floodplain and terrace landform features described below and in **Figure 19**.

(Insert Figure 19 here)

**River channel**: The river channel itself occupies the entrenchment and varies in width and depth with varying river stages. River stages rise until the river becomes bank full, whereupon the banks are overtopped initiating a flood stage. The river channel can be shallowly or deeply entrenched, and can also be occupied by low vegetated areas such as point bars and areas around tributary inflows.

**River entrenchment**: The river entrenchment is similar to the river channel, but can occupy a larger vertical dimension. For example the river entrenchment may become great enough in some locations that overbank flooding is minimal. Portions of the Sheyenne River are deeply entrenched, and rarely flood by overbank flow.

**Point bars, cut banks**: Faster movement of water on the outside of river meanders results in an erosion feature called a cut bank. Conversely, the material eroded from the cut bank is deposited in the slower moving water on the inside of meanders and builds (or accretes) point bars. The progressive erosion of cutbanks and deposition on point bars results in the gradual downstream migration of river meanders. Many areas of the Sheyenne have rough, dissected floodplain soils within and near the meander belt. Soil surveys map the area affected by regular deposition/erosion cycles "*Fluvents*" indicating that the soils are disturbed regularly enough to prevent or retard soil development. In entrenched areas especially Fluvents rapidly drain when floodwaters recede. Thus many Fluvents are moderately well drained soils that are wet only when flooded. Frequent flooding, higher stages, and elevated salinity/sodicity levels could result in a salinization hazards with these soils, however, salts are unlikely to build up to high levels because the soils are flooded regularly enough to leach accumulated salts back to the river.

**Channeled Land**: Channeled land is the result of the downstream movement of meanders as cutbanks are eroded and point bars accrete. Some soil surveys recognize "Channeled Phases" of Fluvents in these dissected areas. The topography of channeled land consists of a subdued relief of low ridges and intervening swales. Channeled areas regularly flood, and swale positions frequently are poorly drained and are wet for long periods of time. Soils occupying channeled land immediately adjacent to the river also have a potential for salinization under the alternatives because of more frequent flooding, higher mean stages, and elevated salinity/sodicity levels. However, the periodic flushing of accumulated salts during regular flooding events would prevent salinization to high levels.

**Natural Levees**: Natural levees are the landforms created by overbank flooding resulting in the rapid loss of energy as the floodwater decreases in velocity. When the floodwater slows, coarser textured silts and very fine sands that were kept in suspension in rapidly moving floodwater in the channel settle out in the slower moving overbank flood water. The resulting convex mound that is frequently observed adjacent to meandering rivers is called the natural levee. Natural levees can accrete to relatively high levels, and frequently are some of the better drained areas in the vicinity of the river. High intensity floods do not necessarily overtop the natural levees, but break out of the natural levees in specific locations called splays, which then flood adjacent land. Natural levee soils along entrenched areas of the Sheyenne River are frequently moderately well drained to well-drained soils that flood occasionally. However, as soon as flood stage declines, these soils rapidly drain and do not remain wet for long periods of time. Soils occupying natural levees immediately adjacent to the river have a slight potential for salinization under the alternatives because of more frequent flooding with blended water having elevated salinity/sodicity levels. However, salinization to high levels would be prevented by the periodic flushing of accumulated salts during regular spring flooding and precipitation and leaching in these permeable soils that occurs prior to the initiation of outlet operations.

**Overbank flood plain**: The overbank floodplain typically consists of fine-grained sediment deposited from suspended load of overbank floodwater. In positions where flooding is frequent, Fluvents form because frequent flooding retards soil development. Moderately well drained soil called *Mollisols* become more dominant in better-drained positions that flood less frequently. Some soils on the overbank flood plain may have a salinization hazard under the alternatives due to more frequent flooding with blended water having elevated salinity/sodicity levels. The hazards would be higher closer to the river and in areas that flood frequently and would potentially receive backflow from bank storage.

**Abandoned meanders and oxbow lakes**: The process of cutbank erosion and point bar accretion in meandering streams can result in a meander being cut-off, resulting in roughly circular to crescent shaped low depressions adjacent to the river and on the flood plain. Once a meander is cut off, it becomes isolated from the stream by silt plugs deposited by faster-moving water in the terminus of the abandoned meander. Abandoned meanders then gradually fill with fine-textured sediments during successive floods. Abandoned meanders are typically dominated by poorly and very poorly drained soils, and can frequently flood if on the active floodplain. Accordingly, soils in abandoned meander positions have significant salinization hazards under the alternatives because they regularly flood, generally retain the salts in the floodwaters as they evaporate, and are subject to high watertables with potentially high levels of subsoil salinity even after floodwaters recede.

**Backswamp**: Backswamp areas are locations where floodwaters slow and pool, resulting in the deposition of fine-textured suspended sediments. Backswamp positions are frequently dominated by poorly and very poorly drained, fine textured soils. Flooding is usually a frequent occurrence in backswamp positions. Accordingly, soils in backswamp positions have significant salinization hazards under the alternatives because they regularly flood, generally retain the salts in the floodwaters as they evaporate, and are subject to high watertables with potentially high levels of subsoil salinity.

**Terrace Deposits**: As rivers erode they downcut into their valley until they reach an equilibrium between erosion and deposition. Downcutting by streams can leave elevated terraces that were once a more-active, more frequently flooded portion of the active flood plain. Soils on elevated terraces are flooded less frequently and usually have better developed soils than the soils of the active floodplain. Relict terraces from Pleistocene outwash events can be observed in many places along the Sheyenne; however, these terraces are a much higher elevations than the active floodplain and rarely if ever flood.

**Valley Margins**: Valley margins are dominated by alluvium/colluvium resulting from erosion along the valley walls. Soils in these positions are moderately well to well drained and would not be affected under the outlet alternatives.

**Miscellaneous landforms**: The Sheyenne River Valley was formed through glacial processes during the Late Wisconsin stage of the Pleistocene glaciation. The present Sheyenne River is a classic underfit stream that meanders across the floor of the valley that is the result of those glacial processes. Isolated glacial landforms such as lake plain sediments and till outliers are occasionally noted along the Sheyenne, along with their associated soils formed in till and lake plain sediments

*3.4.1.2. Flooding*

Flooding is an important soil characteristic affecting potential soil salinization under the outlet alternatives. Soils that rarely or never flood will not be affected by floodwater containing blended Sheyenne River/Devils Lake water. The NRCS rates soils for flooding potential. Flooding is defined as the temporary occurrence of flowing water on the soil surface. With respect to flooding along the Sheyenne River, the following frequency and duration classes apply.

Frequency:

- None — No reasonable possibility
- Rare — 1 to 5 times in 100 years
- Occasional — 5 to 50 times in 100 years
- Frequent — > 50 times in 100 years

Duration:

- Extremely Brief — < 4 hours
- Very Brief — 4-48 hours
- Brief — 2-7 days
- Long — 7 days to one month
- Very Long — > 1 month

NRCS databases and the county soil surveys also provide estimates of the expected period of flooding. The period of flooding has a strong relationship to landscape position. For example, poorly drained Lamoure soils (*fine-silty, mixed, superactive calcareous frigid Cumulic Endoaquolls*) that are adjacent to streams are typically listed as being frequently flooded for brief periods between the months of October through June. Conversely, Moderately well drained LaDelle soils (*fine-silty, mixed, superactive calcareous frigid Cumulic Hapludolls)* that occupy higher portions of the active floodplain are listed as being occasionally flooded for brief periods between the months of April through June.

*3.4.1.3. Soil Drainage*

Drainage class identifies the natural drainage condition of the soil and refers to the frequency and duration of wet periods. Drainage classes are usually inferred from observations of landscape position and soil morphology when soils are mapped in the field. In many soils the depth and duration of wetness relate to the quantity, nature, and pattern of features used to identify hydric soils. The drainage class roughly indicates the degree, frequency, and duration of wetness that is strongly related to landscape position. The following drainage classes are dominant for the soils mapped along the Sheyenne Valley.

**Moderately well drained**. Water is removed from the soil somewhat slowly during some periods of the year. The water table is moderately deep and transitory through permanent. The soils are wet for only a short time within the rooting depth during the growing season, but long enough that most mesophytic crops are affected. They commonly have a moderately low or lower saturated hydraulic conductivity in a layer within the upper 1 meter, periodically receive high rainfall, or both.

**Somewhat poorly drained**. Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The water table is shallow to moderately deep and transitory to permanent. Wetness markedly restricts the growth of intolerant crops. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage.

**Poorly drained**. Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. The water table is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that intolerant crops cannot be grown. The soil, however, is not continuously wet directly below the plow-depth. Free water at shallow depth is usually present.

**Very poorly drained**. Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of the water table is very shallow and persistent or permanent. The soils are commonly level or in depressions and frequently ponded.

Drainage class is a very important characteristic when evaluating soil salinization potential under the outlet alternatives. Poorly and very poorly drained soils adjacent to the river that experience a mean stage increase under the alternatives can accumulate more salt resulting from raised watertables, especially if subsoil salinity is already present. Moderately well drained and well drained soils can leach salts added in floodwater to the subsoil where it is less of a problem.

#### *3.4.1.4. Seasonal High Watertable Depths*

Seasonal high watertable depths are provided as typical ranges for soil in the NRCS Map Unit Interpretations Record (MUIR) database and in official series descriptions (OSDs). Classes are broad, and generally are in the range of 2 to 3 feet. There is a strong relationship between seasonal high watertable depths and drainage classes. A typical description for a moderately well drained soil such as the LaDelle series would be a seasonal high watertable depth ranging from 3.5 to 5 feet in depth sometime during the period extending from April through June.

#### *3.4.1.5. Salinity and Sodicity*

High levels of soil salts are typically associated with high water tables and "wet" soils. Salinity moves with the water and can change in magnitude and distribution relatively quickly with time compared to other more stable soil properties such as texture.

Sodium (Na) affects the physical condition of the soil by dispersing aggregates. The soil becomes pasty when wet and develops a condition called "puddling", where water remains on the surface for an extended period. The soil becomes hard when dry, and its permeability to water and air is reduced.

Salinity and sodicity are listed for applicable soil in the MUIR database and in the published soil surveys. However, rather broad ranges are provided. The classes of salinity apply (ranges are in dS/m).

- Nonsaline 0 - < 2
- Very slightly saline 2 - < 4
- Slightly saline 4 - < 8
- Moderately saline 8 - < 16
- Strongly saline > 16

Saline soils with ECspe values ranging from 4 to 16 are common along the upper reaches of the Sheyenne River.

Sodicity is reflected in the SAR described in detail in section 1.4.1.2 above. The effects are primarily on soil structure and water availability characteristics. Sodic soils are recognized when the SAR in a saturation extract rises above 13, and are relatively rare along the Sheyenne River.

#### *3.4.1.6. "Critical Depth" and "Critical Salinity"*

Critical depth and critical salinity are poorly defined but useful concepts that evaluate the effects of watertable depth and salinity on soil salinization. The essential criteria include the seasonal high water table depth and the salinity of the surface and subsurface soil layers, both of which are available in the MUIR database. "Critical Depth" and "Critical Salinity" are interrelated parameters that generally suggest the potential for soil salinization, and are to a large degree texture dependent. If the salinity of the near surface watertable is low, watertables can raise to near the soil surface without a significant salinization hazard. Similarly, if the salinity of the near surface watertable is high, the watertables must be deeper to ensure that capillary rise and plant evapotranspiration do not concentrate salts above a level that affects plant growth. For example, the moderately well drained LaDelle soil is a common floodplain soil on terraces of the Sheyenne that flood occasionally (5 to 50 years out of a hundred). LaDelle soils are moderately well drained, with a listed seasonal high watertable varying in depth from 3 to 5 feet from the surface. Subsoil salinity is listed as ranging from 0 to 4 dS/m. If the effects of the outlet alternatives result in an increase in mean water table depth to 2-3 feet from the surface, soils with subsoil salinity at the higher listed ranges (e.g. 4 dS/m) could become salinized by evapotranspirative concentration of salts in the rooting zone.

#### *3.4.1.7. Permeability and Infiltration*

Soil permeability is the quality of the soil that enables water or air to move through it. Permeable soils transfer water rapidly through the soil matrix, while impermeable soils transfer water very slowly. The following permeability classes apply (ranges in in/hr).

- Very rapid		>20
- Rapid		6 - <20
- Moderately rapid		2 - <6
- Moderate		0.6 - <2
- Moderately slow		0.2 - <0.6
- Slow		0.06 - <0.2
- Very slow		0.0015 - <0.06
- Impermeable		0.00 - <0.0015

Water and the dissolved salts they carry can move quickly through soils with moderate to rapid permeability. In moderately to well drained, salts can be leached to the subsoil or out of the soil entirely. Salts can accumulate in soils with slow permeability due to the retarded movement of water. Infiltration refers to the ability of water to move into the soil. Usually soils with high permeability have high infiltration rates as well. Infiltration rates are also affected by soil structure and plant cover. Soils with moderately slow to rapid permeability can leach salts received as overbank flooding is the soils are moderately to well drained with deeper seasonal high watertables.

#### *3.4.1.8. Runoff*

Surface runoff refers to the loss of water from an area by flow over the land surface. The estimation of the amount of runoff is important to hydrologic models in assessing the stream flow and water storage. The estimation of runoff involves both permeability and slope. Impermeable soils on high slopes have very high runoff, soils on moderate slopes with moderate permeability have moderate to slow runoff rates. The importance of runoff rates for soil salinization relates to the amount of water available to leach into the soil. For example, salts accumulated in the surface of moderately well drained soils with moderate to slow runoff under periods of inundation will have water available to leach the salts into the subsoil when water becomes available through precipitation or as runoff from adjacent sloping areas.

#### *3.4.1.9. Soil Texture and Structure*

Soil texture (the percentage of sand, silt and clay sized particles in the soil) influences other properties such as water holding capacity, infiltration rate and internal drainage. Fine textured soils usually have slow infiltration rates unless the soil structure is good. Leaching saline water through fine textured soils may be difficult. Limited leaching capacity increases a soil salinity hazard.

Also important for water movement is soil structure. Soil particles are arranged into structural aggregates through the action of weather, organic matter bridging and coating, soil mineral composition, time and outside physical forces such as compaction, root growth and animal activities. Soils containing unstable, easily dispersed aggregates (for example sodium affected soils) may require special management. Movement of water into and within soils is partially dependent on soil structure. Fine textured soils with strong, stable structure can have very good water infiltration and permeability characteristics similar to coarser textured soils.

### *3.4.1.10. Calcium Carbonate and Gypsum Content*

Pedogenic Calcium Carbonate (calcite, $CaCO_3$) and gypsum are sparingly soluble salts that are common constituents of saline soils. Both minerals are the result of in-situ precipitation as water containing soluble salts evaporates in the soil profile. The presence of calcite and especially gypsum in moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained soils indicates a near surface watertable with a potentially high salt load. Frequently groundwater discharge is indicated. Soils with high levels of calcite and especially gypsum can be particularly susceptible to salinization if the watertables are raised further into the rooting zone. Thus poorly drained soils adjacent to the Sheyenne River that already have high subsoil salinity can rapidly salinize when mean water levels rise under the outlet alternatives.

### *3.4.1.11. Soil Series, Soil Survey Map Units, and Inclusions*

Soil texture, structure, permeability, salinity, sodicity, topography, and slope discussed above are relatively consistent properties that, among other characteristics, are associated with soil series designations. North Dakota has 264 soil series as mapped and described in the county soil surveys. Soil mapping units as provided in the county soil surveys consist of varying mixtures of these soil series. Some map units (consociations) identified in the soil survey consist of one dominant soil with included similar soils. More frequently, complexes consist of two or more dissimilar soils occurring in a known and definable pattern are mapped. The pattern is so complex that individual components cannot be delineated at the scale of the mapping. Complexes are usually designated by the names of the dominant soil series (major components).

A minor percentage of each map unit consists of soils that are not included in the name of the map unit. These minor soil inclusions are discussed in the map unit description in the hardcopy soil survey, and are identified in the digital database products (Soil Survey Geographic Database or SSURGO) and Map Unit Interpretations Record or MUIR) available from the Natural Resources Conservation Service (NRCS). Percentages of included soils are provided in the database products; however, links to attribute data for the included soils are not provided.

Many map units along the Sheyenne Rivers consist of complexes of several soils with inclusions. In some cases inclusions can be accounted for if detailed attribute data is not required. However, in many cases, the properties of inclusions are not addressed in the digital database products available from the NRCS.

# 4. RESULTS AND DISCUSSION:

## 4.1. SOIL SALINIZATION HAZARDS ASSOCIATED WITH THE ALTERNATIVES

There are three potential salinization hazards associated with outlet alternatives:

(4) Additional salt loading to affected floodplain soils could result from over-bank flooding with more saline, blended Devils Lake/Sheyenne River water. Blended water would infiltrate and could add to the salinity of the surface and subsoils.

(5) Induced floodplain salinization resulting from the raising of watertables of floodplain and adjacent soils in the Sheyenne River Valley above a "critical depth".

(6) Seepage outflow of mixed Devils Lake/Sheyenne River water could produce additional salt loading to adjacent floodplain soils during periods when the river is contained within the channel. This is a dynamic process that would result in frequent transfers of blended water between the Sheyenne and adjacent soils as the river naturally rises and falls within its banks. However, these transfers of water would be restricted to a narrow band of soils immediately adjacent to the Sheyenne. While the effect is probably minimal under mean stage conditions where the Sheyenne is well within its banks, groundwater mounds developing within the bank during high water stages (bank storage) could dissipate both towards and away from the river. Low soils adjacent to the river in locations where the river is shallowly entrenched could be affected to a greater degree.

## 4.2. SOIL SALINIZATION HAZARDS ALONG THE SHEYENNE RIVER VALLEY ASSOCIATED WITH OUTLET DISCHARGE (300 AND 480 cfs DISCHARGE) AND THE NO ACTION ALTERNATIVE (NATURAL SPILL)

Salinization hazards associated with the constructed outlet alternatives on floodplain soils adjacent to the Sheyenne River will probably be influenced more by the mobilization of existing surface and subsurface salts than they will be by increased salinity of the blended water. Thus, salinization hazards are expected to be more dependent upon flood stage and duration dynamics as related to landscape position than on the salinity actually associated with the blended water itself.

The only caveats to these observations involve the No Action (natural spill) alternative under which spring flooding will occur with much more saline water. Under these conditions, flooding could appreciably add to the salinity and sodicity of the affected soils as the floodwater infiltrates the soil. As indicated above, spring flooding of productive floodplain soils associated with positions more distant from the river will generally occur prior to the initiation of pumping under the constructed outlet alternatives. Even if temporarily flooded with blended water under the outlet alternatives, the productive soils of most concern (LaDelle, LaPrairie, and Fairdale series) are moderately well drained irrigible soils (Irrigibility Group 4A, TDSmax = 1450, SARmax = 6; Franzen et al., 1996) that can periodically handle intermittent flooding with water of the quality represented under the Wet7 climatic scenario with no significant hazards. Under the No Action (natural spill) alternative, spring floodwaters will be much more saline and sodic and could result in additional salinization/sodification hazards.

#### **4.2.1. Soils Maps of Moderately Well Drained, Somewhat Poorly Drained, Poorly Drained, and Very Poorly Drained Soils along the Sheyenne River**

A descriptive legend for the soils digitized along the Sheyenne River is provided by county in Appendix B-1. Official Series Descriptions of the soil series identified along the Sheyenne Valley are provided in Appendix B2.

Data presented in the descriptive legend include:

1. Soil Survey Area Identification
2. Soil survey name
3. Map unit symbol
4. Map unit name
5. Soil series name (Major Components)
6. Percentage composition (major components)
7. Drainage class (Major Components)
8. Sequence Number (major components)
9. Taxonomic classification (major components)
10. Soil Series Name (Inclusions)
11. Percentage composition (inclusions)
12. Hydric soils status (inclusions)

Acreage of the designated map units were determined by query of the spatial dataset and was combined with attribute data to analyze the distribution of the soils by landform, drainage class, salinity and sodicity in the surface and subsurface and their associated salinization hazards.

#### **4.2.2. Results: Acreage Breakdown of Soil Salinization Hazards Associated with No Action (Natural Spill) and Constructed Outlet Alternatives by Soil Association**

##### *4.2.2.1. Lamoure-LaDelle-LaPrairie-Ryan Soil Association*

The Lamoure-LaDelle-LaPrairie-Ryan Association was developed exclusively from soils mapped along the Sheyenne River Valley in Wells, Benson, and Eddy Counties, and the portions of Nelson County adjacent to the Sheyenne River. The association begins near the proposed point of insertion of the constructed outlet alternatives at River Mile 460 and extends to the border of Nelson and Griggs counties at River Mile 344 (see Figure 1). The Soil Survey of Eddy County and Parts of Benson and Nelson Counties North Dakota (Wright and Sweeney, 1977) cover most of the area included in this Association. The portions beyond this survey are covered by the Soil Surveys of Wells County (Seago et al., 1970), Benson County (Strum et al., 1979), and Nelson County (Heidt et al., 1989).

The portion of the Sheyenne River Valley covered by the Lamoure-LaDelle-LaPrairie-Ryan Association is shallowly entrenched into the surrounding floodplain in the upper reaches, and becomes slightly more entrenched downstream. The active floodplain is broad throughout this area, especially in the westernmost upstream reaches, and poorly and very poorly drained soils are extensive. The Tolna Coulee (the Big Stony Spillway, Aronow, 1957) that is the point of insertion for Stump Lake overflow under the No Action (natural spill) alternative enters the Sheyenne River through a broad flat between river mile 374 prior to the point where the Association ends at the border between Nelson and Griggs counties at river mile 344. Thus most of the association is only of concern under 300 cfs Constrained and the 480 cfs Unconstrained outlet alternatives. All but the lower portions of this association would be unaffected by the No Action (natural spill) alternative. The Lamoure-LaDelle-LaPrairie-Ryan Association encompasses 14,000 acres in Wells, Benson, Eddy, and Nelson Counties, North Dakota and consists of poorly and moderately well drained, level to nearly level, fine to moderately fine textured soils on the floodplain of the Sheyenne River and associated terraces.

Soil salinization hazards are summarized by soil association in Table 4 with detailed supporting data provided in Table 5. Detailed soil data in Table 5 include: soil series name, acreage in the association, taxonomic class, drainage, season high watertable depths and duration, annual flooding and timing of flooding, landscape position, salinity/sodicity characteristics, and a summary of salinity hazards.

(Insert Table 4 here)

(Insert Table 5 here)

Representative soils, flooded area outlines, a typical cross-section showing the geomorphic position of the soils, a representative salinity profile, and a representative landscape photograph are provided in **Figure 20**.

(Insert Figure 20 here)

#### *4.2.2.1.1. Major Components*

The major soil components of this association are the Lamoure, LaDelle, LaPrairie, and Ryan soil series comprising 10,280 acres or 73 % of the total acres mapped along the floor of the Sheyenne River Valley in these counties. Minor components and contrasting inclusions of different soil series of minor extent make up the remaining 27 % of the soils along the Sheyenne River Valley floodplain and terraces.

The Lamoure soil series (*fine-silty, mixed, superactive, calcareous, frigid Cumulic Endoaquolls*) represents 3256 acres or 23% of the valley area. Lamoure is a somewhat poorly drained and poorly drained soil formed from silty alluvial deposits located adjacent to the Sheyenne River. Textures range from silt loam to silty clay loam with clay percentages ranging from 18-35 percent. Runoff is slow and permeability is moderate. Lamoure soils are typically ponded early in spring and after unusually heavy rainy periods. Elevated watertables are commonly maintained for a period of several months in the wetter landscape positions. Seasonal high watertables are commonly at 0 to 2 feet in depth from the surface, but can be drawn down during the growing season. Somewhat poorly drained Lamoure soils are found occupying abandoned meanders in higher terraces. Lamoure soils are non-saline with ECspe values in the range of 0-4 dS/m in both the soil surface and in the lower horizons. Calcium carbonate contents ranges from

1-2 % in the surface and 1-3 % in the subsurface. Gypsum is absent at the surface but can range from 0-2 % in the subsoil. Non-saline soils with salinity at the upper ranges of the listed values can be subject to salinization under conditions where water tables rise into the rooting zone, mobilizing subsoil salts and salinizing the soil surface. A saline phase is recognized (*Lamoure saline*) that occupies positions where the watertables are so elevated.

The LaDelle soil series (*fine-silty, mixed, superactive, frigid Cumulic Hapludolls*) represents 3040 acres or 22% of the valley area. LaDelle is a moderately well drained soil formed in alluvial deposits on low stream terraces and flood plains. Textures range from silt loam to clay loam with 18-35 percent clay. Runoff is slow and permeability is moderate. In some years the soils flood in the early spring and occasionally after unusually wet periods with intense rains. A seasonal high watertable is at a depth of 3.5 to 5.0 feet at some time during the growing season. This soil is non-saline with an ECspe of 0-2 dS/m in the soil surface and 0-4 dS/m in the subsoil. Calcium carbonate and gypsum contents (w/w) are absent in the soil surface and range from 4-5 % and 0-2 % in the subsoil, respectively. This soil is located in moderately well drained positions adjacent to the river, and is more characteristic of areas where the river is more entrenched. The presence of elevated salts in the subsoil indicates the potential for salinization if mean watertables rise appreciably. The potential for salinization is highest in the lower lying areas of LaDelle immediately adjacent to the river; however, after spring flooding or ponding soluble salts would likely be leached from the soil surface to the subsoil and subsequently to the river.

The LaPrairie soil series (*fine-loamy, mixed, superactive, frigid Cumulic Hapludolls*) represents 2090 acres or 15% of the area. LaPrairie is a moderately well drained soil formed in fine-loamy alluvial deposits located on stream bottomlands and gently sloping terraces adjacent to the Sheyenne River. LaPrairie soils are similar to LaDelle soils but have coarser textures ranging from silt loam, loam, and clay loam with clay percentages ranging from 18-35 percent. Permeability is moderate and runoff is moderate to slow. LaPrairie soils are subject to flooding and ponding in early spring and during periods of heavy rainfall. Seasonal high watertables range form 3.5 to 5 feet in depth. LaPrairie is a non-saline soil with ECspe <1 dS/m in both the soil surface and subsoil. Calcium carbonate contents range from 0-10 % in the upper horizon and 10-30 % in the subsoil. Gypsum levels are 0-1% in the soil surface and 0-1 % in the subsoil.

The Ryan soil series (*fine, smectitic, frigid Typic Natraquerts*) represents 1900 acres or 14% of the area. Ryan is a poorly drained sodic soil located on stream bottomlands, in abandoned oxbows and abandoned meanders. Ryan soils developed in alkaline clayey alluvial deposits on the active floodplain. Textures range from clay to silty-clay with clay percentages ranging from 35-60 percent. Runoff is slow and permeability is very slow which results in occasional ponding in the spring and after heavy rain periods. Seasonal high water tables typically range from +0.5 feet above to 1.5 feet below the soil surface. This is a sodic soil with an ECspe of <1 dS/m in the soil surface and 4-16 dS/m in the subsoil. Calcium carbonate contents range from 1-5 % in the soil surface and 5-25 % in the subsoil. Gypsum levels are 0-1% in the soil surface and 0-3% or higher in the subsoil.

##### *4.2.2.1.2. Minor Components and Inclusions*

Rauville (*fine-silty, mixed, superactive, calcareous, frigid Cumulic Endoaquolls*) is a minor soil component mapped by itself and as an inclusion in other several map units. It is widely distributed and represents 930 acres or 7% of the area. Rauville is a very poorly drained soil formed from silty alluvial deposits over stratified sands and gravels on low flats, depressions, and oxbows on the active flood plain. Surface textures range from silty clay loam to silt loam with clay percentages ranging from 18-35 percent. Rauville soils are typically underlain by coarse-textured sands and gravels that may be absent in some profiles. Runoff is very slow with slow permeability in the surface and moderately rapid permeability in the subsurface. Rauville soils are subject to flooding and occasional ponding during the spring and periods of heavy rainfall. Rauville soils have watertables at or within 2 feet of the surface even in times of drought. Rauville is non-saline soil with an ECspe of 0-2 dS/m in the soil surface and 0-4 dS/m in the subsoil. Calcium carbonate contents range from 5-15 % in the soil surface and 10-20 % in the subsoil. Gypsum is typically absent in the soil surface and ranges from 0-2% in the subsoil. Rauville soils frequently pond and supply water to adjacent, less poorly drained soils that are frequently saline. For example, Ryan soils are commonly found at the periphery of Rauville and Ludden soils in the Lamoure-LaDelle-LaPrairie-Ryan association

The Ludden soil series (*fine, smectitic, frigid Typic Endoaquerts*) is a minor soil component representing 542 acres or 4% of the area. Ludden is a poorly drained soil formed in clayey alluvial deposits located in flats, depressions and oxbows on the flood plain. Textures range from clay, silty clay or silty clay loam with 35-60 percent clay. The presence of clayey deposits and high organic matter levels suggest deposition in slowly moving, still water characteristic of backswamp positions on the active floodplain. Runoff is negligible to low and permeability is slow. Water ponds in low places for brief periods and is subject to flooding in the spring and during periods if heavy rainfall. Seasonal high watertable depths range from +0.5 (surface ponding) to 1.5 feet in depth from the soil surface. Ludden soils are typically non-saline; however, significant amounts of salt are typically present in the surface and especially the subsoil. Salinity ranges from an ECspe of 0-4 dS/m in the soil surface and 0-8 dS/m in the subsoil. Calcium carbonate contents range from 0-10 % in the soil surface and 5-20 % in the subsoil. Gypsum is typically absent in the soil surface and ranges from 0-2% in the subsoil. A saline phase of Ludden is recognized (*Ludden saline*) but based on map units and inclusion percentages Ludden saline comprises only 17 acres in this association as mapped.

The Walsh series (*fine-loamy, mixed, superactive, frigid Pachic Hapludolls*) is a minor component representing 393 acres or 3% of area. It is a moderately well to well-drained soil formed from glacio-fluvial, and colluvial sediments on footslopes and alluvial fans adjacent to floodplains. It is a characteristic soil on the periphery of the Sheyenne Valley. Textures range from silt loam, silty clay loam, clay loam, and loam with clay percentages ranging from 18-35 percent. Runoff and permeability are moderate. Walsh soils are non-saline; ECspe, calcium carbonate and gypsum are unavailable in the MUIR database. Seasonal high watertables characteristically vary from 4 to 6 feet in depth in Walsh soils. Given the elevations of Walsh soils above the river and their presence on the periphery of the valley above the active flood plain, it is unlikely that these soils would be salinized by changes in river stage and flooding induced by the alternatives.

The Wahpeton soil series (*fine, smectitic, frigid Typic Hapluderts*) is a minor component representing 357 acres or 3% of the association soils examined. Wahpeton is a moderately well drained soil formed in clayey alluvial deposits on the elevated levees and low terraces of the flood plain. It is characteristically found further downstream in the portion of the Sheyenne covered by this association. Textures range from clay, silty clay or silty clay loam with 35-60 percent clay. Runoff is moderate and permeability is moderately slow. Occasional flooding occurs in the spring and during periods of heavy rainfall. However, listed seasonal high watertables are deeper than 6 feet. This soil is non-saline; ECspe, calcium carbonate and gypsum are unavailable in the MUIR database. Given the elevated position of Wahpeton soils and the presence of deep watertables, it is unlikely that Wahpeton soils would be subject to salinization under the outlet alternatives. During an occasional flooding events this soil has the ability to leach the salts from its profile.

#### *4.2.2.1.3. Identified Saline Soils*

Saline soils and potentially saline soils form a significant percentage of the soils in the Lamoure-Ladelle-LaPrairie-Ryan association, with the most significant component being the Ryan series (1900 acres, or 14% of the association) mentioned above. Additional mapped saline soils and saline soils listed as inclusions along the Sheyenne River in Wells, Benson, Eddy, and Nelson Counties are of minor extent and are frequently mapped as saline phase inclusions. Additional mapped saline soils represent 683 acres or 5% of the area. These soils exist as inclusions or independent data mapping units and include the series described below.

Saline phases of the Lamoure and Ludden series exist as separate map units and as inclusions in the corresponding Lamoure and Ludden map units. These saline phases are estimated to comprise 275 acres (approximately 2%) of the association acreage. Both soil series represent areas that accumulate salts to the point where surface and subsurface salinity ranges from 4 to 16 dS/m. Landscape setting and other characteristics are similar to those listed for the non-saline phases discussed above.

Several saline/sodic soils were identified in areas that are not characteristic of the Sheyenne River floodplain and terraces, but represent soils formed on till inclusions and glacio-lacustrine plains at the periphery of the valley and on terraces of the valley floor. These soils total approximately 3% of the area and include Cresbard (*fine, smectitic, frigid Glossic Natrudolls*), Miranda (*fine, smectitic, frigid Leptic Natrustolls*), Exline (*fine, smectitic, frigid Leptic Natrudolls*), Vallers (*fine-loamy, mixed, superactive, frigid Typic Calciaquolls*), and Hamerly (*fine-loamy, mixed, superactive, frigid Aeric Calciaquolls*) soil series. Several of these soils are in positions that could experience a salinization hazard under the alternatives.

#### *4.2.2.1.4. Effects of the Alternatives on Soil Salinization: Lamoure, LaDelle, LaPrairie, Ryan Soil Association*

Of all of the Associations described in this report, the outlet alternatives proposed to reduce flooding in the Devils Lake Basin will probably have the largest and most direct impact on induced soil salinization in the Lamoure-LaDelle-LaPrairie-Ryan Association. Soil salinization hazards are enhanced under the outlet alternatives by: (1) the presence of a shallowly entrenched river subject to regular flooding, (2) high estimated mean stage increases, (3) more saline water undiluted by tributary inflows that would occur further downstream, and (4) the presence of extensive saline and potentially saline soils immediately adjacent to the Sheyenne River and on the active floodplain (see Figure 20). The most significant, potentially impacted area lies just downstream of the proposed point if insertion between river miles 430 to 469. However, several other areas consisting predominantly of saline map units and map units with significant saline inclusions occur downstream to the Griggs Nelson county border. Soils in the Lamoure-Ladelle-

LaPrairie-Ryan Association consist of extensive map units of Ryan, Lamoure, and Ludden soils that are already saline or have major saline inclusions.

The Ryan soils and adjacent Lamoure and Ludden soils are among the most susceptible soils to salinization under the outlet alternatives. An EM-38 salinity transect run across a Ryan soil unit in Eddy County indicated extremely high soil salinity in the range of 40 dS/m closest to the river with salinity dropping of to 10-15 dS/m away from the river (see Figure 15). High salinity immediately adjacent to the river suggests the river as the source of salinity; with continuous evaporative concentration of salts drawn from the river resulting in the elevated salt levels. More frequent and longer duration flooding associated with the outlet alternatives would mimic the conditions under which Ryan soils originally became salinized. Thus, under the outlet alternatives, Ryan soils have the potential for becoming even more highly salinized. However, the amount and magnitude of additional salinization cannot be determined without a detailed knowledge of existing salinity levels and water table dynamics that might be altered by the alternatives. Note that the salinization range listed for Ryan soils is broad, ranging from 4 to 16 dS/m in the subsoil.

Mean stage increase data provided by the St. Paul District USACE (see Table 3) suggest average May and August stage increases at the Warwick gauging station will range from 1.3 to 1 foot under the under the 380 cfs Constrained alternative to between 1.6 and 1 foot under the 480 cfs Unconstrained alternative. Because the USGS gauging station at Warwick is influenced by a low-head dam, actual mean increases in river stage could be higher. HEC RAS modeling data also suggest persistent overbank flooding at 1000 cfs, which is the flow rate proposed as the "normal" flooding stage for this portion of the river under the outlet alternatives (Bob Anfang, Pers. Comm.). Extensive flooding combined with increased water tables will have the effect of aggravating existing salinity in Ryan, Ludden, and Lamoure soils especially, all of which are characterized by naturally high watertables and potentially high levels of naturally occurring salts in the subsoil. Under all alternatives it can be expected that existing naturally saline/sodic soils will become more saline as evapotranspiration mobilizes salts from the subsoil to the surface under raised watertables. Additional flooding will also aggravate salinity in peripheral soils that are currently non-saline but that have levels of salinity in the subsoil ranging from 0-8 dS/m (e.g. Ludden and Lamoure soils). While there are areas within the association where the river is more deeply entrenched, extensive overbank flooding is indicated at the 1000 cfs flow rate over extensive areas throughout the association. Ryan, Ludden, and Lamoure soils were given a salinity hazard risk of Moderate to Severe because of: (1) the potential for increased salinity in already saline soils, (2) the potential to increase salinity to the point where non-saline Ludden, Lamoure, and Ryan soils become saline, and (3) the potential for mobilization of existing salts to other, adjacent non-saline soils. It is also possible that increased persistent flooding and ponding under the outlet alternatives could result in mobilization of salts to the river resulting in an increased salt load in the Sheyenne River itself.

LaDelle, LaPrairie, and Wahpeton soils are extensive, productive soils in the Lamoure-Ladelle-LaPrairie-Ryan Association that are well suited to pasture and cropping. All of these soils also have some potential for salinization when present near the river where watertables could be expected to rise in conjunction with increased overbank flooding that would probably occur with some regularity based on the HEC RAS models. While not listed as saline, subsoil salinity ranging from 0-4 dS/m is indicated for the LaDelle series suggests that this soil could be affected more than Wahpeton or LaPrairie soils that have typically lower subsoil salinity. LaDelle soils near the river that are subject to water table rise and intermittent flooding with poorer quality water could have increased salinization that could affect both crop yields and selection of pasture grasses more tolerant to salinity. LaDelle soils have been evaluated for their irrigation potential, and are listed as irrigible soils with relatively high thresholds for TDS (TDSmax = 1460 mg/L) and SAR (SARmax = 6)(Franzen et al., 1996). Thus LaDelle soils would probably not be substantively affected by periodic spring flooding with water under the constructed outlet alternatives. LaDelle soils were given a salinization risk of slight in more-elevated areas distant from the river to moderate in lower areas closer to the river. LaPrairie soils are coarser textured, and have less subsoil salinity compared to the LaDelle Series and are in the same irrigibility group and have the same recommended maximum TDS and SAR values. However, LaPrairie soils are listed as having surface and subsoil salinity < 1 dS/m, and thus would be less subject to mobilization of significant amounts of subsoil salts due to a mean rise in water table depth induced by the alternatives. Given the low levels of subsoil salts and coarser textures, LaPrairie soils are listed as having a None to Slight salinization hazard. Wahpeton soils are located on natural levees and, while occasionally flooded, have water tables deeper than 6 feet and have low surface and subsurface salinity. However, Wahpeton soils are relatively fine textured, and are thus more susceptible to salinization hazards if flooded frequently; however, frequent flooding is unlikely. Wahpeton soils were given a salinity risk hazard of None-to-Slight given their salinity status, landscape position, and hydrologic regime.

An acreage breakdown of salinization hazards for the Lamoure-LaDelle-LaPrairie-Ryan Association is in Table 4. Detailed supporting data are provided for all soils in the association in Table 5.

#### *4.2.2.2. LaDelle-Ludden-Wahpeton Soil Association*

The LaDelle, Ludden, Wahpeton Association was developed exclusively from the soils mapped along the Sheyenne River Valley in Griggs and Steele Counties. The association begins at the border between Nelson and Griggs counties at River Mile 343.5 and ends where the Sheyenne River becomes the Ashtabula Reservoir at River Mile 277.0 (see Figure 1). Small segments of the river are within Steele County at river mile 314 and between river miles 282 and 284.5. Soils adjacent to Lake Ashtabula proper were not examined for the present report because they represent steeply sloping upland soils that would not be affected under the alternatives. Floodplain and terrace soils associated with the river below river mile 277 are now under Lake Ashtabula. Soils within the Sheyenne Valley in the estuarine, imperfectly flooded northern portions of Lake Ashtabula are covered under this Association. The Griggs County soil survey has not been published but is available in digital format via Internet download from the NRCS (http://www.ftw.nrcs.usda.gov/ssur_data.html). The Steele County Soil Survey has been published (Murphy et al., 1977).

With a few exceptions, the Sheyenne River in Griggs and Steele counties is shallowly entrenched into the surrounding floodplain. The association is dominated by moderately well to poorly drained, level to nearly level, fine to moderately fine textured soils found on the floodplains of the Sheyenne River valley. This association encompasses 9370 acres in Griggs and Steele counties.

The three major soil components of the association are the LaDelle, Ludden and Wahpeton soil series, which comprise 7080 acres or 76 % of the 9370 total acres of this area. Minor components and contrasting inclusions of different soil series of minor extent comprise the remaining 24 % of the area. The distinguishing characteristic between the LaDelle-Ludden-Wahpeton Association and the Lamoure-LaDelle-LaPrairie-Ryan Association discussed previously is the lower percentages of the Ryan and Lamoure soils. Lamoure and Ryan soils, while present in this association, become minor components compared to the poorly drained Ludden soil and the moderately well drained LaDelle and Wahpeton soils on the floodplain and elevated terrace soils. As the River becomes more entrenched, the very poorly drained soil components become limited to portions of the meander belt that are just slightly elevated above the river and abandoned oxbows and meanders on the terraces.

Soil salinization hazards are summarized by soil association in Table 4 with detailed supporting data provided in Table 5. Detailed soil data in Table 5 include: soil series name, acreage in the association, taxonomic class, drainage, season high watertable depths and duration, annual flooding and timing of flooding, landscape position, salinity/sodicity characteristics, and a summary of salinity hazards.

Representative soils, flooded area outlines, a typical cross-section showing the geomorphic position of the soils, a representative salinity profile, and a representative landscape photograph are provided in **Figure 21**.

(Insert Figure 21 here)

#### *4.2.2.2.1. Major Components*

The LaDelle soil series represents 4890 acres or 52% of the area. The characteristics of LaDelle soils were previously described in Section 4.2.2.1.1.

The Ludden soil series represents 1120 acres or 12% of the area. The characteristics of Ludden soils were previously described in Section 4.2.2.1.2. A saline phase of Ludden is recognized (*Ludden saline*) in the LaDelle-Ludden-Wahpeton association, but comprises only 36 acres in this association as mapped.

The Wahpeton soil series described previously in Section 4.2.2.1.2 is a major component representing 1060 acres or 11% of the area.

#### *4.2.2.2.2. Minor Components and Inclusions*

The LaPrairie soil series represents 510 acres or 5% of the area and was previously described in Section 4.2.2.1.1.

The Lamoure soil and its channeled phase are minor but widely distributed components that represent 511 acres or 6 % of the area. Lamoure soils are common component soils of abandoned meanders that are too small to map separately. Lamoure soils were previously described in Section 4.2.2.1.1. A saline phase is recognized (*Lamoure saline*).

The Rauville series is a minor component of widely distributed extent that represents 502 acres or 5% of the area. Rauville soils were previously described in Section 4.2.2.1.1. Rauville soils are frequently mapped in complex with but in lower landscape positions that Lamoure soils.

Colvin (*fine-silty, mixed, superactive, frigid Typic Calciaquolls*), Marysland (*fine-loamy over sandy or sandy-skeletal, mixed, superactive, frigid Typic Calciaquolls*), and Vallers soils are mapped as inclusions in Rauville map units in Griggs County. Colvin is mapped separately on the floodplain in Steele County. Colvin and Vallers soils are poorly and very poorly drained soils formed in silt loam sediments in concave swales and depression on stream terraces, outwash channels and drainageways, and are primarily associated with Lake Plain sediments and till inclusions on the flood plain. Salinity in Vallers and Colvin units can range up to 4 dS/m in the subsoils.

One Bearden (*fine-silty, mixed, superactive, frigid Aeric Calciaquolls*) map unit was identified in the Valley on an elevated terrace. Bearden and its associated major component (Colvin) and inclusions are typically found on Lake Plains. The elevated terrace position on which these soils were found represent an inclusion of Lake Plain sediments above the active floodplain of the river, and would not be expected to be affected under the alternatives.

##### *4.2.2.2.3. Identified Saline Soils*

Mapped saline soils in the association represent 76 acres or 1% of the area, and occur as independent mapping units and contrasting inclusions. Saline soils include Ryan, Ludden (Saline phase), and Colvin Saline.

Ryan soils represent 41 acres as mapped in the association. Ryan is a poorly drained saline/sodic soil formed in clayey alluvial deposits located on stream bottomlands, oxbows and abandoned meanders and was previously described in Section 4.2.2.1.1.

Ludden soils (Saline Phase) represent 40 acres of the area. Ludden is a poorly drained soil located in depressions and oxbows on the flood plain. Ludden is formed from clayey alluvial deposits and was previously described in Section 4.2.2.1.2. ECspe values range up to 8 dS/m in the surface to 16 dS/m in the subsoil.

##### *4.2.2.2.4. Effects of the Outlet Alternatives on Soil Salinization: LaDelle-Ludden-Wahpeton Soil Association*

The most direct effects of the alternatives on soil salinization in the LaDelle-Ludden-Wahpeton association would be confined to poorly and very-poorly drained soils adjacent to the river and adjacent oxbow lakes and low meanders that are relatively fine textured and have considerable surface and subsurface salinity. These soils would be the Ludden, Ludden (saline), Lamoure, Ryan, Colvin, and Rauville series that form a minor percentage of the association (Table 4). Most of these areas would be in native vegetation due to high watertables and the associated difficulty in cropping and haying these areas. However, the HEC RAS modeling indicates that extensive flooding would occur in this association at the 1000 cfs flow rate considered to the typical or "normal" flood level above Baldhill Dam. Under this flooding regime poorly and very poorly drained soils, especially those in low depressions and low areas adjacent to the river would collect more saline water that could result in elevated watertables in adjacent areas that would be moderately to somewhat poorly drained. These areas would likely experience increased salinization under the outlet alternatives. Thus Ludden, Lamoure, Rauville, Ryan, Ludden (saline) and Colvin soils that are on the active floodplain have been given a Moderate to Severe soil salinization hazard under the outlet alternatives.

LaDelle, LaPrairie, and Wahpeton soils are extensive, productive soils in the LaDelle-Ludden-Wahpeton Association that are well suited to pasture and cropping. All of these soils also have some potential for salinization when present near the river where watertables could be expected to rise in conjunction with increased overbank flooding that would probably occur with some regularity based on the HEC RAS models. While not listed as saline, subsoil salinity ranging from 0-4 dS/m is indicated for the LaDelle series suggests that this soil could be affected more than Wahpeton or LaPrairie soils that have typically lower subsoil salinity. LaDelle soils near the river that are subject to water table rise and intermittent flooding with poorer quality water could have increased salinization. LaDelle soils have been evaluated for their irrigation potential, and are listed as irrigible soils with relatively high thresholds for salinity (TDSmax = 1460 mg/L) and sodicity (SARmax = 6)(Franzen et al., 1996). This LaDelle soils would probably not be affected by periodic spring flooding with water under the constructed outlet alternatives. Thus, LaDelle soils were given a salinization risk of slight in more-elevated areas distant from the river to moderate in lower areas closer to the river.

LaPrairie soils are coarser textured, and have less subsoil salinity compared to the LaDelle Series. Both soils are in the same Irrigibility Subgroup (Franzen et al., 1996) and have the same recommended maximum TDS and SAR values. However, LaPrairie soils are listed as having surface and subsoil salinity < 1 dS/m (see Table 4), and thus would be less subject to mobilization of subsoil salts due to a mean rise in water table depth induced by the alternatives. Given the low levels of subsoil salts and coarser textures, LaPrairie soils are listed as having a None to Slight salinization hazard.

Wahpeton soils are located on natural levees and, while occasionally flooded, have water tables deeper than 6 feet and have low surface and subsurface salinity. However, Wahpeton soils are relatively fine textured, and are thus more susceptible to salinization hazards if flooded frequently; however, frequent flooding is unlikely. Wahpeton soils were given a salinity risk hazard of None-to-Slight given their salinity status, landscape position, and hydrologic regime.

Velva (*coarse-loamy, mixed, superactive, frigid Fluventic Haplustolls*), Bearden, Parnell (*fine, smectitic, frigid Vertic Argiaquolls),* Southam (*fine, smectitic, calcareous, frigid cumulic Vertic Endoaquolls*), and Vallers soils are associated with positions above the active flood plain of the Sheyenne River and have formed in till and Lake Plain sediments on higher terraces and drainageways leading to the Sheyenne River. These soils would not receive overbank flooding, and are in positions where they would not receive groundwater discharge originating from the Sheyenne River. Accordingly these soils were given a salinity hazard rating of None.

An acreage breakdown of salinization hazards for the LaDelle-Ludden-Wahpeton Association is in Table 4. Detailed supporting data are provided for all soils in the association in Table 5.

*4.2.2.3. LaDelle and Nutley Soil Association*

The LaDelle-Nutley Association was developed exclusively from soils mapped along the Sheyenne River valley in Barnes County. The association begins at Baldhill Dam at river mile 258.5 and ends at the border between Barnes and Ransom counties at River Mile 198.5 (see Figure 1). Soils in the association are covered by the Soil Survey of Barnes County (Opdahl et al., 1990). Soils adjacent to Lake Ashtabula were not examined for the present report because they represent steeply sloping upland soils of the valley wall that would not be affected under the alternatives. Floodplain and terrace soils associated with the river upstream of Baldhill Dam are now under Lake Ashtabula. Soils within the Sheyenne Valley in the estuarine, imperfectly flooded northern portions of Lake Ashtabula are covered in the LaDelle-Ludden-Wahpeton Association developed for Griggs and Steele Counties.

Flooding downstream of Baldhill Dam is now controlled by releases from Lake Ashtabula, resulting in a reduction of peak flood flows and an increase in flood duration. It is also apparent that the Sheyenne is more deeply entrenched downstream of Baldhill Dam that it is upstream of Lake Ashtabula resulting in a dramatically reduced acreage of poorly and very poorly drained soils compared to the LaDelle-Ludden-Wahpeton and Lamoure-LaDelle-LaPrairie-Ryan associations described above. The effects of the deeper entrenchment on flood flows and flooded area outlines were examined in Section 3.3.5, above. As will become apparent, a deeper entrenchment possibly combined with controlled flooding influences the interpretation of salinization hazards for certain floodplain soils, especially the LaDelle series.

The LaDelle-Nutley Association encompasses 7340 acres in Barnes County, North Dakota where a diverse sequence of glacial events has complicated the distribution of soils along the floor of the Sheyenne Valley. Soils fall into three main groups: 1) soils associated with the active floodplain, 2) soils associated with abandoned elevated terraces adjacent to the valley escarpment, and 3) soils associated with small to medium glacial lakes that once inundated portions of the Sheyenne River Valley in the area of Barnes County.

The active floodplain of the Sheyenne River is dominated by LaDelle and Fairdale soils occupying terraces, natural levees, and channeled land adjacent to the river. Poorly drained Lamoure and Rauville soils occupy recently abandoned meanders that are on the active floodplain. Higher abandoned terraces are dominated by the well-drained Nutley and moderately well-drained Sinai soils. The Nutley/Sinai soils were included in this report because their position within the valley and their close proximity to the Sheyenne entrenchment in many places suggested a potential salinization hazard under the alternatives. Finally, portions of the Sheyenne River Valley in Barnes County were once part of pro-glacial Lake Lanona (Kelly, et al., 1967), resulting in the presence of glacio-lacustrine deposits and minor inclusions of associated Lake Plain soils within the Valley that are not typical floodplain positions. Soil components are explained in detail below.

Soil salinization hazards are summarized by soil association in Table 4 with detailed supporting data provided in Table 5. Detailed soil data in Table 5 include: soil series name, acreage in the association, taxonomic class, drainage, season high watertable depths and duration, annual flooding and timing of flooding, landscape position, salinity/sodicity characteristics, and a summary of salinity hazards.

Representative soils, flooded area outlines, a typical cross section showing the geomorphic position of the soils, a representative salinity profile, and a representative landscape photograph are provided in **Figure 22**.

#### *4.2.2.3.1. Major Components*

The two major soil components are the LaDelle and Nutley soil series comprising 4704 acres or 64 % of the 7340 total acres mapped along the Sheyenne Valley in Barnes County. Minor components, and contrasting inclusions of different soil series of minor extent make up the remaining 36% of the soils along the Sheyenne Valley floodplain and terraces.

The LaDelle soil series represents 3040 acres or 41% of the area. LaDelle soils were previously described in Section 4.2.2.1.1.

The Nutley series (*fine, smectitic, frigid Chromic Hapluderts*) represents 1670 acres or 23 % of the area. Nutley is a well-drained soil located on elevated terraces and on footslopes that are peripheral to the valley. Nutley soils formed in fine-textured colluvial and alluvial deposits. In many places the Nutley soils are immediately adjacent to the Sheyenne River, but are associated with elevated terraces that never flood. Well-drained Nutley soils typically have watertables deeper than 6 feet. Textures range from clay, silty clay or silty clay loam with 35-60 percent clay being typical. Runoff is low and permeability is slow. Nutley soils are highly leached and non-saline with ECspe in both the surface and the subsoil are < 2 dS/m. Calcium carbonate and gypsum are absent. Nutley soils are not expected to have a salinization hazard under the outlet alternatives.

#### *4.2.2.3.2. Minor Components and Inclusions*

Sinai soils (*fine, smectitic, frigid Typic Hapluderts*) are minor component soils that represent 860 acres or 12 % of the area mapped in Barnes County. Sinai is a well-drained soil formed from alluvial and colluvial deposits on elevated terraces and footslopes of the valley walls and is found in association with, but lower than the Nutley soils. Textures range from clay to silty-clay with clay percentages ranging from 35-60 percent. Runoff is slow and permeability is slow. Sinai soils are non-saline with surface and subsoil salinity < 2 dS/m. Calcite and Gypsum are absent from the typical profile. Given the elevations of Sinai soils above the river and their presence on elevated terraces and the periphery of the valley above the active flood plain, Sinai soils are not expected to have a salinization hazard under the outlet alternatives.

Fairdale soils (*fine-loamy, mixed, superactive, calcareous, frigid Mollic Udifluvents*) are minor components representing 725 acres or 10 % of the area mapped. Fairdale soils were not mapped separately, but are significant inclusions (18%) in the LaDelle Map unit that would typically be found adjacent to the river and downslope of the LaDelle soils. Fairdale soils are moderately well drained, poorly developed Udifluvents formed in fine-loamy alluvial deposits on stream bottomlands and terraces and are associated with the active floodplain and natural levees as mapped in Barnes County. Flooding ranges from frequent/occasional on the active floodplain to rare on more elevated terraces. Textures range from silt loam, loam, and clay loam with clay percentages ranging from 18-35 percent. Permeability is moderate and runoff is moderate to slow. Fairdale soils are non-saline with a listed ECspe <1 dS/m in the upper horizons and 0-2 dS/m in the lower horizons. Calcium carbonate ranges from 3-10 % in the soil surface and 5-35

% in the subsurface. Gypsum is typically absent throughout the profile. Fairdale has the potential to flood for brief periods during the spring and during periods of heavy rainfall.

The Lamoure soil and its channeled phase are minor but widely distributed components that represent 439 acres or 6 % of the area. Selected physical, chemical, and hydrologic characteristics of Lamoure soils were described previously in Section 4.2.2.1.1 and are in Table 5. Lamoure soils are somewhat poorly drained or poorly drained and are listed as contrasting inclusions in map units that contain LaDelle and Fairdale soils and as a separate map (Lamoure channeled) with Colvin channeled, Marysland, Rauville, and Colvin saline inclusions. Lamoure soils formed from silty alluvial deposits. Extensive areas of Lamoure soils are commonly found immediately adjacent to the river in low, meandered areas. However, Lamoure soils are also common component soils of oxbow lakes and low abandoned meanders that are too small to map separately. A saline phase is recognized (*Lamoure saline*).

Poorly drained Colvin, Colvin (saline), Marysland, and very poorly drained Rauville soils are mapped as inclusions in the Lamoure channeled Map unit and typically occupy portions of abandoned meanders and oxbow lakes on the active floodplain. These poorly drained units total 528 (7%) of the acres identified in Barnes County.

Colvin and Colvin (saline) soils were described previously in Section 4.2.2.2.2. Salinity can be high in the subsoil, ranging up to 4 dS/m in Colvin and from 4 to 16 dS/m in Colvin saline phases. Rauville soils were previously described in Section 4.2.2.1.2.

Marysland soils are poorly to very poorly drained, moderately permeable to rapidly permeable soils that formed in stratified alluvium and outwash sediments. The soils are non-saline with surface and subsurface salinity < 1 dS/m. Gypsum is absent from the soil profile; however, calcium carbonate can range up to 45% in the subsoil.

Fargo (*fine, smectitic, frigid Typic Epiaquerts*), Overly (*fine-silty, mixed, superactive, frigid Pachic Hapludolls*), Dovray (*fine, smectitic, frigid cumulic Vertic Epiaquolls*), Colvin, Bearden, and Gardena (*coarse-silty, mixed, superactive, frigid Pachic Hapludolls*) soils are associated with small inclusions of Lake Plain sediments on elevated terraces above the river. A check of Lidar elevation data indicated that these Lake Plain soils, while being near the Sheyenne River, are frequently separated from the Sheyenne River by moderately well drained soils and are 4-7 meters above the active floodplain. Given their landscape position they would neither receive groundwater originating in the Sheyenne nor would they receive regular overbank flooding from the Sheyenne.

#### *4.2.2.3.3. Effects of the Outlet Alternatives on Soil Salinization*

Salinization potential under the alternatives relate to; 1) the addition of salts in the more saline riverwater by increased overbank flooding, 2) mobilization of existing salts by increased groundwater levels induced by mean stage increases in the Sheyenne River under the outlet alternatives, and 3) the introduction of blended Sheyenne River/Devils Lake water into the soils adjacent to the river.

Soils in the LaDelle-Nutley Soils Association fall into Three main groups. The first group consists of soils on the active floodplain with a direct hydrologic connection with the river through groundwater interactions resulting from variations in river stage and overbank flooding. These soils consist of the Fairdale, LaDelle, Lamoure, Colvin, Marysland, and Rauville soils.

Fairdale soils are classified as medium-textured Udifluvents characterized by frequent overbank flooding, higher watertables, and slightly elevated levels of subsoil salinity (Table 4). Channeled variants of these soils are recognized that occupy portions of the river that include the entrenchment and dissected lands immediately adjacent to the river that would have groundwater influenced by the Sheyenne River. Fairdale soils have been assessed for their irrigibility (Franzen et al., 1996) and are listed as irrigible soils with relatively high recommended TDS and SAR maximum values (Irrigibility Subgroup 4A, TDSmax = 1460 mg/L; SARmax of 6). Thus, Fairdale soils should be able to withstand intermittent flooding with water under the constructed outlet alternatives that is characterized by TDS and SAR values well under the recommended limits (see Figures 7 and 8). However, Fairdale soils are also in landscape positions that flood regularly and could be influenced by increases in mean groundwater levels. Fairdale soils were placed in the slight to moderate hazard class because of the potential for regular flooding with more saline water under the alternatives coupled with the potential for groundwater effects.

LaDelle soils are more distant from the river and flood less frequently than Fairdale soils. They are better-developed soils (Cumulic Hapludolls) consistent with a less-frequent flooding regime. Both LaDelle and Fairdale soils are in Irrigibility Subgroup 4A indicating a higher tolerance for water with elevated TDS and SAR levels. However, LaDelle soils can have higher levels of subsoil salinity that could be affected by mean water table increases induced under the alternatives.

However, below Baldhill Dam the Sheyenne is much more entrenched into the surrounding floodplain (see Figure 22). HEC-RAS modeling of flooded area outlines indicates that flood flows up to 3000 cfs will be essentially confined to the banks of the Sheyenne, adjacent low channeled areas, and low abandoned meanders and oxbow lakes (see Section 3.3.5). LaDelle soils are typically found in higher positions on the floodplain that are well above the HEC RAS predicted 3000 cfs flood outline. The Corps has indicated that overbank flooding resulting in the inundation of large portions of the adjacent floodplain will be far less frequent downstream of Baldhill Dam compared to areas of the Sheyenne River floodplain that are upstream of Lake Ashtabula (Bob Anfang, Pers. Comm.). Downstream flooding is also controlled by releases of water from Baldhill dam, and that extreme flood flows would be further reduced by controlled releases from Lake Ashtabula.

Accordingly, it is expected that LaDelle soils in the lower reach of the Sheyenne below Baldhill Dam will have a slight potential for regular flooding under the outlet alternatives. LaDelle soils are not typically in positions such as frequently flooded Fairdale soils that could be affected by increases in groundwater levels resulting from increased mean river stage under the outlet alternatives. LaDelle soils are thus listed as having None-to-Slight salinization hazard depending upon proximity to the river.

Poorly drained Colvin, Colvin (saline), Lamoure, and very poorly drained Rauville soils typically occupy portions of abandoned meanders and oxbow lakes on the active floodplain. All of these soils save Marysland have elevated levels of subsoil salinity and occur in positions that could be subject to elevated water table rises in response to the alternatives. When located in channeled land and abandoned meanders adjacent to the river these soils could be subject to salinization. These soils were given a moderate to severe salinization hazard based on landscape position, texture and permeability characteristics, and the presence of elevated levels of subsoil salinity. Marysland soils were given a slight to moderate hazard of salinization due to the absence of significant amounts of surface or subsurface salinity.

Based on landscape position and geomorphic setting data available in the soil survey and OSDs, Nutley and Sinai soils were determined to be associated with elevated terraces and toeslope positions adjacent to the valley wall. They are well drained soils that do not flood and are unlikely to receive groundwater originating in the Sheyenne River. It is unlikely that either Nutley or Sinai soils would be affected by the changes in the mean river stage or flooding dynamics induced by the alternatives. These soils were given a salinization hazard of None under the outlet alternatives.

Several soils were associated with Lake Plain/till outcrops on elevated terrace positions, including Fargo, Tonka, Overly, Dovray, Bearden, and Gardena soils. All of these soils were associated with elevated terrace positions that do not flood and are not likely to receive groundwater originating from the Sheyenne River. It is unlikely that these soils would be salinized by changes in river stage and flooding induced by the outlet alternatives. Fargo, Overly, Dovray, Bearden, and Gardena soils were given a salinization hazard of None.

An acreage breakdown of salinization hazards for the LaDelle-Ludden-Wahpeton Association is in Table 4. Detailed supporting data are provided for all soils in the association in Table 5.

#### *4.2.2.4. Fairdale – LaPrairie - LaDelle - Soil Association*

The Fairdale-LaPrairie-LaDelle Association was developed from soils mapped along the Sheyenne River in Ransom County. The Association begins at the border between Ransom and Barnes counties at River Mile 198 and extends to the border between Ransom and Richland counties at River Mile 94 (see Figure 1). The most recent Ransom County soil survey has not been published but is available in digital format via Internet download from the NRCS (http://www.ftw.nrcs.usda.gov/ssur_data.html). Selected soils in the Association are also covered by the Soil Survey of Richland County and Sheyenne National Grassland Area of Ransom County, North Dakota (Thompson and Joos, 1975).

The Fairdale-LaDelle-LaPraire, Association consists predominantly of moderately well to poorly drained, level to nearly level, fine to moderately fine textured soils found adjacent to the river on the floodplain and terraces of the Sheyenne River Valley. This association encompasses 13,506 acres of the Sheyenne River in Ransom County. The three major soil components are the Fairdale, LaPraire, and LaDelle series that represent 12,903 acres or 96 % of the 13,506 total acres. Minor components and inclusions of different soil series of minor extent represent the remaining 4 % of the mapped area, and consist primarily of poorly and very poorly drained inclusions in the map units.

Soil salinization hazards are summarized by soil association in Table 4 with detailed supporting data provided in Table 5. Detailed soil data in Table 5 include: soil series name, acreage in the association, taxonomic class, drainage, season high watertable depths and duration, annual flooding and timing of flooding, landscape position, salinity/sodicity characteristics, and a summary of salinity hazards.

Representative soils, flooded area outlines, a typical cross-section showing the geomorphic position of the soils, a representative salinity profile, and a representative landscape photograph are provided in **Figure 23**.

(Insert Figure 23 here)

### *4.2.2.4.1. Major Components*

The Fairdale soil series represents 7961 acres or 59 % of the area mapped for this report. The Fairdale series as well as the Fairdale (channeled phase) were previously described in Section 4.2.2.3.2.

The LaPrairie soil series represents 2990 acres or 22 % of the area. A channeled phase is included in the LaPrairie map unit. LaPrairie soils were previously described in Section 4.2.2..1.1. This soil is located in positions immediately adjacent to the river and on more elevated terraces adjacent to the river.

The LaDelle soil series represents 2010 acres or 15 % of the area. A channeled phase is included in the LaDelle map unit. LaDelle soils were previously described in Section 4.2.2.1.1.

### *4.2.2.4.2. Minor Components*

The Lamoure soil series and its channeled phase are minor but widely distributed components that represent 190 acres or 1 % of the area. Lamoure soils were previously discussed in Section 4.2.2.1.1.

The Rauville soil series is a minor component of large and widely distributed extent represents 170 acres or 1 % of the area. Rauville is located in lower positions than Lamoure on the landscape and is subject to frequent flooding. Rauville soils are listed as inclusions in LaPrairie, LaDelle, and Lamoure map units and were discussed previously in Section 4.2.2.1.2..

Marysland soils were not mapped separately but are listed as inclusions in Rauville and Lamoure map units. Marsyland soils are estimated to consist of 29 acres of the area mapped in Ransom County. Selected soils characteristics were previously described in Section 4.2.2..3.2.

Gardena and Eckman (*coarse-silty, mixed, superactive, frigid Calcic Hapludolls*) soils were identified at the periphery of the valley in elevated positions above the active floodplain and low terraces adjacent to the river. Eckman is a well-drained soil formed in glacio-lacustrine deposits outcropping at the edge of the Sheyenne Valley. Gardena is a moderately well and well-drained soil similarly formed in glacio-lacustrine sediments. Both soils would not be affected by changes in stage or flooding dynamics associated with the outlet alternatives.

### *4.2.2.4.3. Effects of the Outlet Alternatives on Soil Salinization*

Salinization potential under the alternatives relate to; 1) the addition of salts in the more saline riverwater by increased overbank flooding, 2) mobilization of existing salts by increased groundwater levels induced by mean stage increases in the Sheyenne River under the outlet alternatives, and 3) The introduction of blended Sheyenne River/Devils Lake water into the soils adjacent to the river.

Virtually all of the units identified in the Fairdale-LaPrairie-LaDelle Association in Ransom County are associated with the floodplain and associated alluvial terraces of the Sheyenne Valley. The Ransom County digital soil survey is consistent with newer soil surveys that incorporate larger map units with a detailed listing of inclusions. Consistent with this practice, poorly drained inclusions that occupy small abandoned meanders and areas of heavily channeled lands immediately adjacent to the river are not mapped separately. It is expected that the poorly drained included soils that occupy meanders adjacent to the river would be more subject to salinization due to both overbank flooding and increased watertables associated with the alternatives. While non-saline, these soils are listed as having subsoil salinity that could range up to 4 dS/m, which is the break between a non-saline soil and a saline soil phase. Similarly, channeled areas adjacent to the river represent dynamic landscapes that are frequently flooded. Swales associated with the channeled land are closer to the watertables that would be increased under the outlet alternatives.

Fairdale soils are classified as Udifluvents characterized by frequent overbank flooding, higher watertables, and slightly elevated levels of subsoil salinity. Channeled variants of these soils are recognized that occupy portions of the river that include the entrenchment and dissected lands immediately adjacent to the river that would have groundwater influenced by the Sheyenne River. These soils would have a Slight-to Moderate hazard of salinization under the alternatives. Moderate hazards would be associated with the channeled areas while the areas of the floodplain well above the entrenchment and away from areas that are frequently flooded would have a Slight salinization hazard. Channeled areas of Fairdale soils are not frequently cropped due to their rough topography and the hazard of more frequent flooding.

LaDelle soils are more distant from the river and flood less frequently than Fairdale soils. They are better-developed soils (Cumulic Hapludolls) consistent with a less-frequent flooding regime. Both LaDelle and Fairdale soils are in Irrigibility Subgroup 4A indicating a higher tolerance for water with elevated TDS and SAR levels. However, LaDelle soils can have higher levels of subsoil salinity that could be affected by mean water table increases induced under the alternatives. LaDelle soils were given a salinization hazard of None-to-Slight due to their presence in areas that do not actively flood and are beyond the influence of a raise in mean watertables under the alternatives. For more explanation regarding the salinization hazard placement of LaDelle soils , see Section 4.2.3.3.3, above.

LaPrairie soils are located in positions adjacent to the river and are mapped in very similar to positions to LaDelle soils, but are coarser textured (fine-silty as opposed to fine loamy) and have lower subsurface salinity (< 1 dS/m). Statements made above regarding the salinization hazard potential of LaDelle soils apply equally to LaPrairie soils. However, LaPrairie soils would be less subject to mobilization of subsoil salts. Given the low levels of subsoil salts, LaPrairie soils are listed as having a None-to-Slight salinization hazard similar to that given to the LaDelle soils.

Rauville, Lamoure, and Marysland soils are poorly drained and are associated with low portions of the floodplain and low abandoned meanders that would flood regularly. Rauville and Lamoure soils characteristically have subsoil salinity that could be easily mobilized under the alternatives assuming a mean watertable rise and more frequent flooding. More frequent flooding and elevated watertables associated with abandoned meanders that include Rauville and Lamoure soils could mobilize existing subsoil salts to the surface and the periphery of the abandoned meanders. Rauville and Lamoure soils have subsoil salinity up to 4 dS/m and were given a salinity hazard rating of Moderate to Severe.

Marysland soils are non-saline and have surface and subsoil salinity listed as less than 1 dS/m. Marysland soils were given a salinity hazard of Slight-to-Moderate based on their lower salinity; however, there is a possibility that Marysland soils could be salinized to a greater degree if in close proximity to Lamoure and Rauville soils that are experiencing salinization under the alternatives.

An acreage breakdown of salinization hazards for the Fairdale-LaPrairie-LaDelle Association is in Table 4. Detailed supporting data are provided for all soils in the association in Table 5.

#### *4.2.2.5. Fairdale-LaDelle-Wahpeton-Delta Soils Association*

The Fairdale-LaDelle-Wahpeton-Delta Soils Association was developed exclusively from the soils mapped along the Sheyenne River Valley in Richland County. The Association begins at the border between Ransom and Richland counties at River Mile 93 and extends to the border Richland and Cass counties at River Mile 63 (see Figure 1). Soils in the Association are covered by the Soil Survey of Richland County and Sheyenne National Grassland Area of Ransom County, North Dakota (Thompson and Joos, 1975).

This association transitions to the Fargo-Fairdale Association described below. In general, the Sheyenne River is deeply entrenched into the surrounding floodplain in Richland County. The association encompasses four groups of moderately well drained, somewhat poorly drained, and poorly drained soils found along the Sheyenne Valley floor. The first group has a direct hydrologic connection with the Sheyenne River through groundwater interactions resulting from variations in river stage and overbank flooding. Soils in this group occupy the present Sheyenne channel within the entrenchment, adjacent low areas within the entrenchment that include dissected (channeled) land resulting from downstream meander movement, and floodplain soils occupying low terraces that are intermittently to frequently flooded. The second group of soils occupies elevated terraces that represent post-glacial deposition of the Sheyenne River when it was less deeply entrenched into the floodplain. The third group of soils occupies the periphery of the valley and represents coarse textured soils that transition to the uplands on the delta proper. The fourth group represents the transition where the Sheyenne River flows out of the Sheyenne Delta and onto the Glacial Lake Agassiz Lake Plain. The Fairdale-LaDelle-Wahpeton Delta soils Association encompasses 6830 acres in Richland County.

Soil salinization hazards are summarized by soil association in Table 4 with detailed supporting data provided in Table 5. Detailed soil data in Table 5 include: soil series name, acreage in the association, taxonomic class, drainage, season high watertable depths and duration, annual flooding and timing of flooding, landscape position, salinity/sodicity characteristics, and a summary of salinity hazards.

Representative soils, flooded area outlines, a typical cross-section showing the geomorphic position of the soils, a representative salinity profile, and a representative landscape photograph are provided in **Figure 24**.

(Insert Figure 24 here)

### *4.2.2.5.1. Major Components*

The three major soil components are Fairdale, LaDelle, and Wahpeton series comprising 4305 acres or 63 % of the 6830 total acres mapped along the Sheyenne Valley in Richland County. The majority of these soils are associated with the current floodplain of the Sheyenne. Minor components and contrasting inclusions of different soil series of minor extent represent the remaining 38 % of soils along the Sheyenne Valley floodplain and adjacent terraces. The majority of these soils fall into the second, third, and fourth groups of soils discussed above.

Fairdale soils are major soil components representing 2562 acres or 38 % of the area mapped and were previously described in Section 4.2.2.3.2. Fairdale soils are found in channeled areas representing active erosion and downstream movement of meanders, as well as more stable elevated positions above the active floodplain.

The LaDelle soil series represents 1000 acres or 15% of the area and was previously described in Section 4.2.2.1.1. LaDelle is a moderately well drained soil found on low stream terraces and flood plains generally above the more frequently flooded Fairdale soils.

The Wahpeton soil series represents 740 acres or 11% of the area. The Wahpeton series was described previously in Section 4.2.2.1.1. This is a moderately well drained soil located on convex positions on elevated natural levees and low terraces of the flood plain.

### *4.2.2.5.2. Minor Components and Inclusions*

The LaPrairie soil series represents 190 acres or 3% of the area. LaPrairie soils were described previously in Section 4.2.2.1.1. LaPrairie soils are moderately well drained soil located on stream bottomlands and gently sloping terraces in positions similar to those occupied by LaDelle soils.

The Gardena soil series represent 560 acres or 8 % of the area. Gardena is a somewhat poorly drained soil located on lake plains and broad flats some distance from the Sheyenne River. Gardena soils formed in from coarse-silty near-shore lacustrine sediments associated with Glacial Lake Agassiz. Textures ranging from silt to silt loam and clay percent ranging from 0-18 percent. Runoff is slow and permeability is moderate. Gardena is a non-saline soil; however, a saline phase is recognized but was not mapped in the area. The ECspe is <1 dS/m in the soil surface and 0-2 dS/m in the subsoil. Calcium carbonate contents range from 0-3 % in the soil surface and 3-15 % in the lower horizons. Gypsum is absent in the surface, but gypsum levels can range from 0-2 % in the subsoil.

The Towner (*sandy over loamy, mixed, superactive, frigid Calcic Hapludolls*), Embden (*coarse-loamy, mixed, superactive, frigid Pachic Hapludolls*), Arveson (*coarse-loamy, mixed, superactive, frigid Typic Calciaquolls*), Fossum (*sandy, mixed, calcareous, frigid Typic Endoaquolls*), Hecla (*sandy, mixed, frigid Oxyaquic Hapludolls*), Tiffany (*coarse-loamy, mixed, superactive, frigid Typic Endoaquolls*), Hamar (*sandy, mixed, frigid Typic Endoaquolls*), Swenoda (*coarse-loamy, mixed, superactive, frigid Pachic Hapludolls*), and Ulen (*sandy, mixed, frigid Aeric Calciaquolls*) soils are minor components mapped on the periphery of the Sheyenne

Valley. All eight soils are associated with the Sheyenne Delta and areas of the valley that are proximate to the delta (e.g. low draws that lead from the uplands to the valley floor). All eight soils formed from moderately coarse textured lacustrine and aeolian sediments associated with the delta proper in landscape positions that would preclude receiving groundwater originating from the Sheyenne River. Moderately well drained Swenoda, Towner, Embden, and Hecla soils typically occupy better-drained positions on the periphery of the valley. Poorly drained Arveson, Hamar, and Fossum soils occupy concave depressions on the delta proper, with Arveson soils more typically found on the periphery of the depressions. Again, these soils are found primarily on the periphery of the Sheyenne Valley proper.

Overly, Colvin, Glyndon (*coarse-silty, mixed, superactive, frigid Aeric Calciaquolls*), Galchutt (*fine, smectitic, frigid Vertic Argialbolls*), and Perella (*fine-silty, mixed, superactive, frigid Typic Endoaquolls*) soils are associated with the transition between the Sheyenne Delta and the Glacial Lake Agassiz Lake Plain. Overly soils are moderately well drained and occur on low terraces above the river. Poorly drained Colvin and Perella soils occupy depressions, swales, and abandoned meanders adjacent to the Sheyenne on the Lake Plain. Perella soils are in elevated meanders above the present flood plain. Somewhat poorly drained Galchutt soils are mapped on the Lake Plain and are listed as having a perched water table.

#### *4.2.2.5.3. Identified Saline Soils*

Saline soils are not mapped as consociations, as major components of soil map unit complexes, or as inclusions along the portions of the Sheyenne River that were examined in Richland County. However, a vaguely described miscellaneous land type called "Wet Alluvial Land" was mapped as potentially saline. In addition, extensive saline soils are mapped on the toe of slope positions where the delta merges into the Glacial Lake Agassiz Lake Plain (the Red River Valley; however, these saline areas are not adjacent to the Sheyenne River.

Wet Alluvial Land represents 322 acres or 5% of the area. Alluvial land is very poorly drained and is frequently associated with strong groundwater seepage areas and groundwater fed abandoned meanders on relict terraces elevated well above the River. Textures, permeability and, runoff are variable. This soil is saline in some areas the listed ECspe can ranges from 2-16 dS/m from 0-60 inches.

#### *4.2.2.5.4. Effects of the Outlet Alternatives on Soil Salinization*

Salinization potential under the alternatives relate to; 1) the addition of salts in the more saline riverwater by increased overbank flooding, 2) mobilization of existing salts by increased groundwater levels induced by mean stage increases in the Sheyenne River under the alternatives, and 3) The introduction of blended Sheyenne River/Devils Lake water into the soils adjacent to the river.

Soils in the Fairdale-LaDelle-Wahpeton-Delta Soils Association fall into four main groups. The first group consists of soils in the Sheyenne Delta with a direct hydrologic connection with the river through groundwater interactions resulting from variations in river stage and overbank flooding. These soils consist of the Fairdale, LaDelle, LaPrairie, and Wahpeton soil series that are the dominant soils of the association.

Wahpeton soils rarely to occasionally flood, have watertables deeper than 6 feet, and have low levels of surface and subsoil salinity. Flooding is not expected to be frequent enough, nor is salinity under the outlet alternatives expected to be high enough to result in a persistent salinization of these soils. Transient salinization may occur during very high flood periods as floodwaters infiltrate the soil; however, the Wahpeton soils are well enough drained to leach accumulated salts from the profile, and water table depths are deep enough to ensure that leaching to depth would occur. For this reason Wahpeton soils have a none to slight salinization hazard under the alternatives.

Fairdale soils are classified as Udifluvents characterized by frequent overbank flooding, higher watertables, and slightly elevated levels of subsoil salinity. Channeled variants of these soils are recognized that occupy portions of the river that include the entrenchment and dissected lands immediately adjacent to the river that would have groundwater influenced by the Sheyenne River. These soils would have a slight to moderate hazard of salinization under the alternatives.

LaDelle soils are more distant from the river and flood less frequently than Fairdale soils. They are better-developed soils (Cumulic Hapludolls) consistent with a less-frequent flooding regime. Both LaDelle and Fairdale soils are in Irrigibility Subgroup 4A indicating a higher tolerance for water with elevated TDS and SAR levels. However, LaDelle soils can have higher levels of subsoil salinity that could be affected by mean water table increases induced under the alternatives. LaDelle soils were given a salinization hazard of None-to-Slight due to their presence in areas that do not actively flood and are beyond the influence of a raise in mean watertables under the alternatives. For more explanation regarding the salinization hazard placement of LaDelle soils , see Section 4.2.3.3.3, above.

LaPrairie soils are located in positions adjacent to the river and are mapped in very similar to positions to LaDelle soils, but are coarser textured (fine-silty as opposed to fine loamy) and have lower subsurface salinity (< 1 dS/m). Statements made above regarding the salinization hazard potential of LaDelle soils apply equally to LaPrairie soils. However, LaPrairie soils would be less subject to mobilization of subsoil salts. Given the low levels of subsoil salts, LaPrairie soils are listed as having a None-to-Slight salinization hazard similar to that given to the LaDelle soils.

Wet Alluvial Land is a miscellaneous land type that describes wet lands of varying textures and landscape positions in the association. By inspection of the digitized soil map, most units are associated with the periphery of the valley and occur as groundwater-fed seeps. Some areas mapped into the Wet Alluvial Land map unit occupy abandoned meanders that are elevated well above the present floodplain. Based on landscape position and Lidar elevation data comparing the elevation of the Wet Alluvial Land units and the active floodplain, these units appear to represent groundwater discharge from the surrounding uplands, and are unlikely to be affected under the outlet alternatives. Based on this information, Wet Alluvial Land was given a salinization hazard of None to Slight.

Based on landscape position and geomorphic setting data available in the soil survey and OSDs, several soils mapped primarily on the periphery of the Sheyenne Valley in Richland County were determined to be associated with elevated terraces and the Sheyenne Delta proper. While they are moderately well to very poorly drained soils associated with the valley, their location on the periphery of the valley adjacent to the uplands indicates that they are groundwater fed by recharge originating in the sandy uplands, and would not receive water groundwater or floodwater originating from the Sheyenne River. It is unlikely that Towner, Embden, Arveson, Fossum, Hecla, Tiffany, Hamar, Swenoda, or Ulen soils would be affected by the changes in the mean river stage or flooding dynamics induced by the alternatives. These soils were given a salinization hazard of None under the outlet alternatives.

Several soils were associated with the Glacial Lake Agassiz Lake Plain, including Gardena, Overly, Colvin, Glyndon, Galchutt, and Perella soils. Gardena and Glyndon soils are located away from the river and at slightly elevated positions not likely to receive groundwater originating from the Sheyenne River. It is unlikely that Gardena or Glyndon soils would be salinized by changes in river stage and flooding induced by the outlet alternatives. Both soils were given salinization hazards of None.

Somewhat poorly drained Galchutt and moderately well drained Overly soils are mapped in complex and are associated with low terraces immediately adjacent to the river. Both soils are listed as never flooding; however, their position and proximity to the river suggests that they may be influenced by a mean rise in river stage under the alternatives. Galchutt has a perched watertable and would not receive groundwater originating from the Sheyenne River. Thus the Galchutt soils was given a salinization hazard of None. Overly soils have subsoil salinity up to 4 dS/m and an apparent watertable as opposed to a perched watertable. Overly soils were given a salinization hazard of Slight to Moderate.

Perella soils occupy elevated abandoned meanders on the Lake Plain. Perella is listed as having a perched watertable, never floods, and has limited surface and subsoil salinity. Perella soils were given a salinity hazard of none. One Colvin soil Map Unit was identified in an elevated terrace position away from the Sheyenne on the Lake Plain. Based on its position and distance from the river, this Colvin map unit was given a salinization hazard of None.

An acreage breakdown of salinization hazards for the Fairdale-LaPrairie-LaDelle Association is in Table 4. Detailed supporting data are provided for all soils in the association in Table 5.

#### *4.2.2.6. Fairdale-Fargo Soil Association*

The Fairdale-Fargo soil association was developed exclusively from soils mapped along the Sheyenne River valley in Cass County. The Association begins at the border between Richland and Cass counties at River Mile 63 and extends to the confluence of the Sheyenne and Red Rivers at River Mile 0 (see Figure 1). The association is covered by the Soil Survey of Cass County, North Dakota (Prochnow et al., 1985).

In the Red River Valley (the bed of Glacial Lake Agassiz), the "valley" of the Sheyenne River is essentially confined to the entrenchment itself and several geomorphic settings immediately adjacent to the river. Soils associated with the river include moderately well drained to poorly and very poorly drained alluvial soils within the entrenchment, adjacent channeled land resulting from downstream meander movement, and natural levees and abandoned meanders near the river. Soils in uplands beyond the natural levees developed in nearly level, fine, and moderately fine textured lacustrine lake plain sediments distant from the active floodplain. The area is extensively ditched. The majority of the upland soils on the Lake Plain are moderately well through poorly drained soils with high watertables maintained by the presence of fine textures and low subsoil permeability rather than a direct recharge of groundwater from the Sheyenne River itself. Groundwater movement is primarily towards the river, but is limited by the low permeability of the lacustrine sediments. The Fairdale-Fargo association encompasses 13,740 acres of the Sheyenne entrenchment and immediately adjacent soils in Cass County North Dakota.

Soil salinization hazards are summarized by soil association in Table 4 with detailed supporting data provided in Table 5. Detailed soil data in Table 5 include: soil series name, acreage in the association, taxonomic class, drainage, season high watertable depths and duration, annual flooding and timing of flooding, landscape position, salinity/sodicity characteristics, and a summary of salinity hazards.

Representative soils, flooded area outlines, a typical cross-section showing the geomorphic position of the soils, a representative salinity profile, and a representative landscape photograph are provided in **Figure 25**.

(Insert Figure 25 here)

#### *4.2.2.6.1. Major Components*

The two major soil components are the Fairdale, and Fargo soil series, comprising 7980 acres or 58 % of the 13,742 total acres mapped along the Sheyenne River Valley in Cass County. Minor components and inclusions of different soil series of minor extent make up the remaining 42% of the area.

The Fairdale series is a major component representing 4470 acres or 33 % of the area mapped. Fairdale soils are moderately well drained soils that formed in fine-loamy recent alluvium on stream bottomlands, low terraces, and natural levees of the active floodplain. They are typically found near and within the river channel. Fairdale soils were described in Section 4.2.2.3.2.

The natural levees consist primarily of Wahpeton and Fairdale soils, with Fairdale soils also being found within the entrenchment and in channeled lands. An analysis of the effects of river stage on flooding indicates that the natural levees are frequently the highest land in the area. Flooding beyond the levees frequently breaks out along splays occupied by Fairdale Variant soils. These higher levees rarely flood Dakota (Prochnow et al., 1985; J.L. Richardson, Pers. Comm.)(see Figure 6).

The Fargo soil series represents 3504 acres or 26 % of the area. Fargo is a poorly drained soil located on glacial lake plains adjacent to the Sheyenne River Valley. Fargo consists of fine textured lacustrine sediments. The absence of recent alluvium indicates that the Fargo soils rarely flood, and that when flooding occurs it is overland flooding not typically associated with the Sheyenne River. Textures range from clay to silty clay with clay percentages ranging from 35-60 percent. Permeability and runoff are slow. Fargo soils are not classified as saline and have listed ECspe values of 0-2 dS/m in the soil surface and 0-2 dS/m in the subsoil. Calcium carbonate equivalents and gypsum contents are not available in the MUIR database, however, the soil is described as having strong effervescence indicative of carbonate concentration in the subsoil.

Three different Fargo map units exist in the Fairdale-Fargo Association. Fargo-Ryan complex, Fargo depressional, and Fargo smooth surface. The Fargo depressional is located in depressions on the Lake Plain, and Fargo smooth surface are on level landscapes. The major unit is the Fargo-Ryan complex that is located non-adjacent to the river on the nearly level Lake Plain. This complex contains the saline/sodic component Ryan soils.

#### *4.2.2.6.2. Minor Components*

The LaDelle soil series represents 1100 acres or 8% of the area mapped in discontinuous areas where the Sheyenne River leaves the Sheyenne Delta and flows onto the Lake Agassiz plain. LaDelle soils were previously discussed in Section 4.2.2.1.1.

The Cashel soil series (*fine, smectitic, calcareous, frigid Aquertic Udifluvents*) is a minor component of limited extent representing 1098 acres or 8 % of the area. Cashel is a somewhat poorly drained soil located adjacent to the river on low stream terraces in channeled areas and the active flood plain in similar locations to the Fairdale series described previously. Cashel soils consist of fine textured alluvial deposits. The textures range from silty clay to clay with 18-35 percent clay. Runoff is negligible to rapid and permeability is moderate to moderately slow with flooding in the early spring and after unusually heavy rain periods. This soil is non-saline with an ECspe of <1 dS/m in the soil surface and <1dS/m in the subsoil. Calcium carbonate and gypsum contents are unavailable in the MUIR database.

Other soils of minor extent were mapped as units within the Sheyenne River entrenchment and adjacent areas in Cass County. Several of these soils represent Lake Plain soils mapped as inclusions and map units of limited extent. These soils are more distant from the river and rarely flood from Sheyenne River overflow. These soils include the following soil series: Hegne, Overly, Bearden, Nahon (*fine, smectitic, frigid Calcic Natrudolls*), Perella, Nutley, Lindaas (*fine, smectitic, frigid Typic Argiaquolls*), and Great Bend (*fine-silty, mixed, superactive, frigid Calcic Hapludolls*)(see Table 5).

In addition to the major soils including Fairdale and Ladelle discussed above, several soils of minor extent are associated with the Sheyenne River entrenchment and adjacent levees and abandoned meanders. These soils are can be influenced by riverwater salinity and flooding hydrology and include the following series: Wahpeton, Dovray, Rauville, Colvin, Colvin (saline), Ludden, and Lamoure.

Wahpeton soils are on natural levees and have listed groundwater depths greater than 6 feet. The remaining minor soils associated with the Sheyenne River in the Red River Valley are poorly and very poorly drained soils located on the active floodplain on the periphery of the entrenchment, in abandoned meanders at low positions, and strongly dissected channeled areas. These soils include Dovray, Ludden, Rauville, Lamoure, and Colvin soils associated with poorly and very poorly drained positions along the floodplain and in low abandoned meanders that are close to the watertable and periodically receive floodwater from the Sheyenne.

#### *4.2.2.6.3. Effects of the Outlet Alternatives on Soil Salinization*

Soils in the Fairdale-Fargo Association fall into two main groups: soils hydrologically connected to the Sheyenne River by groundwater and overbank flooding, and soils associated with adjacent areas of the Glacial Lake Agassiz floodplain. Soils associated with the Lake Plain are beyond the regular floodplain of the Sheyenne River, rarely flood, and have high water tables associated with low subsoil permeability coupled with low relief. While periodic inundation does occur, it is primarily due to overland flow resulting from low infiltration rates coupled with low permeability under conditions of excessive rainfall, frozen soils, and/or periods of rapid snowmelt. The soils are typically poorly drained, with watertables elevated above the normal stage of the Sheyenne River. These soils are extensive in the Red River Valley, and occur in many areas distant from the river that are in locations that would preclude the river as a source of groundwater. The outlet alternatives are not expected to have a significant effect on these soils, which include the following soil series: Fargo, Ryan, Hegne, Overly, Enloe, Bearden, Nahon, Perella, Nutley, Great Bend, and Lindaas. These soils were given a salinity hazard of None.

Soils hydrologically connected to the Sheyenne River include soils above the channel but that flood regularly (Fairdale and Cashel series), and occasionally-to-rarely (LaDelle and Wahpeton series). Other soils are associated with low positions adjacent to the river and are also present in low abandoned meanders that would flood regularly and would also have watertables affected by a mean rise in river stage (Colvin, Colvin Saline, Lamoure, Ludden, and Rauville series in abandoned meanders).

Wahpeton soils rarely to occasionally flood, have watertables deeper than 6 feet, and have low levels of surface and subsoil salinity. Flooding is neither expected to be frequent enough, nor is salinity under the outlet alternatives expected to be high enough to result in a persistent salinization of these soils. Transient salinization may occur during very high flood periods as floodwaters infiltrate the soil; however, the Wahpeton soils are well enough drained to leach accumulated salts from the profile, and water table depths are deep enough to ensure that leaching to depth would occur. For this reason Wahpeton soils have a None-to-Slight salinization hazard under the outlet alternatives.

Cashel and Fairdale soils are classified as Udifluvents characterized by frequent overbank flooding, higher watertables, and slightly elevated levels of subsoil salinity. Channeled variants of these soils are recognized that occupy portions of the river that include the entrenchment and dissected lands immediately adjacent to the river that would have groundwater influenced by the Sheyenne River. These soils would have a Slight-to-Moderate hazard of salinization under the outlet alternatives.

LaDelle soils are more distant from the river and flood less frequently than Cashel and Fairdale soils. However, LaDelle soils can have higher levels of subsoil salinity (up to 4 dS/m). They are better-developed soils (Cumulic Hapludolls) consistent with less frequent flooding. HEC-RAS data provided by the USACE indicates that flooding in the entrenched areas of the Sheyenne River on the Lake Agassiz Lake Plain would not occur regularly. This was confirmed by Dr. J.L. Richardson (Pers. Comm.) who indicated that LaDelle soils were not normally mapped in a position to receive appreciable overbank flooding or to be influenced by a mean rise in stage of the Sheyenne River. LaDelle soils are thus listed as having None-to-Slight salinization hazard depending upon proximity to the river and the potential for significant water table rises.

Salinization hazards would be slight in areas of LaDelle soils that are close to the river with a greater potential to be more affected by water table rises under the alternatives.

Several soils are poorly drained and are associated with low portions of the floodplain and low abandoned meanders that would flood regularly. These soils are poorly to very poorly drained and have subsoil salinity that could be easily mobilized under the alternatives assuming a mean watertable rise and more frequent flooding. It is expected that poorly drained Dovray, Lamoure and Ludden soils associated with low positions on the floodplain and low abandoned meanders may become more saline under the alternatives. In addition, more frequent flooding and elevated watertables associated with abandoned meanders that include Rauville and Colvin soils could mobilize existing subsoil salts to the surface and the periphery of the abandoned meanders. These soils are therefore listed as having a Moderate-to-Severe hazard of salinization under the outlet alternatives. Dovray soils are non-saline and are fed by surface as opposed to groundwater (epiaquic hydrologic regime). Accordingly Dovray soils were listed as having a Slight-to-Moderate salinization hazard given their poor drainage and proximity to the Sheyenne river.

An acreage breakdown of salinization hazards for the Fargo-Fairdale Association is in Table 4. Detailed supporting data are provided for all soils in the association in Table 5.

### 4.2.3. Specific Effects of the Outlet Alternatives on Soil Salinization

Soil salinization hazards associated with the outlet alternatives relate to; (1) the addition of salts by increased overbank flooding with more-saline blended Sheyenne River/Devils Lake water, (2) mobilization of existing salts by increased groundwater levels induced by stage increases in the Sheyenne River under the alternatives, and (3) the introduction of blended Sheyenne River/Devils Lake water into the soils adjacent to the river.

Floodplain morphology and the entrenchment of the Sheyenne River can strongly influence the salinization hazards under the alternatives. In general, areas characterized by shallow entrenchment of the river, a broad active floodplain, and the presence of extensive acreages of poorly drained and very poorly drained soils in meanders and flats will have the greatest potential for soil salinization. These areas are characterized by low acreages of fine textured, poorly drained and very poorly drained, slowly permeable soils with high levels of subsoil salts. Such soils occupy low channeled areas and abandoned meanders and oxbow lakes close to the Sheyenne River would are expected to regularly flood. Conversely, areas where the river is deeply entrenched have elevated floodplains dominated by moderately well drained soils that flood occasionally to rarely have little potential for induced salinization problems.

In the discussion that follows, only the soils with significant acreages in their respective soil associations will be discussed. Soils of minor extent or inclusions that represent soils not associated with the Sheyenne River floodplain will not be discussed. The reader is directed to Table 5 and the detailed discussion of salinization hazards by association, above, for more information regarding minor soil components.

*4.2.3.1. 300 cfs Constrained Outlet Alternative.*

Of the outlet alternatives, the 300 cfs Constrained Outlet alternative would generally provide the lowest salinization hazard because outlet operation would be limited to periods where combined flows at the point of insertion are less than 600 cfs and contain no more than 450 ppm sulfate. These constraints lower; (1) the magnitude of discharge, (2) the amount of overbank flooding, and (3) the mean rise in watertables adjacent to the river when compared to the 480 cfs Unconstrained Outlet alternative discussed below. Floodplain morphology has an impact on soil salinization under the 300 cfs Constrained outlet alternative, with increased hazards in the shallowly entrenched upper reaches of the Sheyenne compared to the more deeply entrenched reaches below Baldhill Dam.

*4.2.3.1.1. Lamoure-LaDelle-LaPrairie-Ryan and LaDelle-Ludden-Wahpeton Associations*

There is a distinct difference between the soil associations upstream of Lake Ashtabula (the Lamoure-LaDelle-LaPrairie-Ryan Association and the LaDelle-Ludden-Wahpeton Association) compared to the soil associations downstream of Baldhill Dam (the LaDelle-Nutley, Fairdale-LaPrairie-LaDelle, Fairdale-LaDelle-Wahpeton-Delta soils, and Fairdale Fargo associations). The Lamoure-LaDelle-LaPrairie-Ryan and LaDelle-Ludden-Wahpeton Associations. The upstream associations:

- are nearest the point of insertion for the constructed outlet alternatives (see Figure 1),
- have the highest levels of mean salinity/sodicity in blended water compared to areas further downstream (see Figures 7 and 8), and
- have extensive areas where the Sheyenne River is shallowly entrenched with adjacent poorly and very poorly drained soils. Many of these soils are already saline (e.g. Ryan and Lamoure saline), are near or have included saline soils, or have substantial amounts of subsoil salinity (e.g. Rauville and Ludden soils)(see Figures 21 and 22 and Table 5).

Both upstream associations have areas that were identified as "problem areas" that would experience flooding at lower flow rates (NDSWC, 1997). Because of shallow entrenchments and broad active floodplains with soils whose watertables are set by the river stage, the Lamoure-LaDelle-LaPrairie-Ryan and LaDelle-Ludden-Wahpeton associations have the largest acreage of soils in the Moderate to Severe hazard classifications that are expected to have salinization problems under both of the constructed alternatives (see Table 4). These soils are fine-textured and slowly permeable with substantial amounts of subsoil salinity (see Table 5)

Problems would not necessarily be limited to the poorly and very poorly drained soils. Moderately well drained Fairdale and LaDelle soils that are in low positions and frequently to occasionally flood could be expected to have increased salinization hazards in response to raised water tables and more frequent flooding with blended water. LaDelle soils especially have subsoil salinity as high as 4 dS/m. Raised watertables in LaDelle soils close to the river could result in mobilization of salts to the soil surface resulting in a moderate salinization hazard. Similarly, Fairdale soils are frequently flooded and are very near the river. Fairdale soils could experience salinization hazards due to their proximity to the river, increased groundwater salinity, and raised watertables. Accordingly, both Fairdale and LaDelle soils were placed in the Slight-to-Moderate salinization hazard category.

#### *4.2.3.1.2. LaDelle-Nutley, Fairdale-LaPrairie-LaDelle, Fairdale-LaDelle-Wahpeton-Delta soils, and Fairdale-Fargo Associations*

As discussed in Sections 3.3.5, there is a considerable difference in the floodplain morphology downstream of Baldhill Dam compared to portions upstream of Lake Ashtabula. Downstream, the river is deeply entrenched with a narrow, less active floodplain. HEC RAS modeling indicates that flood flows up to 3000 cfs would be confined to the channel, adjacent abandoned meanders, and channeled lands. Many areas of the designated floodplain downstream of Baldhill Dam apparently do not flood regularly. Further confirmation of this is the much lower acreage of poorly and very poorly drained soils that have been mapped along the valley floor downstream of Baldhill Dam. Downstream of Baldhill dam, poorly and very poorly drained soils associated with the floodplain are confined to abandoned meanders and channeled areas, and are primarily mapped as minor inclusions in moderately well drained floodplain soils. Thus, soils in the Moderate to Severe salinization hazard class form a minor percentage of soils in the LaDelle-Nutley, Fairdale-LaPrairie-LaDelle, Fairdale-LaDelle-Wahpeton-Delta soils, and Fairdale-Fargo associations (see Table 4). LaDelle soils that were placed in the Slight-to-Moderate salinity hazard class in soil associations above Baldhill Dam have had their salinization class lowered to None-to-Slight to account for the lack of overbank flooding documented in the HEC RAS flooded area outline models.

Predicted mean stage increases under the 300 cfs Constrained alternative for control points below Baldhill Dam vary from 1.5 to 3 feet (see Table 3). Under the 300 cfs Constrained alternative salinization hazards will be essentially confined to channeled land adjacent to the Sheyenne River and low meanders and abandoned oxbows that would flood regularly with blended water. These soils may also be affected by increased mean watertables and possible groundwater intrusion from the Sheyenne River during outlet operation. Thus soils with potential salinization hazards are limited to the poorly and very poorly drained soils that form a minor component of the associations and those moderately well drained floodplain soils next to the river that are listed as flooding regularly. Fairdale soils have been placed in the Slight-to-Moderate salinization hazard category because of their classification as Udifluvents and the fact that they are listed as frequently flooded. However, Fairdale soils are also mapped in positions more distant from the river in areas similar to LaDelle soils. Fairdale soils in these positions would have a salinity hazard classification of Slight. It is likely that only the channeled variants of Fairdale soils will experience a salinization hazard of Moderate.

#### **Need for Additional Hydrology Studies**

The vast majority of soils in the Slight-to-Moderate hazard classification are in the occasionally flooded LaDelle and frequently to occasionally flooded Fairdale soil series. Little is known regarding the hydrologic connection between the Sheyenne River and groundwater in Fairdale and LaDelle soils. Groundwater recharge can be assumed during flooding events when the soils are inundated. However, groundwater discharge from upslope may maintain elevated watertable levels in the interim between flooding events. In most cases the dominant groundwater movement is towards the Sheyenne River. Thus Fairdale and Ladelle soils that are not directly flooded with blended water would be unaffected under the alternatives because groundwater movement would be towards the river.

However, the interim USGS data discussed in Section 3.3.4 indicate that groundwater levels may be affected by variations in Sheyenne River stages at substantial distances from the river in response to the "damming" effects of bank storage. Thus the outlet alternatives may have an indirect effect on watertables in adjacent floodplain soils that would not involve groundwater intrusion of blended Sheyenne River/Devils Lake water. This induced increase in groundwater levels may adversely effect salinization potential by mobilizing subsoil salts, especially in LaDelle soils that are listed as having subsoil salinity up to 4 dS/m. It is recommended that under any of the outlet alternatives that the USGS monitoring program be continued and expanded to establish the effects of Sheyenne River stage on watertables and subsoil salt mobilization in floodplain soils. LaDelle and Fairdale soils should receive the most emphasis for research.

#### *4.2.3.2. 400 cfs Unconstrained Outlet Alternative.*

Outlet discharge under the 480 cfs Unconstrained Outlet alternative is not constrained by flow or water quality considerations. Accordingly, salinization hazards under the 480 cfs Unconstrained alternative would be higher than the 300 cfs constrained outlet alternative due to increased watertables from higher mean river stages and additional flooding. Differences in salinity hazards due to poorer water quality would likely not be significant because the TDS and SAR values associated with both constructed outlet alternatives are very similar (see Section 3.2.1, above).

##### *4.2.3.2.1. Lamoure-LaDelle-LaPrairie-Ryan and LaDelle-Ludden-Wahpeton Associations*

Salinization hazards associated with increased mean stage under the 480 cfs alternative would be most significant in the Lamoure-LaDelle-LaPrairie-Ryan and LaDelle-Ludden-Wahpeton associations due to the presence of poorly and very poorly drained soils that would experience an additional mean increase in watertables of approximately 0.5 feet when compared to the 300 cfs Constrained alternative (see Table 3). It is expected that the increase in mean river stage combined with greater overbank flooding under the 480 cfs Unconstrained alternative would result in increased watertable rise and additional salinzation hazards when compared to the 300 cfs alternative. The most susceptible soils would be the poorly and very poorly drained Ryan, Lamoure, Ludden, and Rauville series that are fine textured, slowly permeable, and already have high levels of subsoil salts. It is expected that the increased salinization hazard will be due more to raised watertables than to differences in water quality between the 300 cfs Constrained and the 480 cfs Unconstrained alternative.

##### *4.2.3.2.2. LaDelle-Nutley, Fairdale-LaPrairie-LaDelle, Fairdale-LaDelle-Wahpeton-Delta soils, and Fairdale-Fargo Associations*

In areas downstream of Baldhill Dam, the differences in stage between the 300 cfs Constrained and the 480 cfs Unconstrained alternatives are approximately one foot (see Table 3) when compared to stage increases under the 300 cfs Constrained alternative (see Table 3). Stage increases below Baldhill Dam would be confined essentially to the channel due to the deep entrenchment of the Sheyenne River (see Section 3.3.5). The minor differences in stage and water quality comparing the 300 cfs Constrained and the 480 cfs Unconstrained alternatives should not result in significant additional soil salinization hazards downstream of Baldhill Dam. Any additional salinization hazards the be limited to channeled areas and abandoned meanders with poorly drained soils whose water level for which is influenced by the stage of the Sheyenne River. These settings form a minor component of the soils in the subject associations.

#### *4.2.3.3. No Action (natural spill) Alternative*

The No Action (natural spill) Alternative represents the natural overflow of Devils Lake water from Stump Lake through the Tolna Coulee to the Sheyenne River. The point of insertion for the natural spill is at river mile 374 near the lower end of the Lamoure-LaDelle-LaPrairie-Ryan Association (see Figure 1). Salinity and sodicity of the blended water is much greater under the No Action (natural spill) alternative than it is under either of the constructed outlet alternatives (see Figures 7 and 8, and Tables 1 and 2). Mean TDS and SAR values vary by control point and are highest for the Cooperstown control point (1616 mg/L and 7, respectively) and are lowest for the Kindred control point (972 mg/L and 4.37, respectively). Maximum values in TDS and SAR are 2886 mg/L and 11, respectively for Cooperstown. Maximum values in TDS and SAR for Kindred are 1894 mg/L and 8.5, respectively.

While salinity and sodicity values under the constructed outlet alternatives are elevated above base values, the magnitude of the increases in TDS and SAR are much smaller than those under the No Action alternative. TDS and SAR values for the constructed outlet alternatives and are well below the maximum TDS and SAR values recommended for most irrigated soils in North Dakota (see PEC Report Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives: Irrigation dated October 9, 2001). However, as indicated in the PEC Irrigation Report, the TDS and SAR values associated with the natural spill are elevated to the point where they exceed recommended levels for many soils. Accordingly, salinization hazards under the No Action alternative are the most extreme of the outlet alternatives considered. Most of the productive agricultural soils along the floodplain of the Sheyenne River are fine to medium textured, moderately well drained soils that would be placed in Irrigibility Subgroups 4A (e.g. LaDelle, Fairdale, LaPrairie soils) and 3B (Wahpeton). Such soils would have recommended TDS and SAR maximums of 1460 mg/L or less and SAR values of 6 or less, respectively. These recommended maximum values are exceeded regularly in blended water under the No Action alternative (see Appendix A1), suggesting that significant soil salinization/sodification hazards would result in soils affected by regular flooding or by groundwater intrusion. Effects would be worse for fine textured, poorly drained soils with existing high levels of surface or subsurface salinity such as the Lamoure, Ludden, and Rauville series.

Most soils potentially affected by frequent flooding or persistent groundwater intrusion under the No Action (natural spill) alternative would have Moderate to Severe hazards, indicating that the effects would adversely affect land use, soil conditions, and salt-intolerant vegetation. Again, the effects of the No Action alternative would be influenced by the floodplain morphology of the Sheyenne River. More severe salinization hazards would be expected upstream of Lake Ashtabula where regular overbank flooding would be more common. Downstream of Baldhill

Dam, the effects would still be severe, but would likely be confined to channeled areas adjacent to the river, low, regularly flooded areas, and in abandoned meanders and oxbow lakes. However, if pluvial conditions result in frequent flooding, all soils potentially inundated within the floodplain could be affected. Fine textured soils could be expected to experience dispersion due to elevated sodium levels and increased salinity due to additional salt loading.

It is important to note that pumping under the constructed outlet alternatives begins May 1 after much of the serious flood potential has passed. However, under the No Action (natural spill) alternative, Devils Lake discharge can continue year round, and spring floodwaters that would not have elevated salt loading under the constructed outlet alternatives could be quite saline under the No Action (natural spill) alternative. Extensive salinization/sodification of susceptible soils higher on the floodplain could result.

### 4.2.4. Wetland Plant Community Responses to Increased Salinity/Sodicity

The flora of the Sheyenne River valley have adapted to various niches dependent upon specific soils, climate, topography, and aspect, among other environmental factors. The effects of the outlet alternatives on the distribution and composition of plant communities adjacent to the Sheyenne will depend primarily upon changes in river hydraulics, groundwater hydrology, and salinity. Saline soils intermingled with non-saline soils are a naturally occurring component of the Sheyenne River floodplain along virtually its entire reach, but are much more common upstream of Baldhill Dam. Salinization associated with the outlet alternatives will primarily affect wetland plant communities found in frequently flooded and poorly and very poorly drained soils. The hydric soils associated with the valley represent the full range in wetland salinity: from fresh recharge wetlands dominated by precipitation run-on and groundwater recharge to hypersaline wetlands associated with groundwater discharge in the upper reaches of the Sheyenne River. The range of naturally occurring soil salinity along the Sheyenne River is likely 4 orders of magnitude: from EC = 100 umho/cm to 100,000 umho/cm. When compared to this range, the variability in blended water salinity seems small.

A useful guide regarding the salt tolerance of wetland plants is Stewart and Kantrud (1972), who developed a classification system for wetlands in North Dakota specifically related to hydrologic regime (temporarily through permanently flooded) and the salinity of the water as TDS (mg/L) and EC. Stewart and Kantrud classified wetlands based on; (1) flooding regime, (2) respective plant vegetation that is characteristic of the flooding regimes, (3) salinity associated with the hydrologic regime/plant community classes, and (4) disturbance (e.g. plowing, drawdown, flooding). Their classification system is particularly applicable to evaluating plant community changes under the alternatives. The majority of the wetland soils discussed in the present report would, using Stewart and Kantrud' s salinity categories, range from slightly brackish (EC range from 500 to 2000 umho/cm) to saline (EC range from 45000 to 100000 umho/cm).

Wetland plant community composition would respond to the outlet alternatives by changes in distribution depending upon; (1) the intensity of disturbance (e.g. flooding), (2) the persistence of disturbance (e.g. more regular flooding or water table rise), and (3) changes in salinity induced by the alternatives. For example, increases in watertable depth are expected to affect existing saline soils in the Lamoure-LaDelle-LaPrairie-Ryan association by the mobilization of subsurface salts to the soil surface in response to wetter hydrologic regimes under the alternatives. Under these conditions, wetland plants representing brackish to saline condition in the existing saline wetland will gradually move out into areas that were formerly dominated by plants adapted to drier conditions and less salinity. In essence, the wetland will expand outward at the edges, and native plant communities will respond accordingly. In wetlands where salinization changes are gradual the transition to more salt tolerant plants will also be gradual. The preexisting native plant community would shift toward a native plant community tolerant of wetter and more saline conditions. If the disturbance is rapid (e.g. for example frequent overbank flooding with saline water under the No Action (natural spill) alternative), invasive plants that are more tolerant of disturbance and salinity may completely replace salt-intolerant native plant communities. A similar set of responses would be expected with wetland plant communities adapted to brackish or fresh conditions. The most severe and noticeable impacts would occur under the No Action (natural spill) alternative where wetlands adapted to relatively fresh water are flooded with saline water to which they are intolerant. Rapid changes from native plant communities to invasive plant communities would result. The reader is directed to Stewart and Kantrud (1972) for more information regarding wetland vegetation in relation to ponding/flooding regime, water quality, and disturbance factors.

### 4.2.5. Mitigation

#### *4.2.5.1. Mitigation Measures: Constructed Outlet Operation*

Under the constructed outlet alternatives, the only available operational mitigation measure appears to be managing the initiation of outlet operations to begin after the recession of spring flooding. It is apparent from the HEC 5Q hydrograph GUI data (see examples in Figures 9 through 12) examined for the duration of the 45-year operational period that the majority of overbank flooding would be associated with the recession of spring flooding. With the exception of rare summer flood events, the spring flood event is the only major, reoccurring flood event that would result in the inundation of productive floodplain soils such as the LaDelle, LaPrairie, and many Fairdale soils that are the most extensive soils in the Sheyenne River Valley. Managing the timing of outlet operations to ensure that these soils would not be flooded with blended water would have the benefit of removing any potential salinization hazards associated with overbank flooding with more-saline, blended water. The salinization hazard of floodplain soils not influenced by elevated groundwater tables under the alternatives would essentially drop from None-to-Slight to None and from slight to moderate to slight.

Based on the broad range of spring flooding events in the HEC 5Q GUI observed at various control points, the initiation of outlet operations would normally be delayed by about two weeks in most years.

#### *4.2.5.2. Initial Assessment of Applicable Soil Characteristics on Potentially Affected Lands*

Mitigation measures must be based on a detailed knowledge of the potentially affected soils, especially focusing on texture, drainage class, and existing in-situ salinity/sodicity. Under any alternative, it is necessary that the impacted growers have a detailed soil assessment performed to assess these parameters. A professional Soil Scientist licensed to practice in the States of North Dakota and Minnesota can perform such assessments.

Salt and sodium in soils can limit their use, reduce crop yields, and influence management (Bresler et al., 1982; Franzen et al., 1994; Holm and Henry, No date). Soils that have an EC greater than 4 dS/m are considered saline (U.S. Salinity Laboratory Staff, 1954). Depending on crop salt tolerance, significant yield reductions of intolerant crops occur beyond an ECspe of 4 dS/m. Crop tolerances to soil salinity/sodicity have been quantified (Francois, 1994, 1996) and management techniques to reduce the negative impacts of soil salinity are known (Johnsgard, 1967; Franzen et al., 1994). Many of these techniques are already in general use on saline/sodic soils in the region (Bresler et al., 1982; Franzen et al., 1994; Maianu, 1983, 1984, 1985). Secondary soil salinization has a negative economic impact that can be quantified through an assessment of increased management costs, limits to use, and reduced crop yields. Soil water compatibility issues involving irrigation are well documented, requiring a knowledge of applicable soil/groundwater characteristics, water chemistry, and rates of water applications (U.S. Salinity Laboratory Staff, 1954; Franzen et al., 1996; Scherer et al., 1996). Given a knowledge of soil type and quality in the blended Sheyenne River/Devils Lake, salinity hazards can be identified and mitigated or accounted for.

Common management techniques use adapted crops and manipulate watertables and groundwater flow to minimize soil salinization in sensitive areas. Land and water management practices that can help producers to reduce the risk of salinization include but are not limited to:

- increasing minimum tillage or no-tillage
- increasing the area of forages, pastures, and tree crops
- ensure adequate drainage
- including crops that are more salt-tolerant in rotations

#### *4.2.5.3. Regular Soil Testing and Crop Monitoring*

Regular soil tests should be performed on lands potentially salinized by flooding or groundwater rise under the outlet alternatives. This would include at a minimum the measurement of soil EC and SAR. These tests are recommended in order to ensure that salts do not become a problem in low hayland and cropland. EC and SAR tests could be augmented with a suite of saturation extract soluble ions on representative and problem areas. These ions include calcium, magnesium, sodium, potassium, alkalinity, chloride and sulfate. Franzen et al. (1996) recommend such testing for several listed irrigability groups that have potential salinity/sodicity problems resulting from high water tables and slow permeability. An alternative would be periodic testing using an electromagnetic conductivity meter, though the availability of this instrument is limited. It does have the advantage of performing quick, relatively accurate measurements on several field locations in a short time.

#### *4.2.5.4. Plant Salt Tolerant Crops*

Most growers in North Dakota are well acquainted with the effects of soil salinity on crop yields. Many North Dakota soils contain inclusions that are naturally saline. Under conditions of extensive salinity, growers can plant salt tolerant crops that provide good economic yields under conditions where soil salinity is high.

Several researchers have investigated the effects of salinity on crop yields. Extensive lists of crop salt tolerances exist in the literature and will not be reviewed here. Much unpublished research performed during the 1980s by Alex Maianu at North Dakota State University on the salt tolerance of common North Dakota crops is available through the NDSU Department of Soil Science. Other sources include Richards (1954), the Agricultural Research Service's United States Salinity Laboratory Staff and various State Universities and State Agricultural Extension offices in the Northern Plains States where salinity is a factor in crop production.

In general, most common crops in North Dakota are tolerant to root-zone salinity of up to 4 mmho/cm EC (4000 umho/cm or an approximate TDS value of 2600 mg/l). Above 4 mmho/cm crop yields decline, some faster than others. Potatoes are less salt tolerant while sunflowers are more tolerant. Wheat and soybeans maintain high yields up to 6-8 mmho/cm EC (see Seelig and Richardson, 1991).

Growers with floodplain soils potentially affected by flooding with blended Sheyenne River/Devils Lake water under any of the outlet alternatives are strongly advised to consult with NDSU Extension Service representatives prior to choosing the planting of salt tolerant crops as mitigation for perceived salinity/sodicity problems.

#### *4.2.5.5. Mitigation of Sodicity Hazards*

The data suggest that sodicity hazards are secondary to salinity hazards under the constructed outlet alternatives. However, sodicity could be a serious problem under the No Action (natural spill) alternative especially due to the increased sodium load associated with releases of water from Stump Lake. Growers upstream of the natural confluence would be unaffected; however, downstream users along the Sheyenne River would have to deal with water that may periodically have unacceptable levels of both salinity and sodicity. As with salinity, sodicity is a familiar hazard to growers in North Dakota. Saline and sodic soil inclusions are relatively common along the Sheyenne River (e.g. Ryan soils), and the Red River Valley (e.g. Ryan soils in the Fargo-Ryan Association).

Sodium affects soil structure by breaking apart soil colloids resulting in a soil that is dispersed and "puddled" when wet and hard and massive when dry. One indicator of sodium-affected soils is the presence of large, massive soil clods in recently plowed fields. Poor plant-water relationships and poor crop root penetration result from the effects of excessive sodium in soils. Less water and nutrients are available for plant growth. Sodicity problems are reduced in coarse textured soils, soils high in soil organic matter, and soils that contain naturally high levels of the calcium-containing salts Calcium Carbonate (calcite or "lime") and gypsum.

Mitigation for the effects of sodicity involves the application of calcium-containing salts. The soluble calcium in these salts replace the more weakly held ("exchangeable") sodium ions that are adsorbed to soil particle surfaces. Various calcium amendments are available to counter the effects of sodium on affected soils, including calcium sulfate (gypsum), calcium chloride, and various other calcium sulfate salts. Elemental sulfur may be used to convert naturally occurring calcium carbonate to calcium sulfate. The kind and amount of chemical amendment to be used depends upon the soil characteristics, the desired rate of replacement, and economic considerations. A list of potential chemical amendments and procedures for determining application rates is provided in Richards (1954). Further information specific to mitigating sodium problems in North Dakota soils is in Franzen et al. (October 1988). Soil inspection and analysis by a qualified, licensed soil science professional is recommended before any calcium amendments are applied to fields with sodicity problems. The development of site-specific sodification management measures can be developed in conjunction with salinity management measures.

# 5. CONCLUSIONS

## 5.1. THE EFFECTS THE ALTERNATIVES ON SALINITY IN SHEYENNE RIVER WATER

Based on an assessment of TDS and SAR relationships in HEC5Q predictions for a conservative, 45-year trace (Wet7 climatic scenario) it has been concluded that:

1. When compared to base conditions, the increase in SAR and TDS in Sheyenne River/Devils Lake blended water under the constructed outlet alternatives is not, by itself, of sufficient magnitude to create significant soil salinization/sodification problems in soils to which it is intermittently applied.

2. TDS and SAR values associated with the No Action (natural spill) alternative are well above the recommended maximum values for most irrigated soils in North Dakota, and would represent a significant salinization/sodification hazard for the typical soils found on the floodplain along the Sheyenne River Valley.

## 5.2. STAGE AND FLOW IN THE SHEYENNE RIVER

Based on; (1) HEC5Q predicted flows at representative control points, (2) average increases in May and June mean stages for various control points under the constructed outlet alternatives, (3) HEC RAS flooded area outlines developed from accurate Lidar data, (4) percentage flow exceedance graphs, and (5) interim USGS watertable well data, the following conclusions have been drawn:

1. The initiation of constructed outlet operations on May 1 ensures that the introduction of Devils Lake water into the Sheyenne River will occur near the end of normal spring flooding, minimizing the acreage of floodplain soils inundated with blended water.

2. Mean stage increases of 1-2 feet over base conditions are expected under the 300 cfs Constrained alternative. Increases of up to an additional foot are expected under the 480 cfs Unconstrained alternative.

3. Interim data supplied by the USGS indicates that stage variations in the Sheyenne River can be reflected in variations in groundwater levels several hundred feet perpendicular to the river.

4. Flooded area outlines developed from Lidar data indicate that extensive overbank flooding will occur at 1000 cfs in the portions of the Sheyenne River that are above Lake Ashtabula. The St. Paul District, USACE indicated the 1000 cfs flow rate as the "normal" flood flow for this section of the river.

5. Flooded area outlines for the reaches of the Sheyenne River below Baldhill Dam indicate that flows up to 3000 cfs will be confined to the more deeply entrenched channel and adjacent low abandoned meanders and channeled land. The St. Paul District, USACE

indicated the 1500 cfs flow rate as the "normal" flood flow for this section of the river. Extensive, regular flooding of the adjacent floodplain is not expected in this reach.

6. Percentage flow exceedance graphs (Wet7 climatic scenario) developed for Cooperstown suggest that flooding above 1000 cfs (i.e. the normal flow) during the period of outlet operations will occur during less than 5% of the May 1 through September 31 growing season when considered over the entire planning period for all alternatives.

7. Percentage flow exceedance graphs (Wet7 climatic scenario) developed for Kindred suggest that flooding above 1500 cfs (i.e. the normal flow) during the period of outlet operations will again occur during less than 5% of the May 1 through September 31 growing season when considered over the entire planning period for all alternatives.

8. Percentage flow exceedance graphs indicate that flows above base level will be highest under the 480 cfs Unconstrained Outlet alternative and will be intermediate under the 300 cfs Constrained Outlet alternative. Flows under the No Action (natural spill) alternative are very similar to base flows.

## 5.3. SOIL SALINIZATION HAZARDS

Soil Salinization Hazards are summarized by soil association in Table 6.

(Insert Table 6 here)

### 5.3.1. Salinization Hazards associated with Upstream Associations: The Lamoure-LaDelle-LaPrairie-Ryan Association and the LaDelle-Ludden Wahpeton Association

1. The greatest salinization hazards for the constructed outlet alternatives occur upstream of Lake Ashtabula between river miles 469 and 277 (192 river miles) in the Lamoure-LaDelle-LaPrairie-Ryan and the LaDelle-Ludden-Wahpeton associations (Upstream Associations).

2. The Upstream Associations comprise 23,676 acres (36%) of the total 65,096 acres of soils examined along the floor of the Sheyenne River valley. Of this 23,676 acres, 2142 (9%), 3313 (14%), 7959 (34%), and 10,040 (42%) acres were given salinity hazard ratings of None, None-to-Slight, Slight-to-Moderate, and Moderate-to-Severe, respectively. Just over 200 acres of soils were not rated because they represented numerous soil series each of insignificant extent.

3. Of the 65,096 acres of potentially affected soils examined along the floor of the Sheyenne River valley, 10,040 acres (over 42% of the total Upstream Association acreage) were in the Moderate-to-Severe hazard class indicating salinization hazards sufficient to adversely affect land use and soil physical characteristics. It is likely that most of these lands are currently in native range or are pastured.

4. Salinization hazards in the Upstream Associations result from; (1) the shallow entrenchment of the Sheyenne River, and (2) the presence of extensive areas of poorly and very poorly drained, fine-textured, slowly permeable soils that are already saline or have substantial, readily mobilized subsoil salinity.

5. All three salinization mechanisms would act to salinize soils in the Moderate-to-Severe hazard category under the constructed outlet alternatives, including; (1) added salt provided from overbank flooding, (2) added salt from groundwater intrusion, and (3) elevated water tables resulting in a mobilization of existing subsoil salts. Mobilization of existing subsoil salt is probably the most significant hazard in the Upstream Associations.

6. Moderately well drained soils that occupy levees and low rises on the floodplain were given a Slight-to-Moderate hazard due to the potential for additional salt loading from flooding and water table rise. Salinization hazards are less than the Moderate to Severe category because of less frequent flooding, little or no groundwater intrusion, and deeper seasonal high watertables. Just under 8,000 acres of primarily fine and medium textured, moderately well drained floodplain soils were placed in the Slight-to-Moderate salinization categories. LaDelle soils may be the most affected because of potential high levels of subsoil salinity, occasional flooding and seasonal high watertables within 3 to 4 feet of the soil surface.

7. Soils placed into the None and None-to-Slight hazard categories consisted primarily of LaPrairie and Wahpeton soils whose landscape position and soil properties do not indicate significant salinization hazards.

8. Salinization hazards in the Lamoure-LaDelle-LaPrairie-Ryan and LaDelle-Ludden-Wahpeton associations will be lower under the 300 cfs Constrained alternative due to the constraints on Sheyenne River stage imposed by channel capacity and water quality considerations. Salinization hazards would be greater under the 480 cfs Unconstrained alternative due to increased flow and more frequent flooding.

9. The 95-mile portion of the Sheyenne River valley that lies between river mile 469 and the point of insertion for the natural spill from Stump Lake at river mile 374 would be unaffected by the No Action (natural spill) alternative. Much of the floodplain in this area consists of saline or potentially saline Ryan and Lamoure soils.

10. The remainder of the Upstream Associations from river mile 374 down to river mile 277 would be affected by the No Action (natural spill) alternative.

11. The severity of the impacts under the No Action (natural spill) alternative are difficult to quantify due to potentially offsetting processes affecting soil salinization hazards.

### 5.3.2. Salinization Hazards Associated with Downstream Associations: The LaDelle-Nutley, Fairdale-LaPrairie-LaDelle, Fairdale-Ladelle-Wahpeton-Delta Soils, and Fargo-Fairdale Soil Associations

1. The acreage of soils with significant salinization hazards decreases dramatically below Baldhill Dam due to the greater entrenchment of the Sheyenne River, less frequent and extensive overbank flooding, and minimal poorly and very poorly drained soils. The four Downstream Associations begin at Baldhill Dam at river mile 257 and extend 257 river miles downstream to the confluence of the Sheyenne and Red rivers north of Harwood, North Dakota at river mile 0.

2. The Downstream Associations comprise 41,420 acres (64%) of the total 65,096 acres of soils examined along the floor of the Sheyenne River valley. Of this 41,420 acres, 11,198 (27%), 12,439 (30%), 16,620 (40%), and 1087 (2.6%) acres were given salinity hazard ratings of None, None-to-Slight, Slight-to-Moderate, and Moderate-to-Severe, respectively. Seventy-six acres were not rated because they represented numerous soils of very limited extent.

3. Fine textured, slowly permeable poorly and very poorly drained soils are confined to channeled areas, abandoned meanders, and oxbow lakes immediately adjacent to the river. Because these soils are the most susceptible to salinization, the acreage of soils in the Moderate-to-Severe hazard class dropped to 1087 acres, or just 2.6% of the total Downstream Association acreage.

4. Accordingly, significant salinization hazards are not expected under the constructed outlet alternatives in the Downstream Associations.

5. The primary floodplain soils in the Downstream Associations are the moderately well drained, non-saline Fairdale (14,973 acres), LaDelle (7157 acres), LaPrairie (3182 acres), and Wahpeton (1029 acres) series. These series cumulatively account for 26,341 acres, or over 40% of the total acreage examined for this report. All of the listed series are floodplain soils that are moderately well drained, occasionally flooded soils subject to overbank flooding and potential groundwater effects in channeled and low areas. This hydrologic relationship precluded the placement of these soils in the "None" salinization hazard category.

6. LaDelle soils that were placed in the Slight-to-Moderate salinity hazard category in the upstream reaches were downgraded in the downstream reaches to the None-to-Slight category. This was based on floodplain morphology, the deep entrenchment of the Sheyenne, and the reduced potential for regular flooding and water table increases.

7. Fairdale soils are classified as Udifluvents, are typically frequently flooded, and can have subsoil salinity as high as 2 dS/m. They occupy channeled lands as well as terrace positions more characteristic of LaDelle and LaPrairie soils. Fairdale soils that occupy channeled areas are susceptible to salinization from frequent flooding, groundwater intrusion, and watertable rise. However, Fairdale soils are non-saline, relatively coarse textured soils that drain well and would have the ability to leach salts accumulated during

periods when the river is drawn down. Accordingly, Fairdale soils were placed in the Slight to Moderate category. Moderate hazards would be associated with channeled variants of Fairdale soils.

8. Fairdale soils in positions above the entrenchment and adjacent channeled lands would more appropriately be placed in the Slight salinity hazard category. However, most soil surveys did not separate out channeled phases of Fairdale. To be conservative, all Fairdale soils were placed in the Slight to Moderate category. Many of these soils may be more appropriately placed with LaDelle soils in the None-to-Slight category.

## 5.4. SALINIZATION HAZARDS AND THE OUTLET ALTERNATIVES

### 5.4.1. Constructed Outlet Alternatives

Of the three outlet alternatives, the 300 cfs Constrained alternative has the least salinization hazards because operational constraints limit both overbank flooding and stage increases in the Sheyenne River. River stages and overbank flooding would increase under the 480 cfs Alternative causing higher salinization hazards. While the differences appear minor, they may be greater upstream of Lake Ashtabula where the shallow entrenchment of the Sheyenne and the presence of poorly and very poorly drained soils would magnify the effects of even minor increases in overall mean stage.

Stage increases would likely be less important downstream of Baldhill Dam, where the Sheyenne River is deeply entrenched and lacks extensive areas of adjacent poorly and very poorly drained soils. Stage differences between the 380 cfs Constrained and the 480 cfs Unconstrained Outlet alternatives would result in relatively minor increases in-bank stage relative to the watertable.

Similarly, while water quality differences exist between the two constructed outlet alternatives, the differences are not of a sufficient magnitude to substantively affect salinization hazards. Regarding water quality, the salinization hazards associated with the two constructed-outlet alternatives are essentially the same.

### 5.4.2. The No Action (natural spill) Alternative

Salinity and sodicity are much higher under the No Action (natural spill) alternative than the constructed outlet alternatives. However, several potentially offsetting processes or factors obscure the comparison somewhat. The following conclusions have been drawn:

1. Higher salinity/sodicity would result in higher soil salinization hazards in Sheyenne River water as compared to the constructed outlet alternatives.

2. Flow exceedance data indicate that flows under the No Action (natural spill) alternative will approximate base flows. Significant increases in mean stage would not occur and would reduce the salinization hazards of increasing water table elevations on mobilization of existing salts. This effect could minimize salinization hazards, especially

in those portions of the Upper Associations that are downstream of the confluence of the Sheyenne and the Tolna Coulee and have existing saline soils.

3. Even though flow under the No Action (natural spill) alternative approximates base flow, the highly saline blended water would be present in the Sheyenne for the full period that the natural spill is occurring. Spring flooding could result in the inundation of far more floodplain area with saline blended water than would occur under either of the constructed outlet alternatives.

4. Blended water would be present over winter during drawdown periods, minimizing the effects of leaching and flushing of accumulated salts that would typically occur during spring prior to the initiation of pumping under the constructed outlet alternatives. Bank storage events could result in the intrusion of more saline water farther from the river.

5. Under the Wet7 climatic scenario, the natural spill occurs for only approximately 23% of the 45-year plan period and assumes a continuation of pluvial conditions that are well above historic norms. It is unknown whether more intense salinization over a shorter period of time under the No Action (natural spill) alternative would represent a more or less adverse impact versus the less intense salinization over a longer period of time associated with the constructed outlet alternatives.

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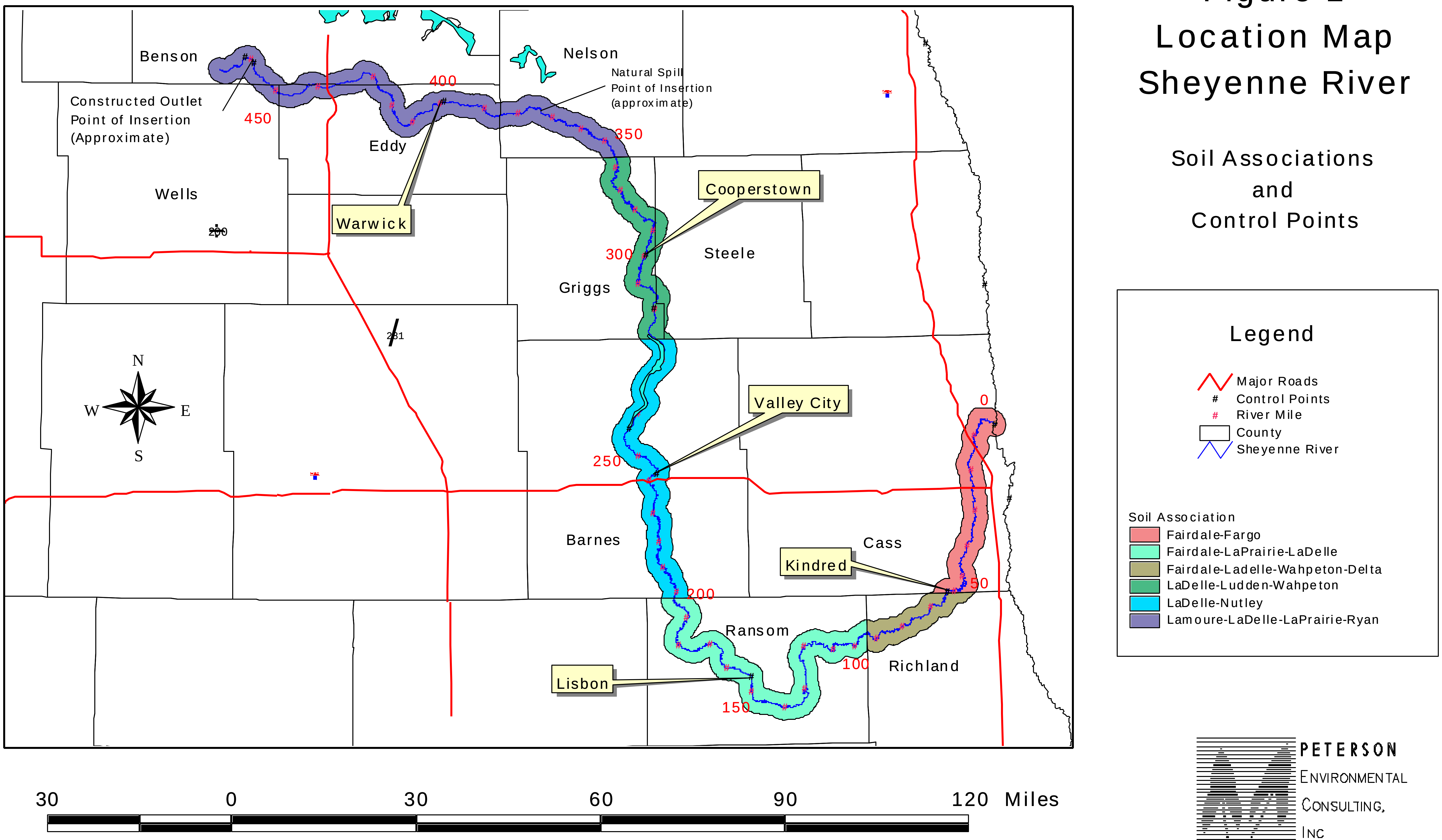
# Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives:

## Sheyenne River Valley

# Report Figures

# Figure 1
# Location Map
# Sheyenne River

## Soil Associations and Control Points



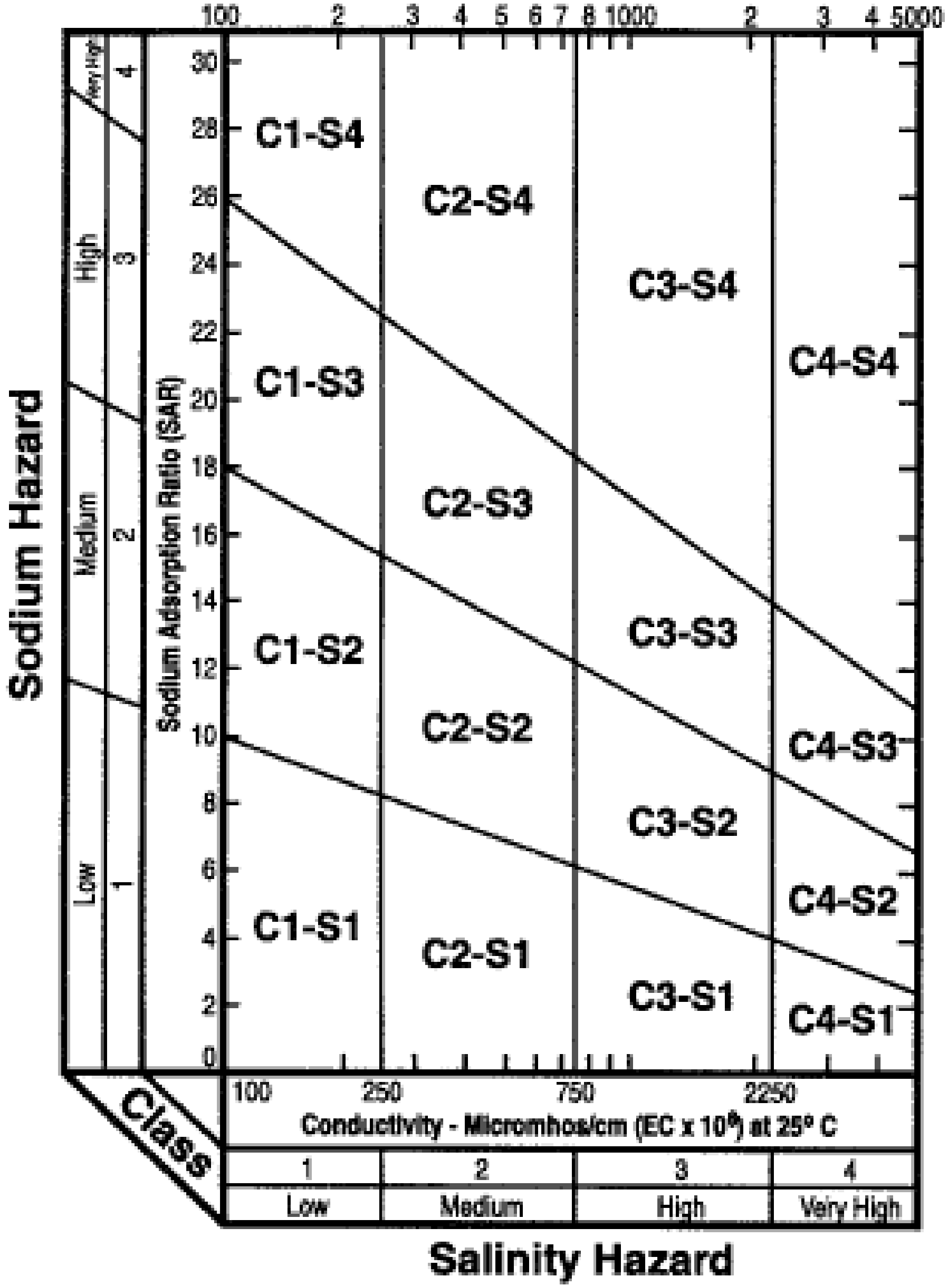



Figure 2. Classification of irrigation water (from Agriculture Handbook No. 60, USDA Salinity Laboratory, Riverside, CA).

Low meander in shallowly entrenched portion of the Sheyenne River. Adjacent soils are poorly drained Lamoure, Ryan, and LaDelle soils characteristic of the adjacent floodplain of this reach.

# Shallowly Entrenched Meander, Upper Reach

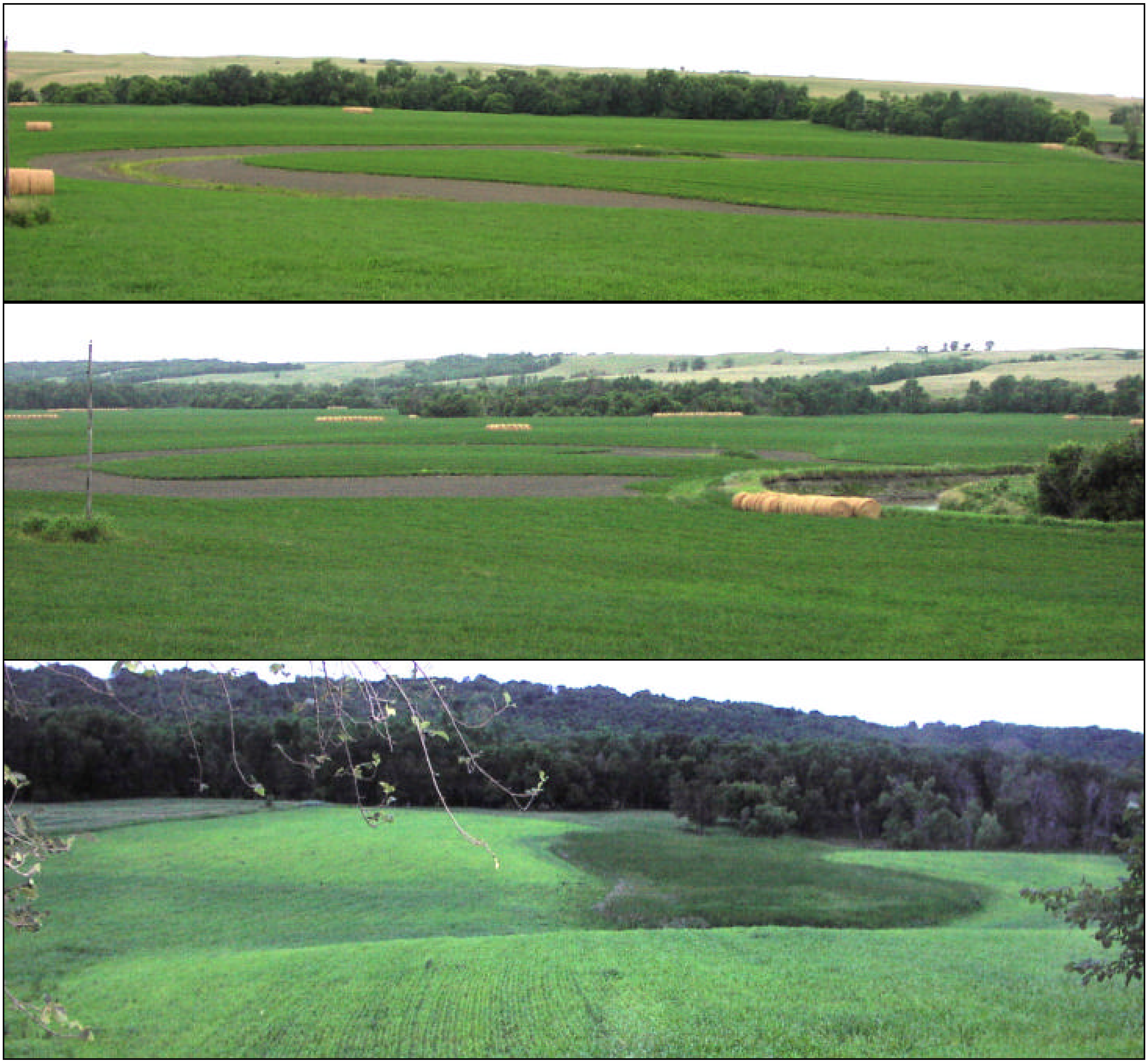
**Devils Lake Salinity Study: Sheyenne River**
**Eddy County, North Dakota**

**N**

**FIGURE 3**

PETERSON ENVIRONMENTAL CONSULTING, INC.

PEC Project No. 2001-026



Abandoned meanders in Channeled Fairdale/LaDelle soil Map Unit. Note proximity of Sheyenne River in middle and lower pictures. Rauville/Lamoure soils occur as inclusions within the meanders.

# Abandoned Meanders, Till Plain Reach

**Devils Lake Salinity Study: Sheyenne River**
**Barnes and Ransom Counties, North Dakota**

**N**

**FIGURE 4**

PETERSON ENVIRONMENTAL CONSULTING, INC.

PEC Project No. 2001-026

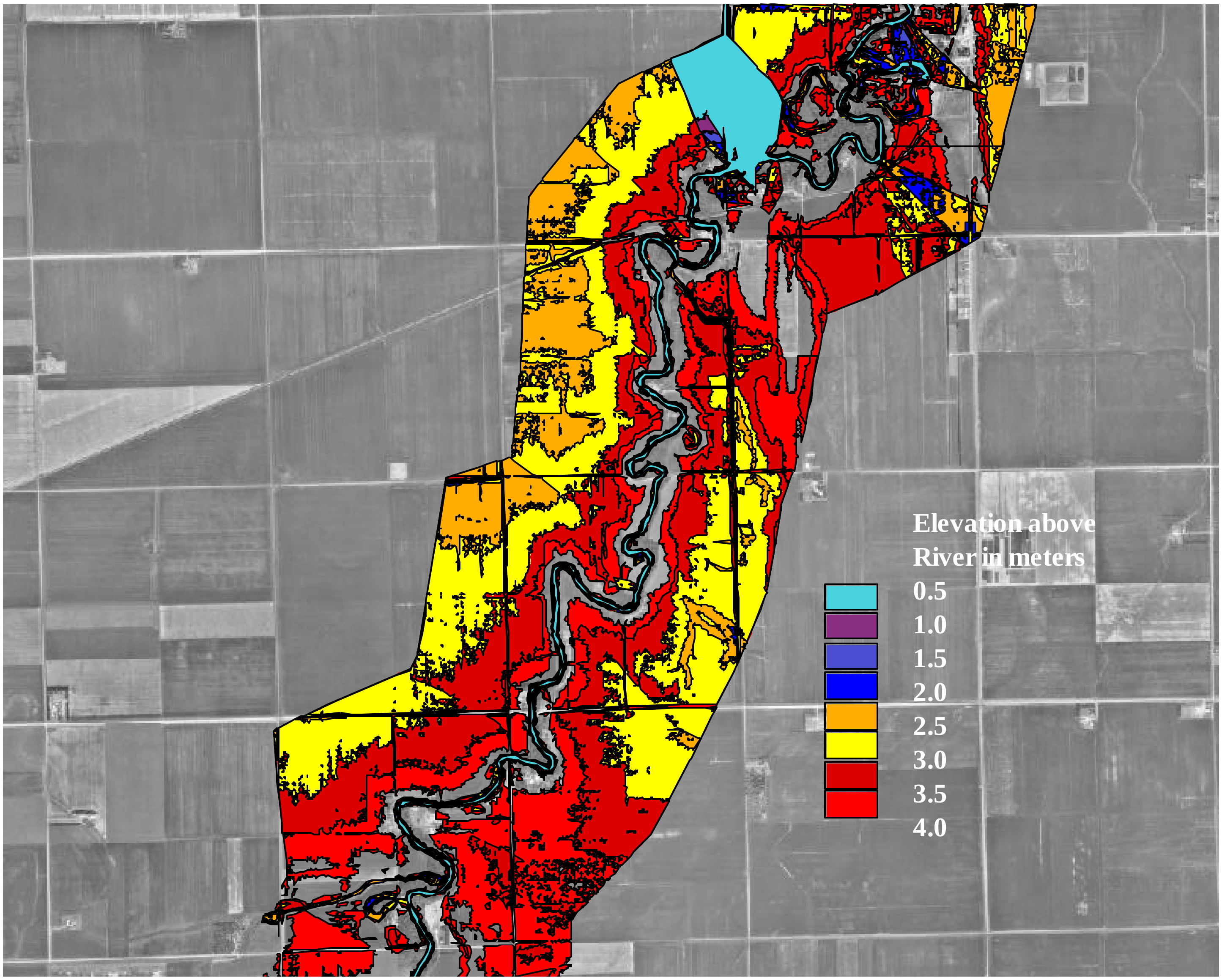
Saline spot near transition from the Sheyenne Delta to the Lake Agassiz Plain. Photo taken approximately 5 miles from Sheyenne River. Salt deposits result from discharge of groundwater at the base of the Sheyenne Delta.

# Saline Soils, Transition between Sheyenne Delta and Lake Agassiz Plain

**Devils Lake Salinity Study: Sheyenne River**
**Richland County, North Dakota**

N

**FIGURE 5**




Manipulation of Lidar elevation data to show natural levees along the Sheyenne River. River elevations were raised in 0.5-meter increments creating polygons representing flooded area outlines at the buffer elevations. Note the area immediately adjacent to the river is not flooded even at + 4.0 meters above the river' s elevation at the time the Lidar data was collected. The blue area at the top of the picture is an error in river placement where the river line feature provided by the USACE did not overlap exactly with the Lidar data for the river.

# Natural Levees Adjacent to the Sheyenne River on the Lake Agassiz Plain

## Devils Lake Salinity Study: Sheyenne River
## Cass County, North Dakota

N

**FIGURE 6**

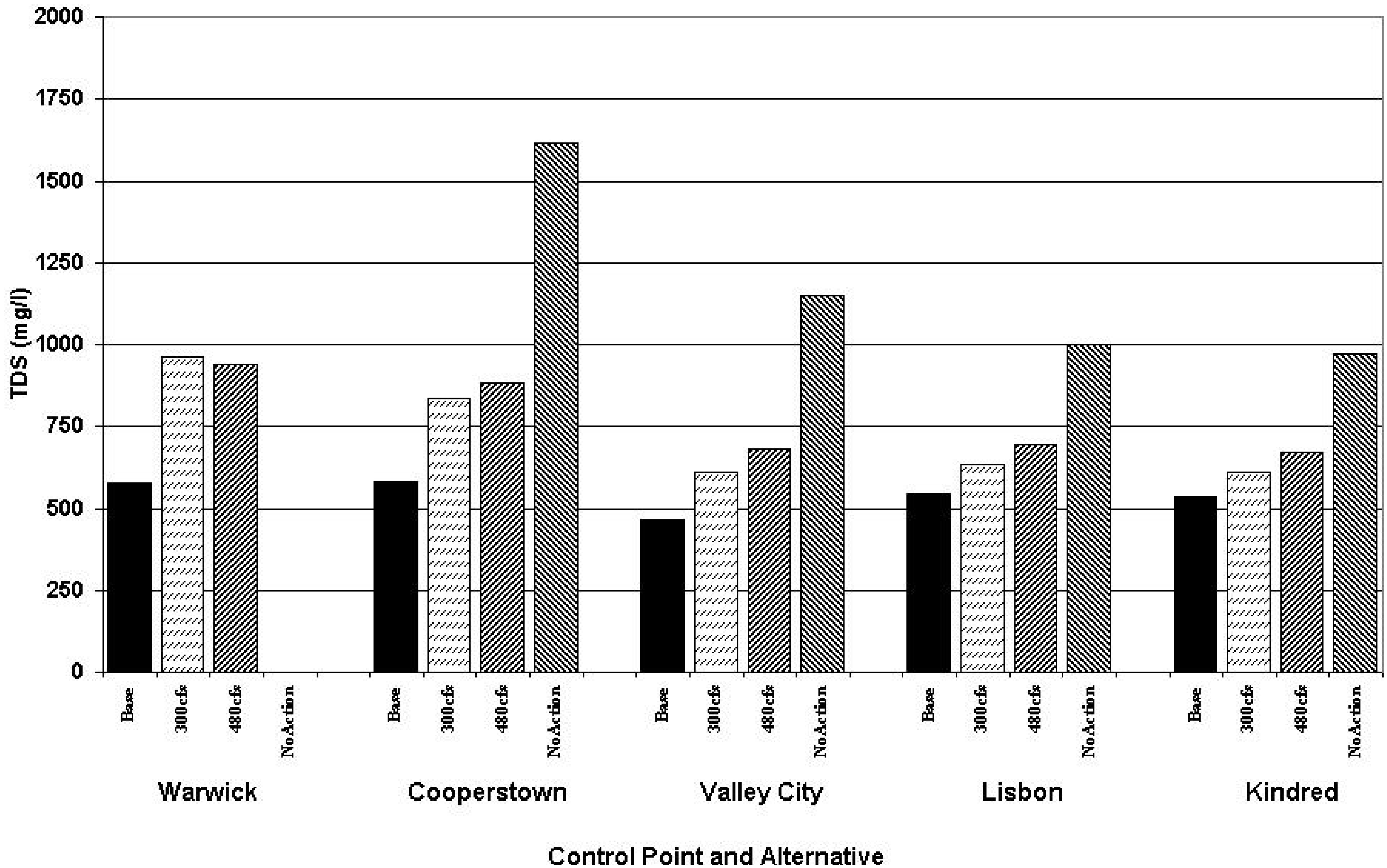



Figure 7. Mean TDS values for base conditions and blended water only by outlet alternative and control point. Base conditions include all samples. Outlet alternatives were restricted to the Blended Water Only dataset (baseflow conditions removed).

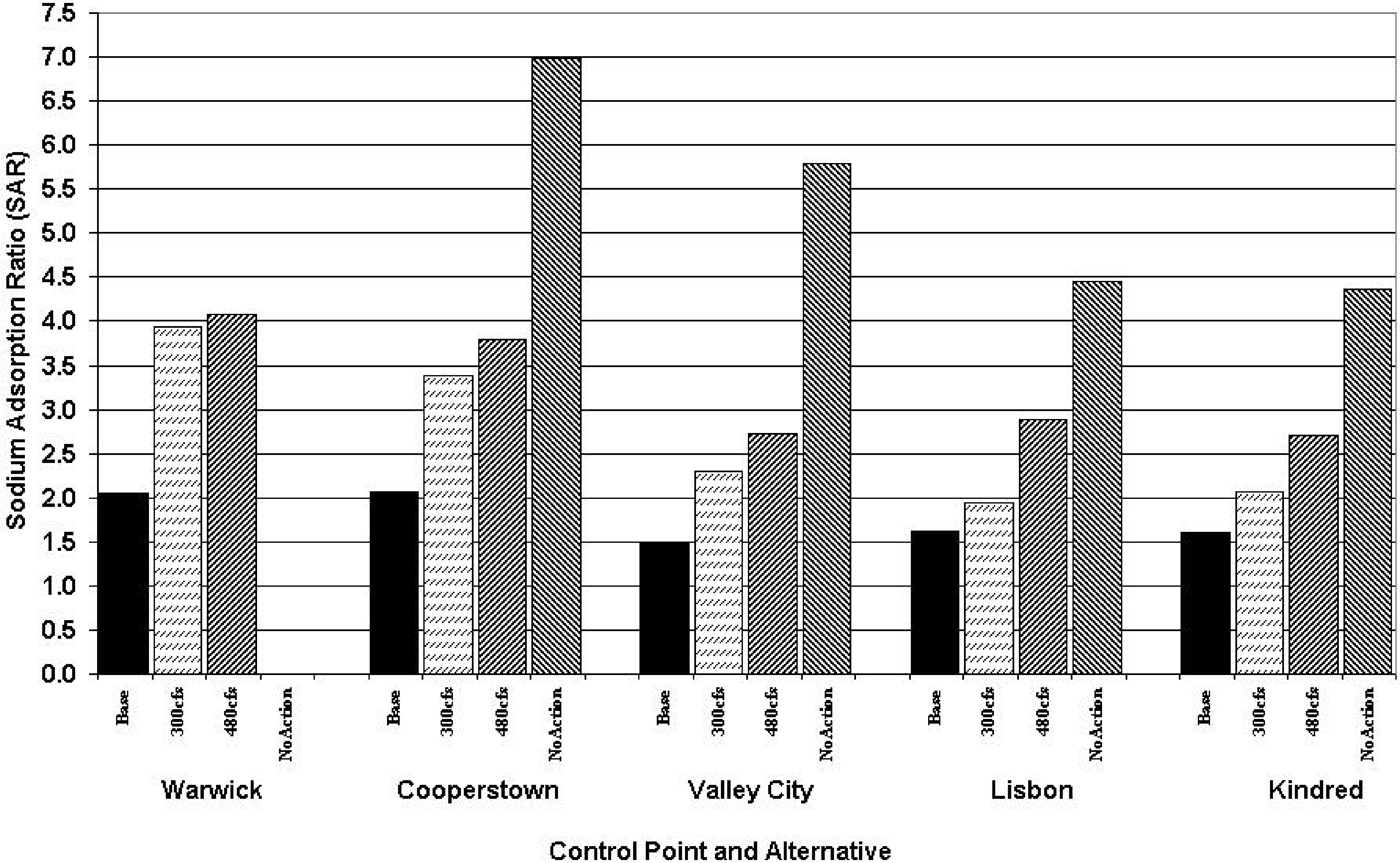



Figure 8. Mean SAR values for base conditions and blended water only by outlet alternative and control point. Base conditions include all samples. Outlet alternatives were restricted to the Blended Water Only dataset (Baseflow conditions removed).

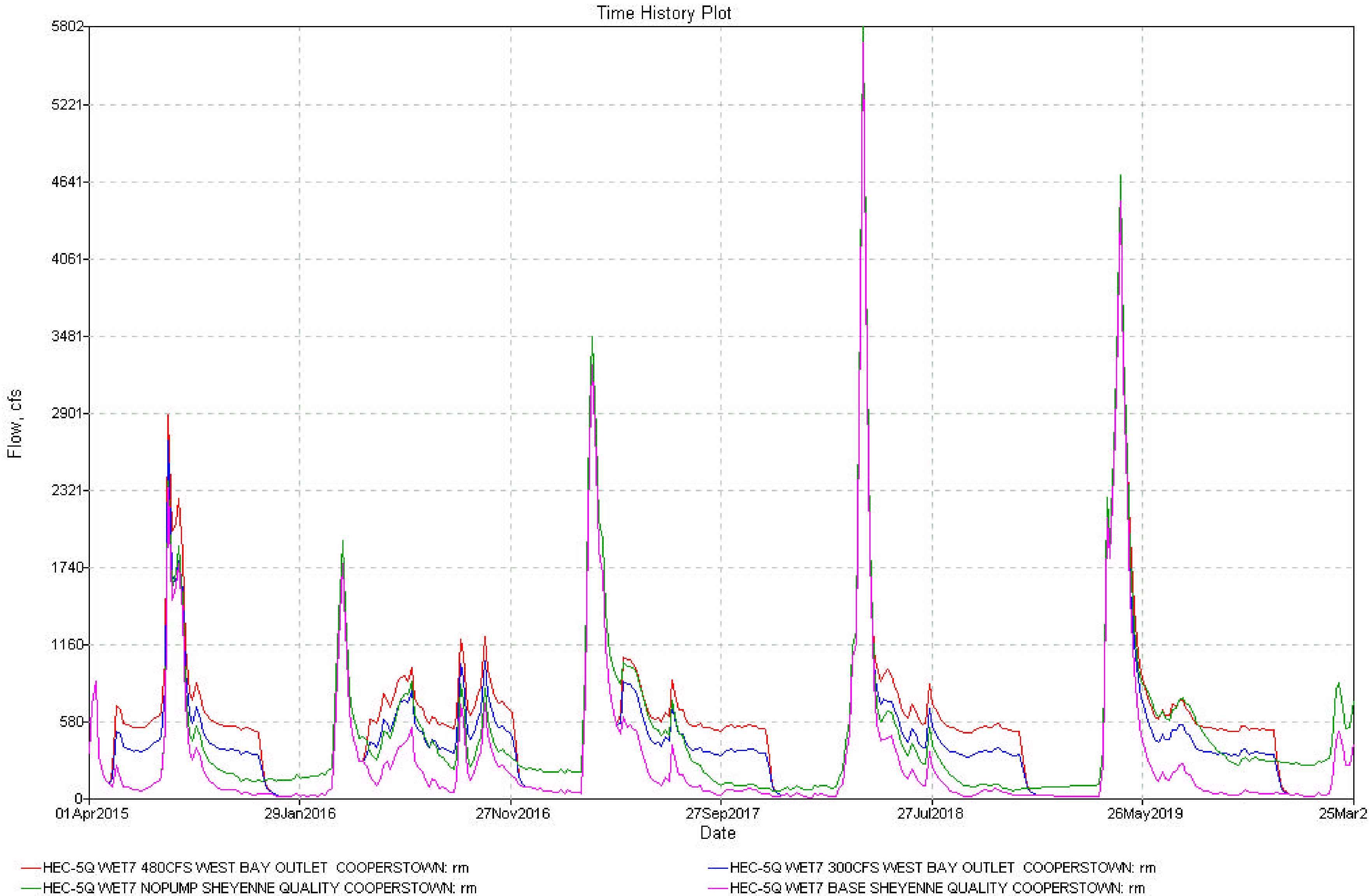



Figure 9. HEC5Q GUI predicted flow (Wet7 climatic scenario) near Cooperstown for the period beginning April 1, 2015 and extending through April 1, 2020.

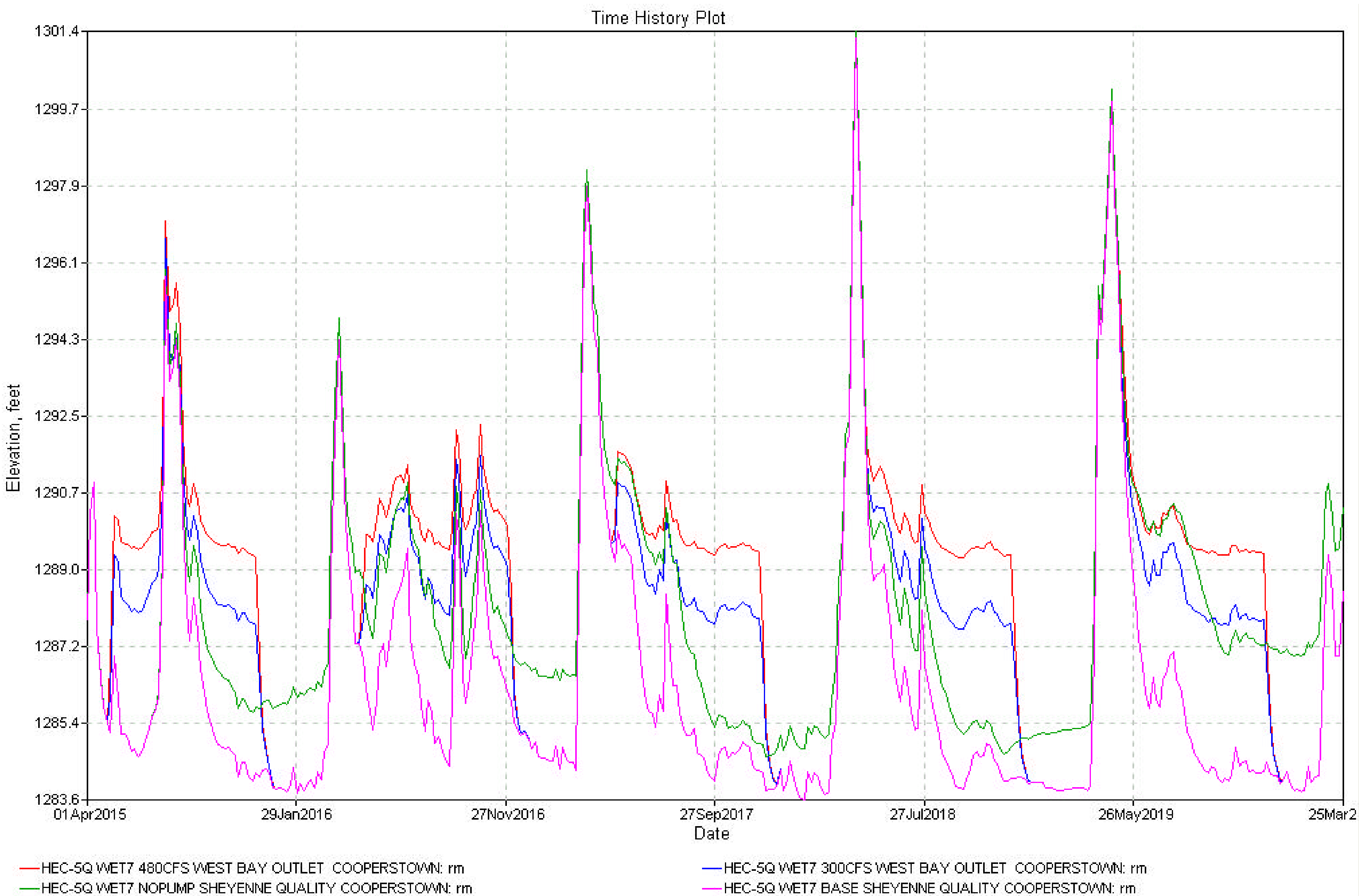



Figure 10. HEC5Q GUI predicted stage (Wet7 climatic scenario) near Cooperstown for the period beginning April 1, 2015 and extending through April 1, 2020.

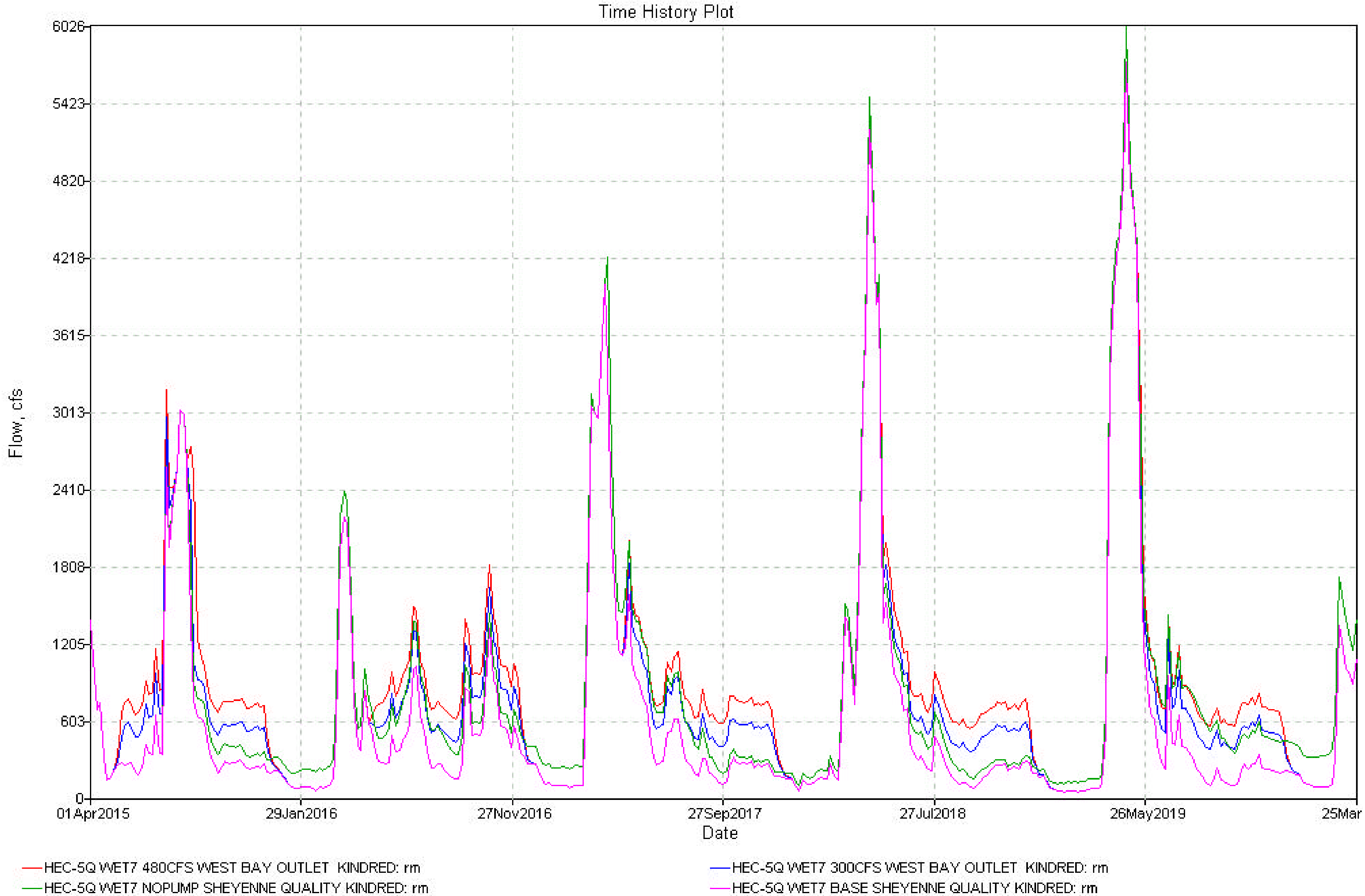



Figure 11. HEC5Q GUI predicted flow (Wet7 climatic scenario) near Kindred for the period beginning April 1, 2015 and extending through April 1, 2020.

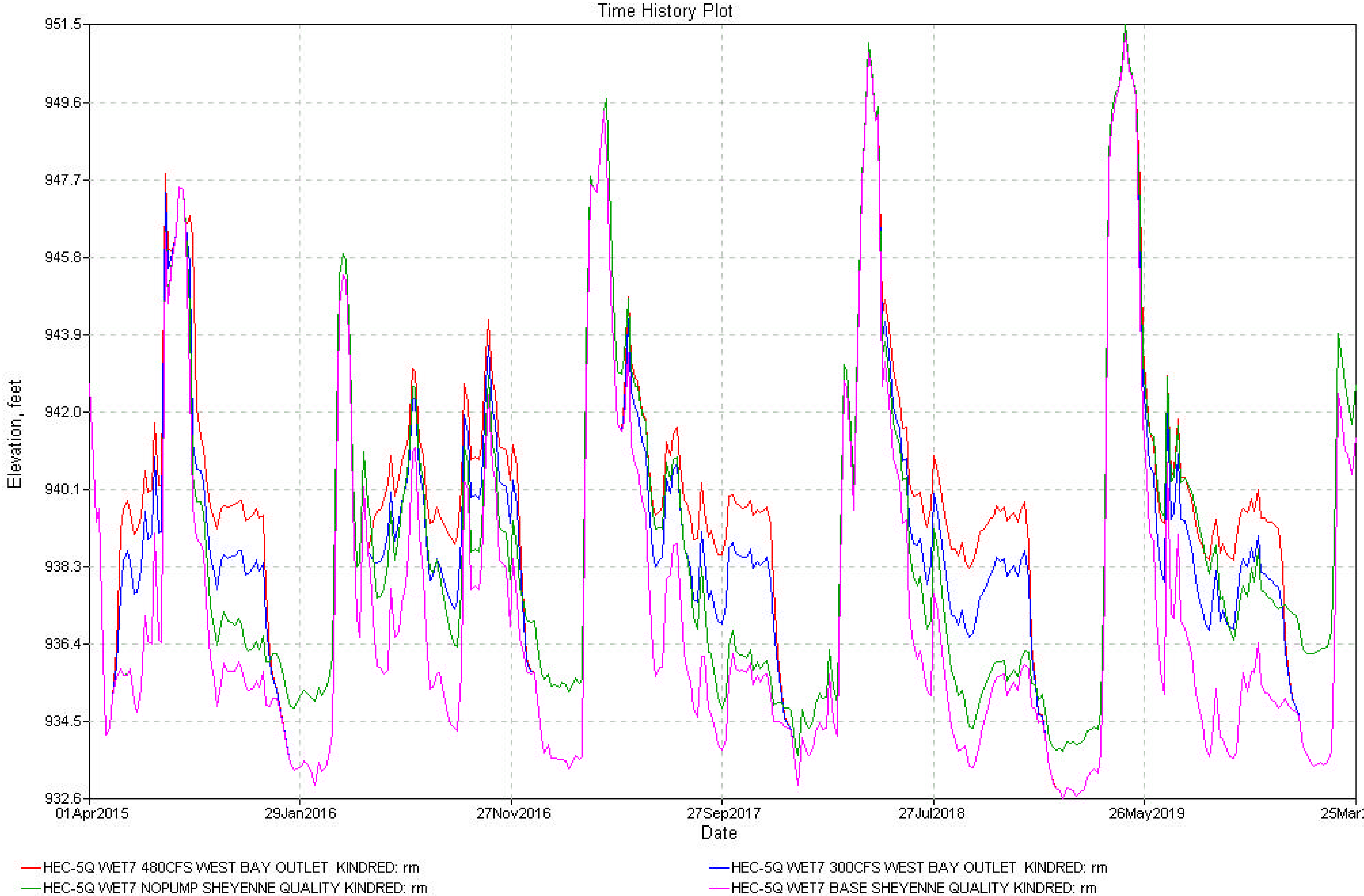
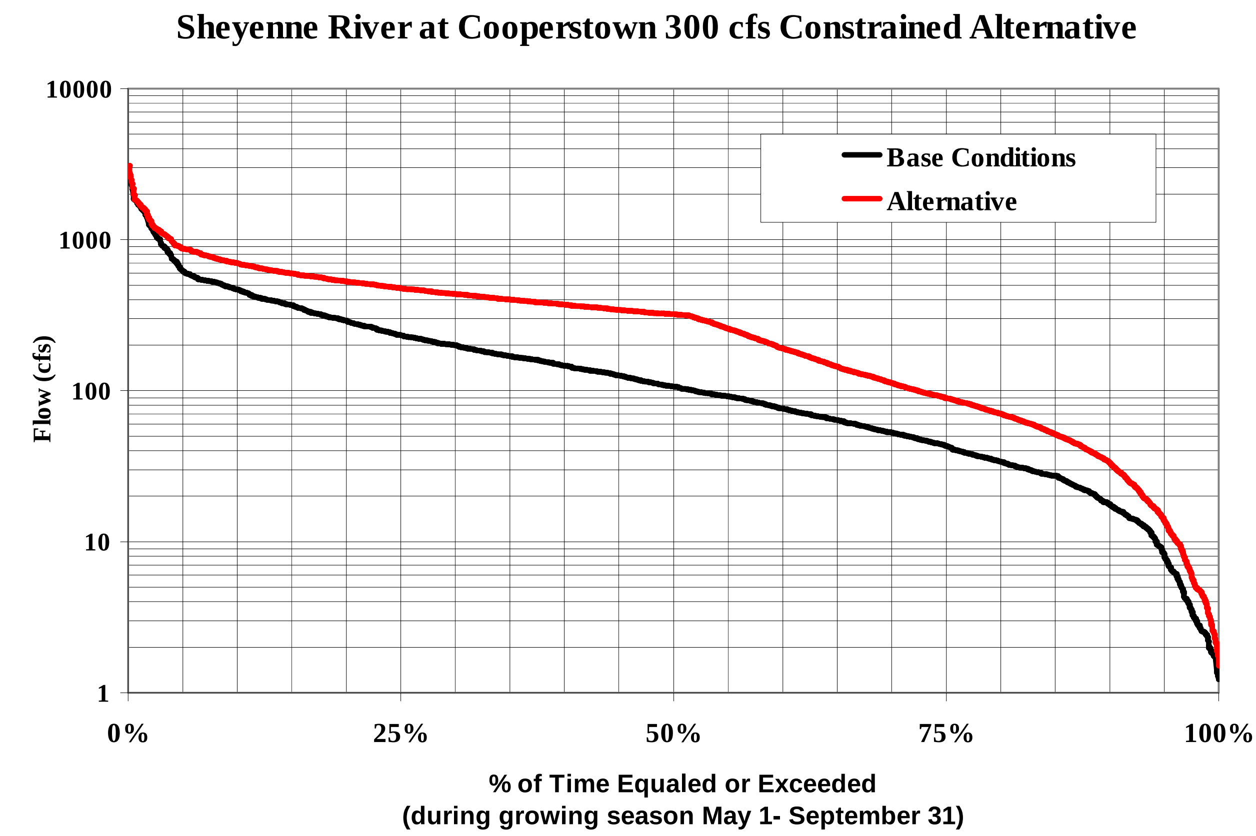
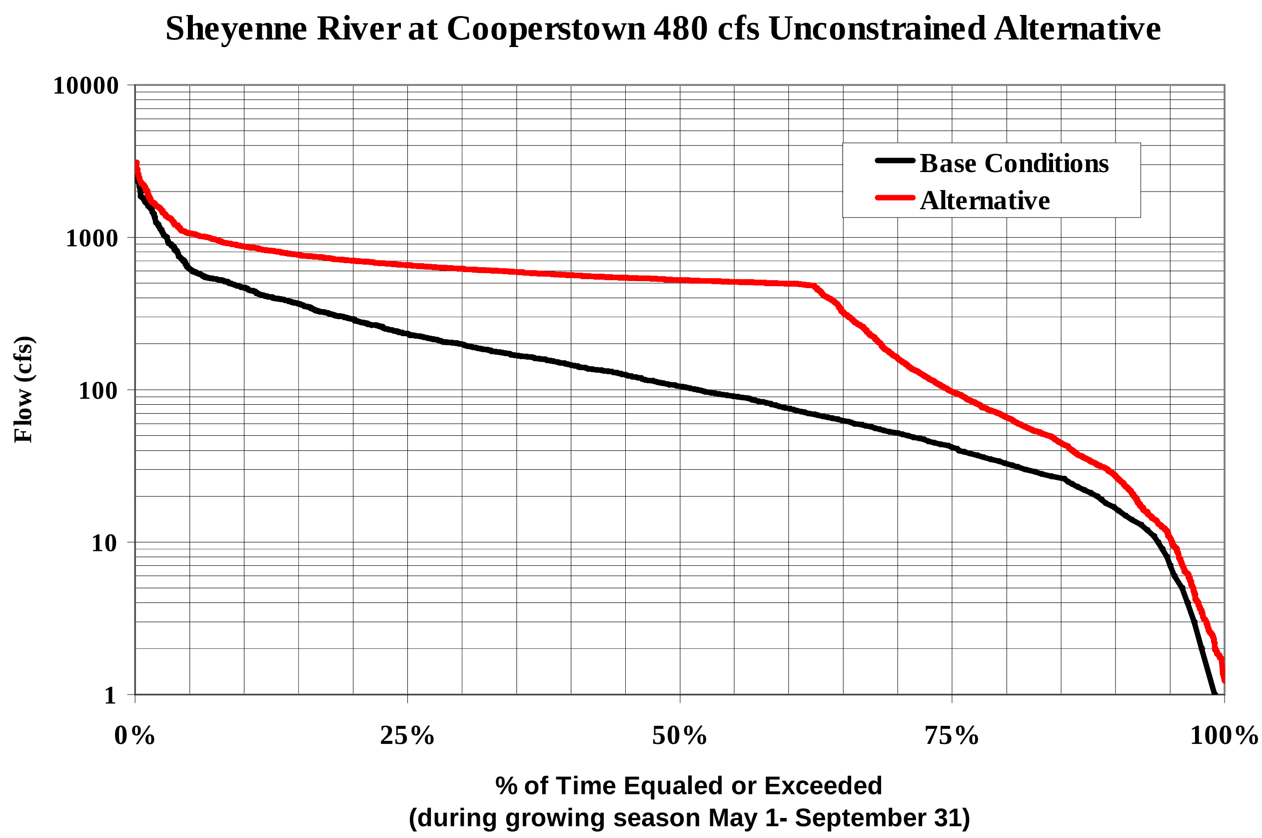


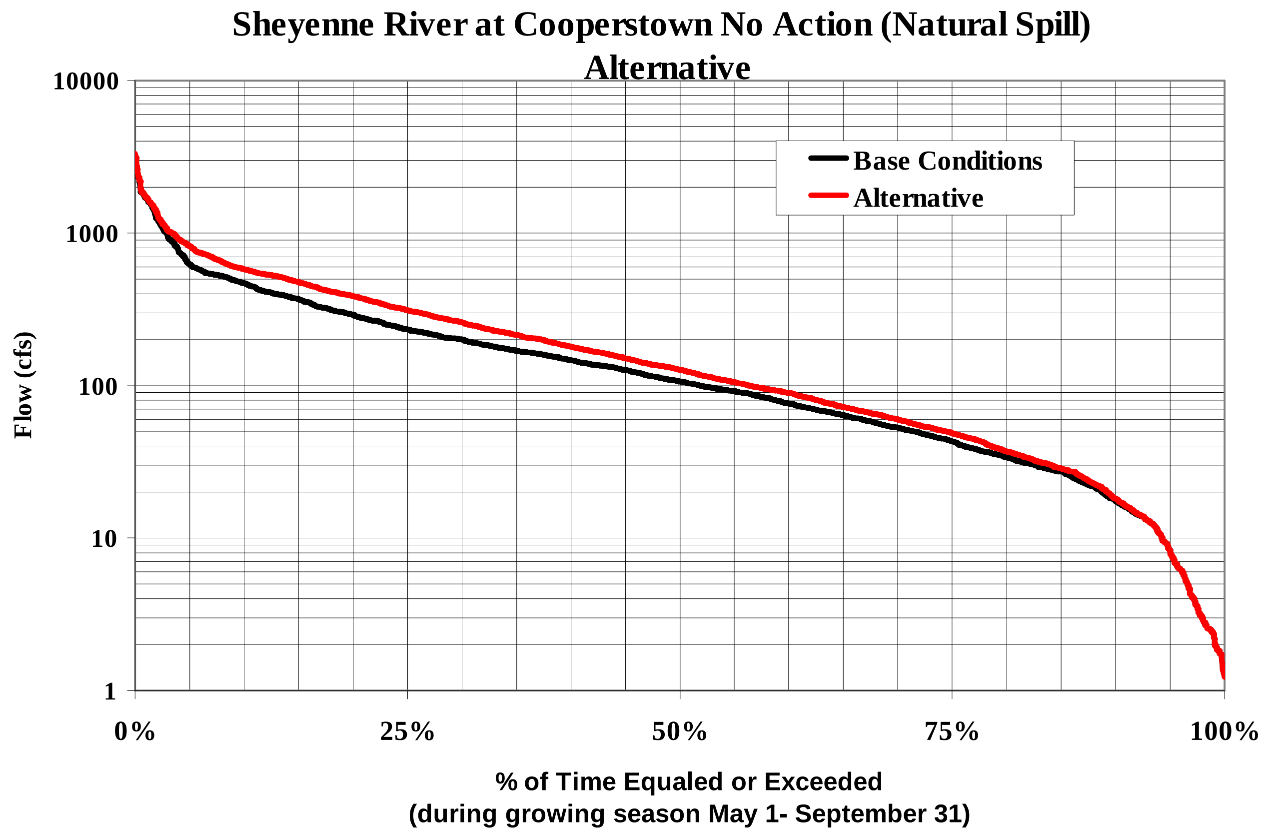

Figure 12. HEC5Q GUI predicted stage (Wet7 climatic scenario) near Kindred for the period beginning April 1, 2015 and extending through April 1, 2020.




(A)



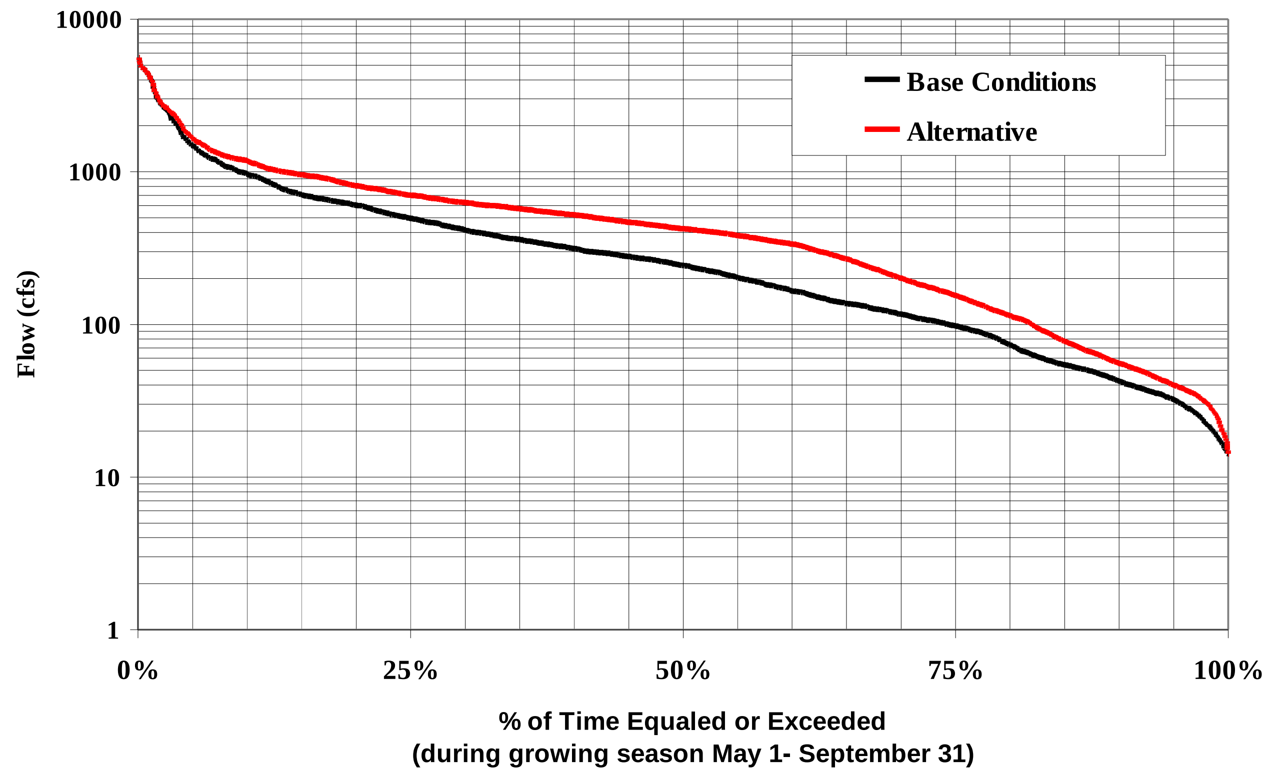

(B)




(C)

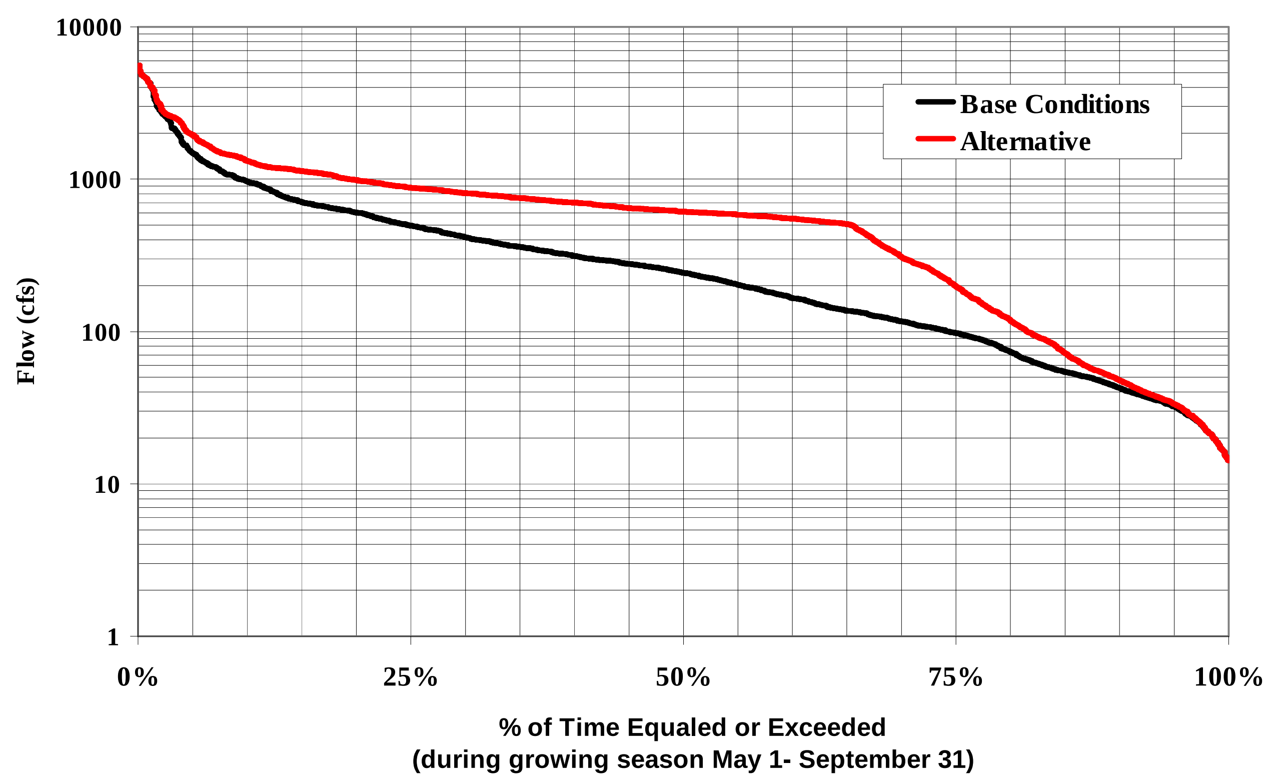
Figure 13. Percent exceedance flow graphs for the 300 cfs Constrained (A), the 480 cfs Unconstrained (B), and the No Action (Natural Spill) Alternative (C), Cooperstown Control Point, Wet7 climatic scenario. Note that the 480 Unconstrained Scenario has the highest overall flow rates of the three outlet alternatives.

Sheyenne River at Kindred 300 cfs Constrained Alternative



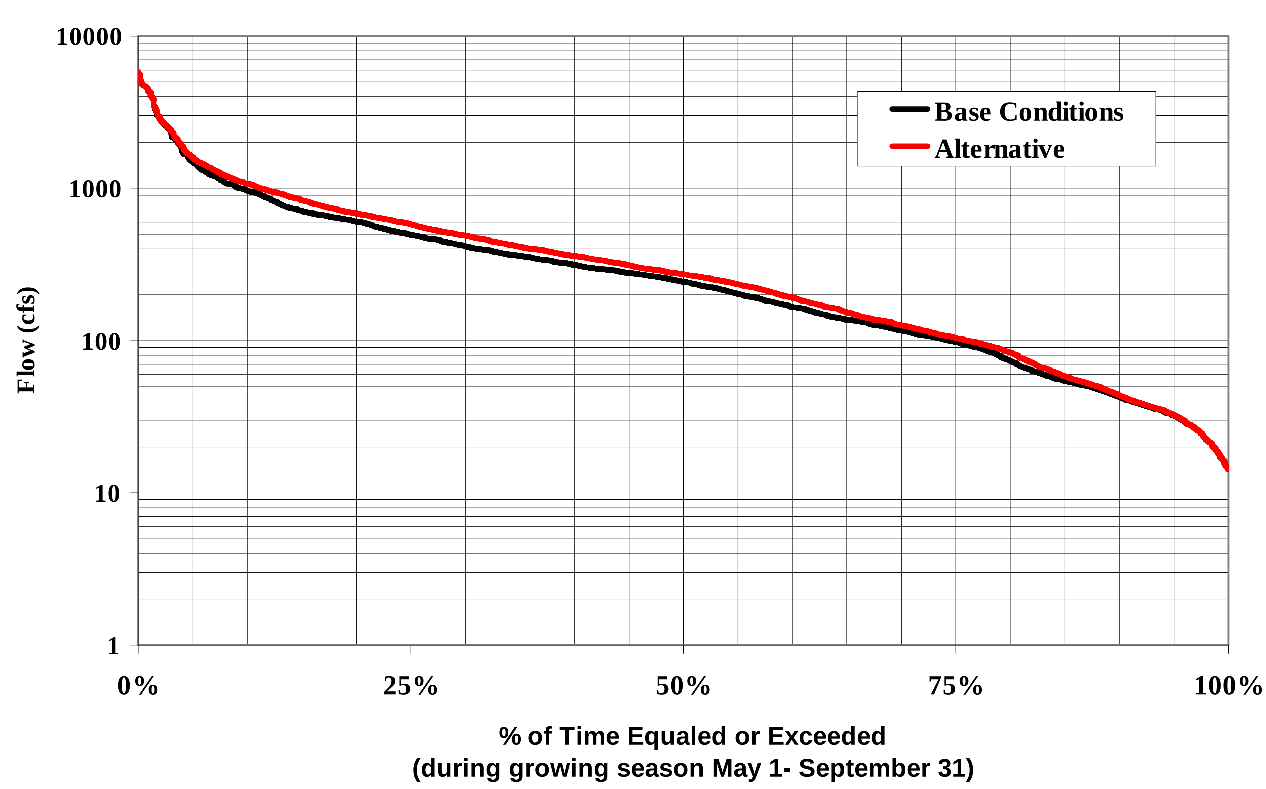

(A)

Sheyenne River at Kindred 480 cfs UnConstrained Alternative



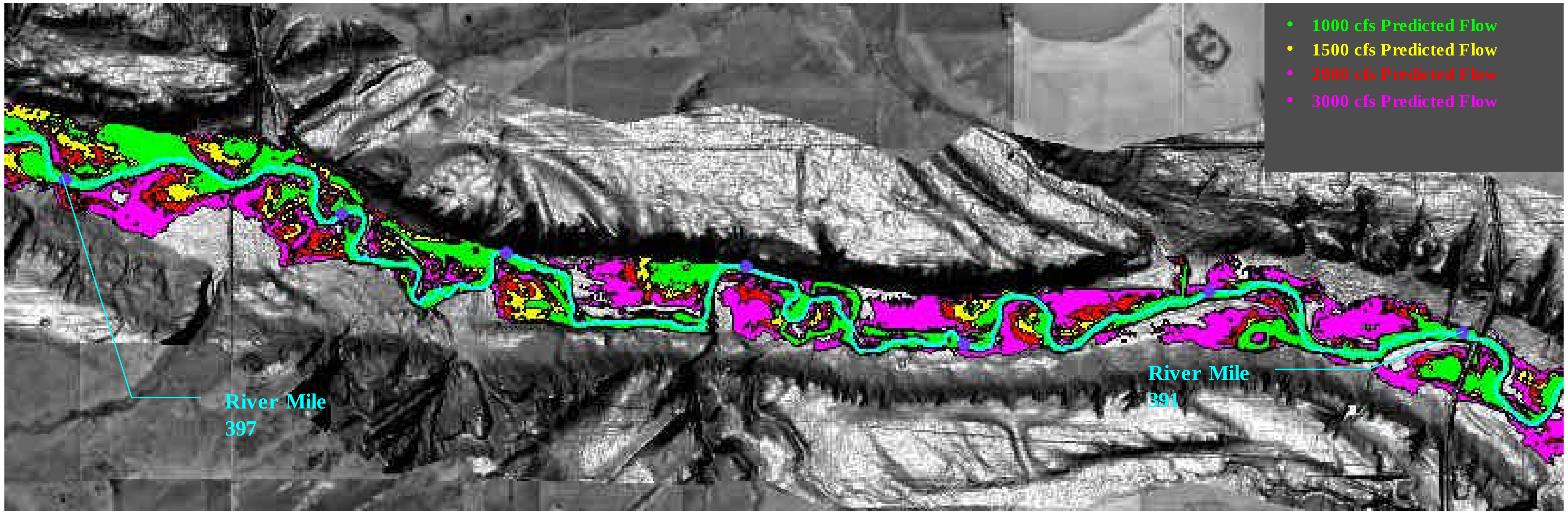

(B)

Sheyenne River at Kindred No Action (Natural Spill) Alternative

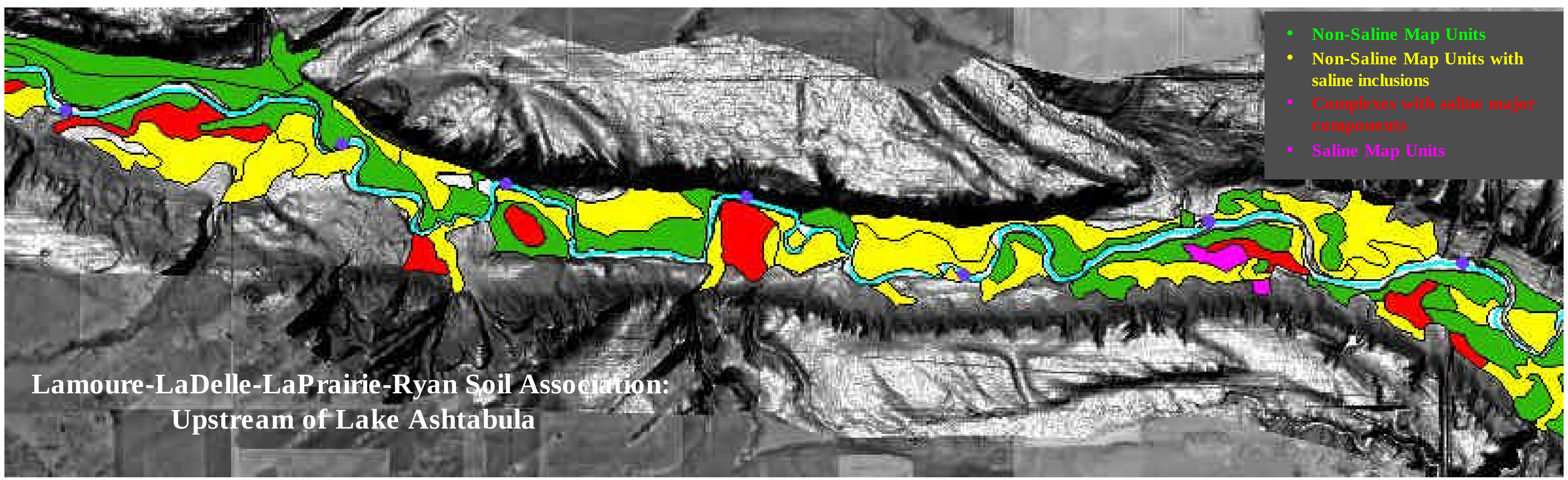



(C)

Figure 14. Percent exceedance flow graphs for the 300 cfs Constrained (A), the 480 cfs Unconstrained (B), and the No Action (Natural Spill) Alternative (C), Kindred Control Point, Wet7 climatic scenario. Note that the 480 Unconstrained Scenario has the highest overall flow rates of the three outlet alternatives.



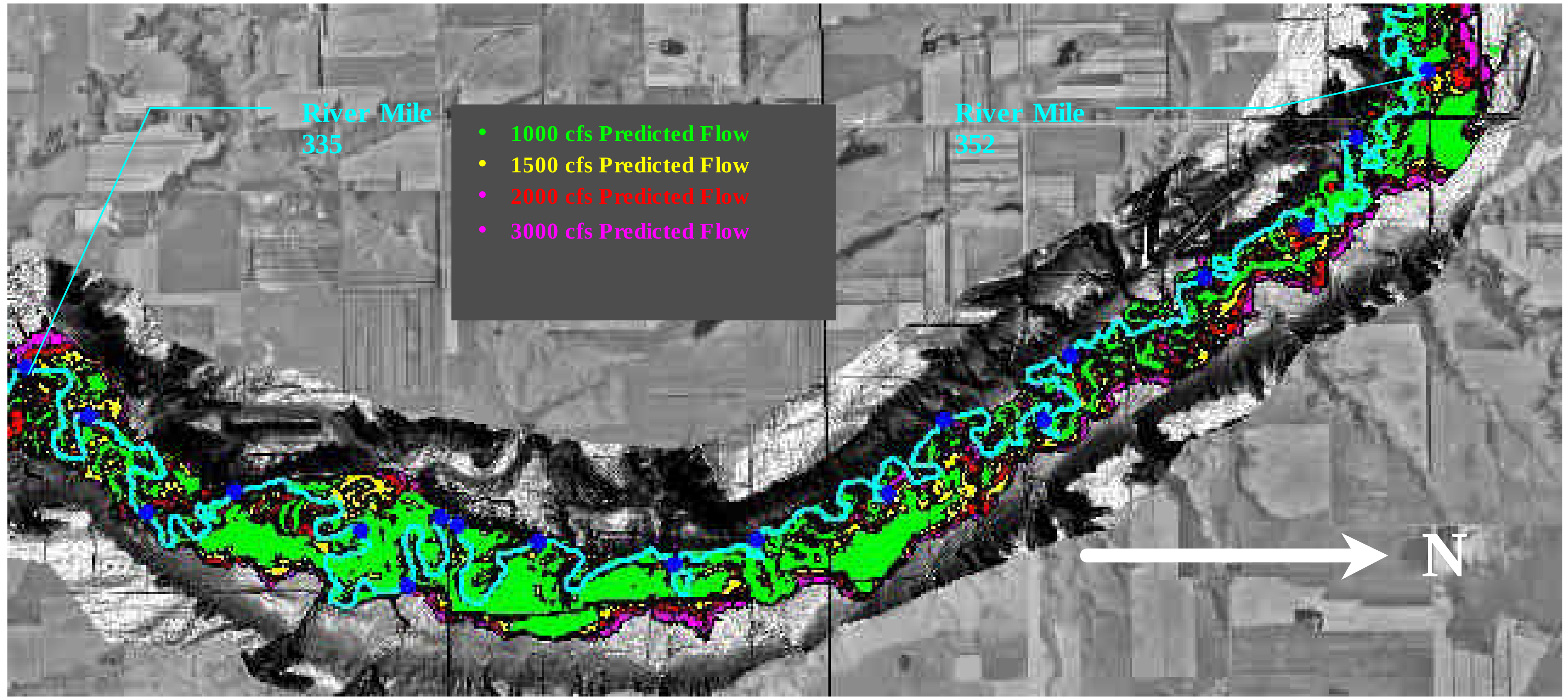

(A) HEC-RAS predicted flow for the portion of the upper reach of the Sheyenne beginning at river mile 397 and extending to river mile 391. Extensive overbank flooding occurs at 1000 cfs. At 3000 cfs flooding covers virtually the entire valley floor. Note patterns in distribution of saline soils with elevations inferred by flow rates.




(B) Characteristic soil distribution in the shallowly entrenched upper reach. Note predominance of soil map units that are either saline (magenta), contain major components that are saline (red) or that contain saline inclusions (yellow). Non-saline units (green) are typically associated with levee positions next to river. Soil salinization associated with this portion of the river is high. Soils in green are predominantly LaDelle, LaPrairie, and Rauville soils.

**Figure 15**. HEC RAS predicted flooded area outlines compared to the listed saline composition of soil map units. The 1000 cfs flow value has been indicated by the St. Paul District, USACE as the "normal" flood stage for this portion of the Sheyenne River. Considerable overbank flooding at 1000 cfs is indicated in this low relief portion of the upper reach of the Sheyenne River. Basemaps are hillshaded Lidar DEMs overlaid onto MrSID ortho-rectified aerial photography.

(A) HEC-RAS predicted flow for the upper portion of the Sheyenne beginning at river mile 335 and extending to river mile 352. Extensive overbank flooding occurs at 1000 cfs, and much of the valley is flooded at the 3000 cfs flow.




(B) Characteristic soil distribution in the shallowly entrenched upper reach. Note the saline map units (magenta) and map units with major saline components (red). Map units with saline inclusions are confined to meanders and backswamp/low positions. Natural salinity associated with this portion of the upper reach is fairly high. Most of the yellow units are Ludden soils that have high subsoil salinity.

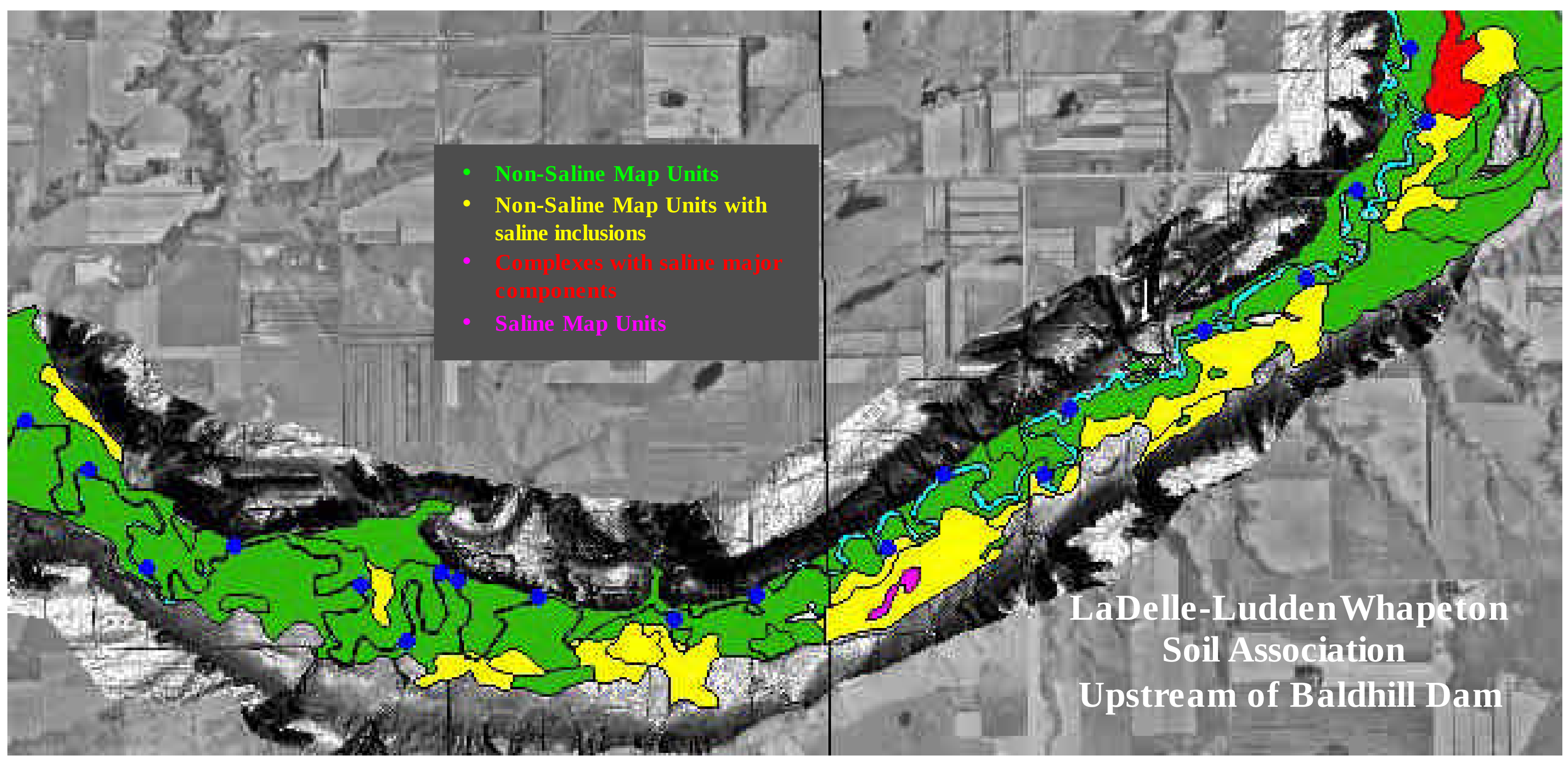
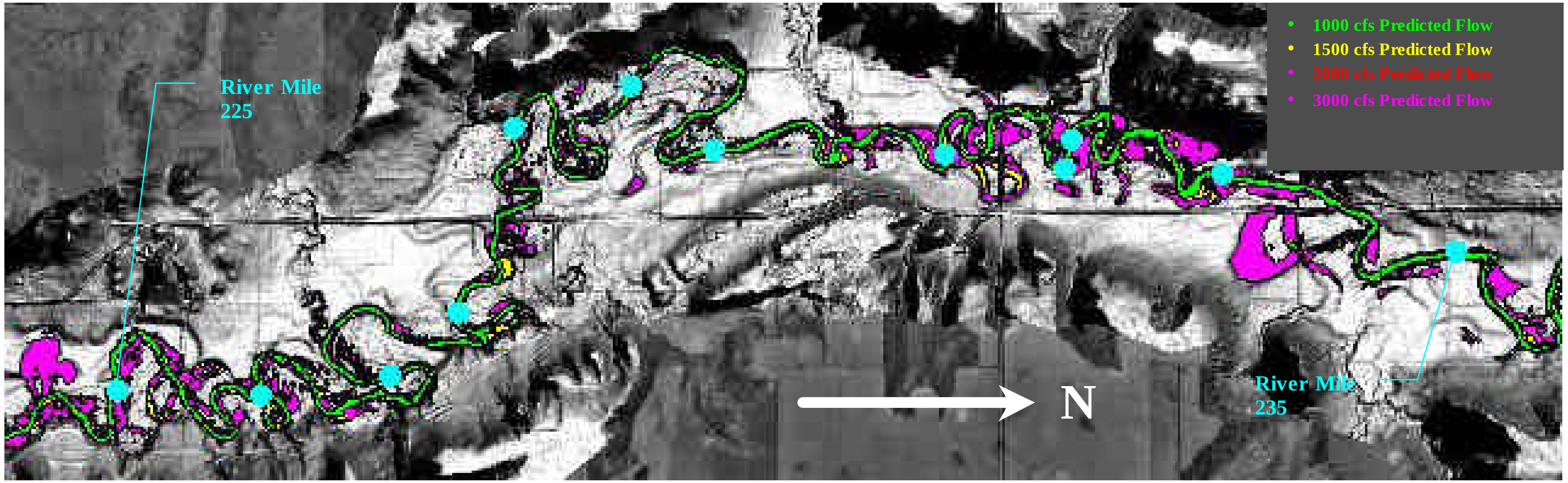
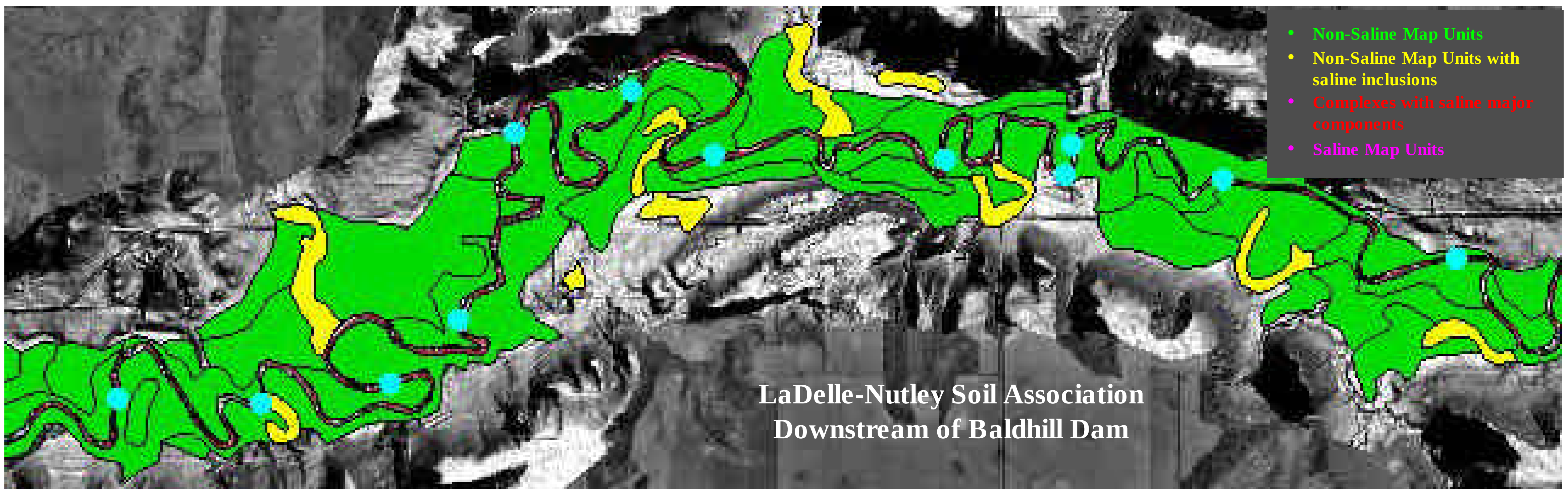



**Figure 16**. HEC RAS predicted flooded area outlines compared to the listed saline composition of soil map units for the portion of the Sheyenne River extending from river mile 352 to river mile 335. The 1000 cfs flow value has been indicated by the St. Paul District, USACE as the "normal" flood stage for this portion of the of the Sheyenne River. Considerable overbank flooding at 1000 cfs is indicated in this low relief portion of the upper reach of the Sheyenne River. Basemaps are hillshaded Lidar DEMs overlaid onto MrSID ortho-rectified aerial photography.

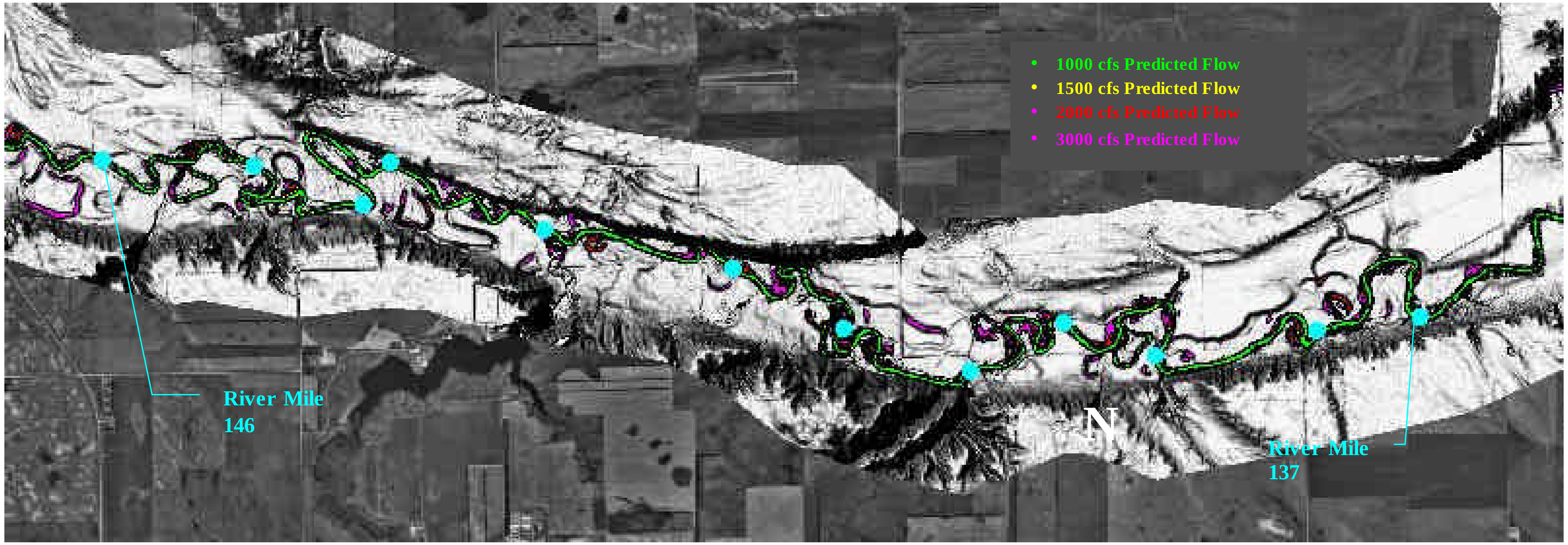



(A) HEC-RAS predicted flow for the lower reach of the Sheyenne beginning at river mile 225 and extending to river mile 235. Limited overbank flooding occurs at 1000 cfs. At 3000 cfs, virtually the entire flow is confined to the channel and a few abandoned meanders.

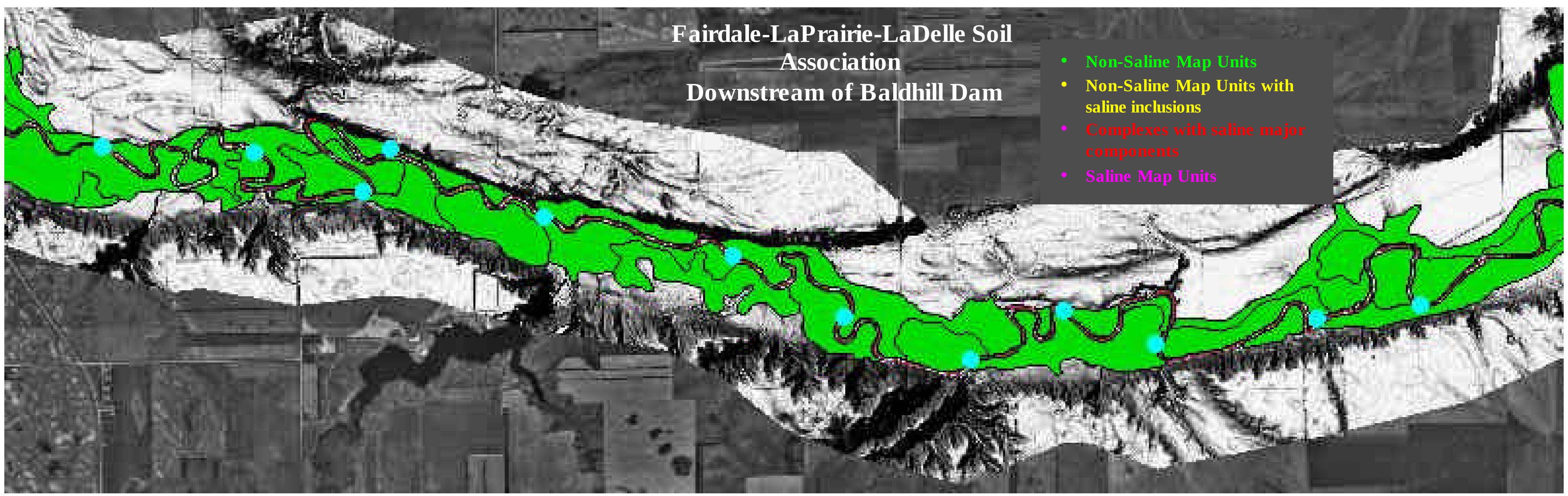



(B) Characteristic soil distribution in the deeply entrenched lower reach. Note the complete lack of saline map units and map units with major saline components. Map units with saline inclusions (yellow) are confined to meanders and tributary inflow areas. Natural salinity associated with the lower reach of the river is low.

**Figure 17**. HEC RAS predicted flooded area outlines compared to the listed saline composition of soil map units for the lower reach of the Sheyenne River. Note that the 1500 cfs flow value has been indicated by the St. Paul District, USACE as the "normal" flood stage for the lower portions of the Sheyenne River. Limited overbank flooding is expected in the lower reaches of the river. Basemaps are hillshaded Lidar DEMs overlaid onto MrSid ortho-rectified aerial photography.

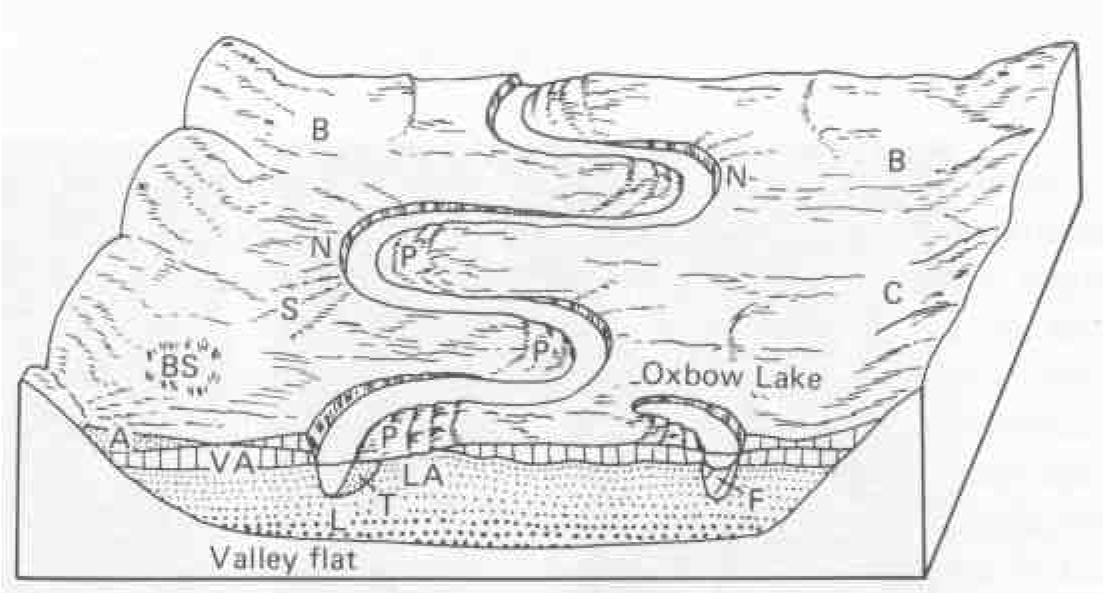



(A) HEC-RAS predicted flow for the Lower reach of the SHeyenne beginning at river mile 146 and extending to rivermile 147. Limited overbank flooding occurs at 1000 cfs. At 3000 cfs virtually the entire flow is confined to the channel and a few abandoned meanders. Note the lack of saline soils.




(B) Characteristic soil distribution in the deeply entrenched lower reach. Note the complete lack of saline map units, map units with major saline components, and map units with saline inclusions. Natural salinity associated with the lower reach of the river is low. Soils are predominently LaDelle and Fairdale series

**Figure 18**. HEC RAS predicted flooded area outlines compared to the listed saline composition of soil map units for the lower reach of the Sheyenne River. Note that the 1500 cfs flow value has been indicated by the St. Paul District, USACE as the "normal" flood stage for the lower portions of the Sheyenne River. Limited overbank flooding is expected in the lower reaches of the river. Basemaps are hillshaded Lidar DEMs overlaid onto MrSid ortho-rectified photography.




## Legend

| Landform | Discussion |
|---|---|
| P – Point Bar | The series of ascending point bars in the figure represents "Channeled Soils" as identified in several Soil Surveys. These soils would typically be poorly developed "Fluvents." |
| N – Natural Levee | The natural levees are frequently the highest elevation landform on the active floodplain. Vertical accretion deposits on and behind the natural levee are the active floodplain. |
| BS – Backswamp | Backswamp positions are low areas dominated by very poorly drained and poorly drained soils. Water levels are usually closely tied to flooding events and river stage. Lamoure, Ludden, and Ryan are typical backswamp soils |
| S – Splay | A landform where flooding breaks out of the Natural Levees. |
| C – Colluvium | Sediments eroded from the valley side-wall, usually accumulated by gravity fall. |
| LA – Lateral Accretion (Point Bars) | Sediments that are deposited laterally as point bars accrete |
| VA – Vertical Accretion (Overbank Floodplain) | Vertical accretion is how floodplains are built by the deposition of sediments suspended in overbank flow. |
| F – Channel Fill | Abandoned meanders and oxbow lakes fill in gradually with fine-textured sediments deposited from floodwater and from runoff. |
| B – Backland (terraces) | In the figure "backland" refers to terraces above the active floodplain. These terraces flood far less frequently than the active floodplain, and may have well developed soils associated with them. |

**Floodplain geomorphology**

**Devils Lake Salinity Study: Sheyenne River**

**Eddy County, North Dakota**

Adapted from Bloom, 1978

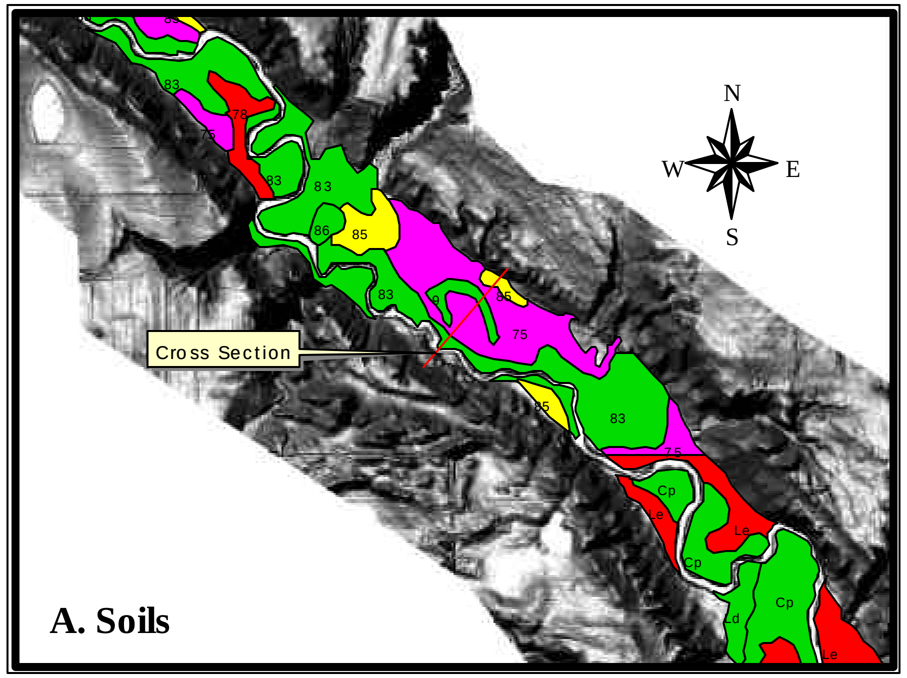
**FIGURE 19**

PETERSON ENVIRONMENTAL CONSULTING, INC.

PEC Project No. 2001-036

# Figure 20

## Devils Lake Salinity: Sheyenne Valley
## Lamoure-LaDelle-LaPrairie-Ryan Soil Association

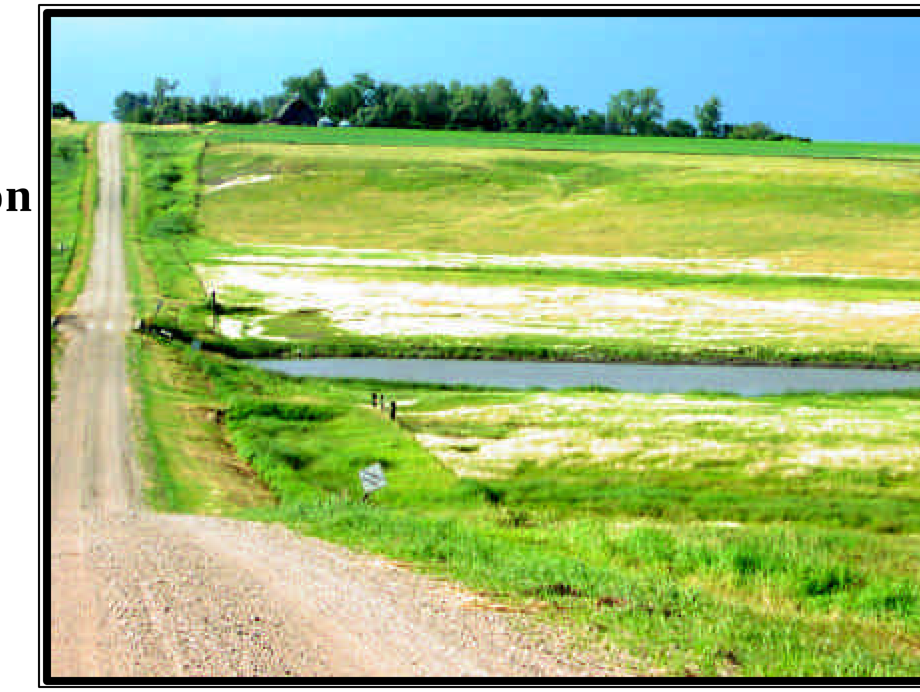



A. Soils

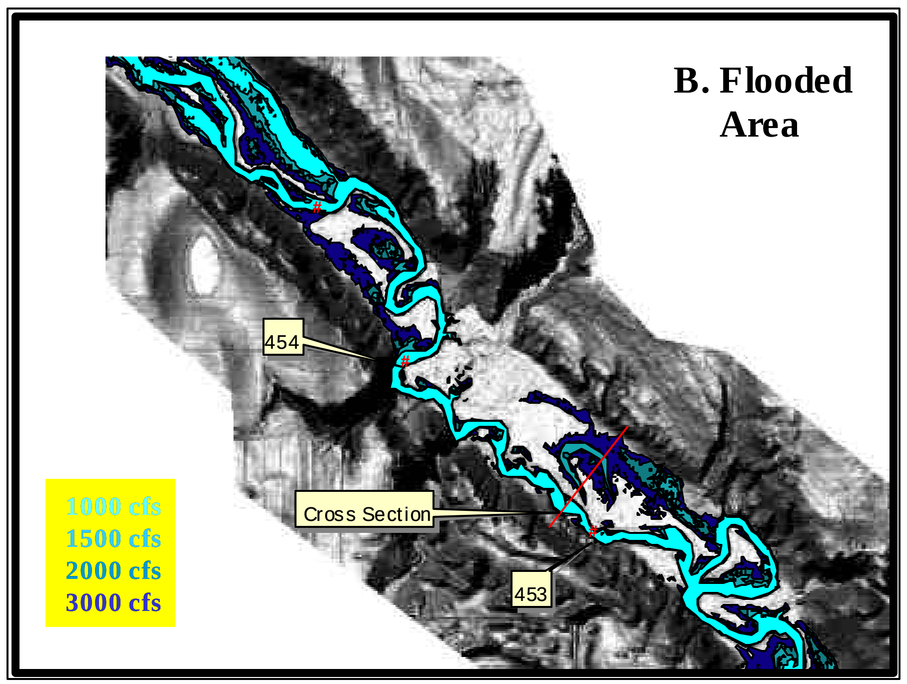
**Soil Legend**

9 Rauville
75 Ryan
78 LaDelle-Aberdeen
85 Lamoure
83 LaDelle
86 LaDelle Channeled
Cp Colvin-LaPrairie
Le Lamoure

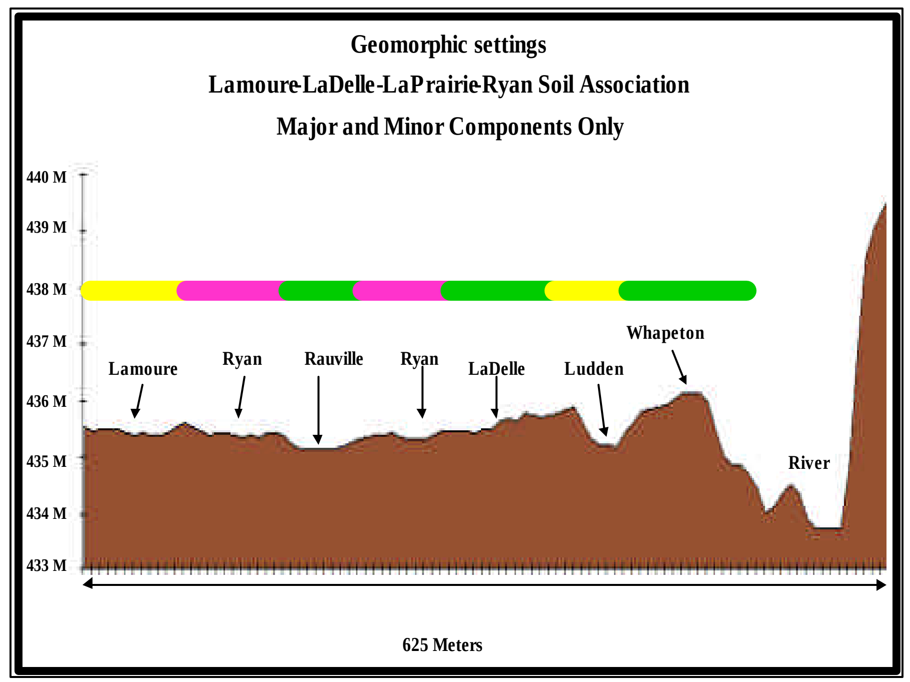
- Non-Saline Map Units
- Non-Saline Map Units with saline inclusions
- Complexes with saline major components
- Saline Map Units



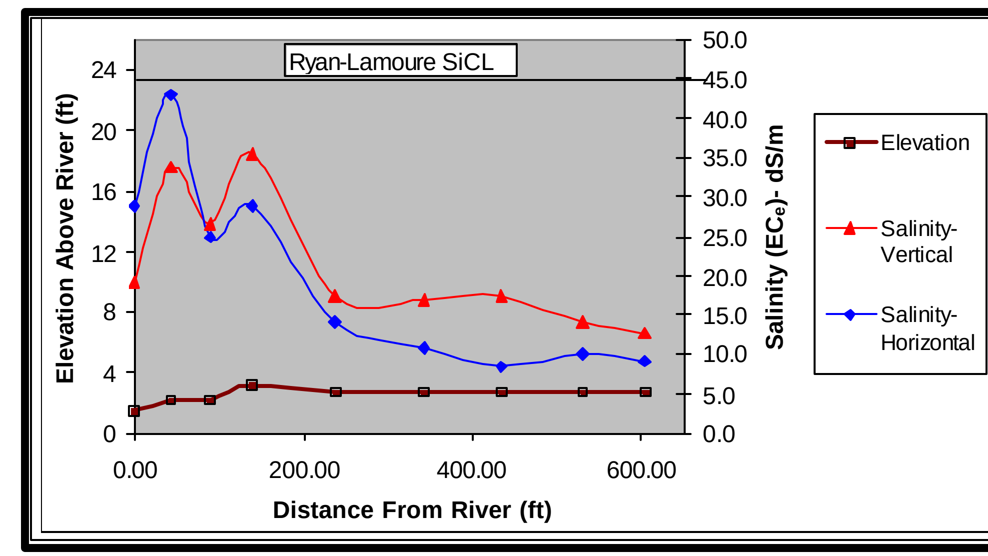
E. Representative Landscape (Ryan-Lamoure)




B. Flooded Area




C. Cross Section




D. EM-38 Salinity, Representative Landscape

Peterson Environmental Consulting, Inc.

**Location Data**

**Legal**: Sec. 34, 35 T151N R68W

**County:** Benson, North Dakota

**Soil Survey:** Eddy and Parts of Benson and Nelson

**River Mile:** 453 - 454

Discussion

A. Typical soils. The Association is contained within a portion of the upper reaches of the Sheyenne in Benson, Wells, Eddy, and Nelson counties that are characterized by shallow entrenchment, a relatively broad active floodplain, and the presence of extensive poorly and very poorly drained soils adjacent to or near the river and in abandoned meanders. Poorly and very poorly drained soils consist of 50% of the Association. Saline soils are mapped as both major units and as inclusions.

B. Significant portions of the valley floor would be flooded at 1000 cfs, which is considered by the USACE to be the normal flood stage for this reach of the river. Overbank flooding coupled with high water tables and shallow Sheyenne River entrenchment provide significant salinization hazards for many of the soils in the association that would be affected by elevated water tables and more frequent flooding under the alternatives.

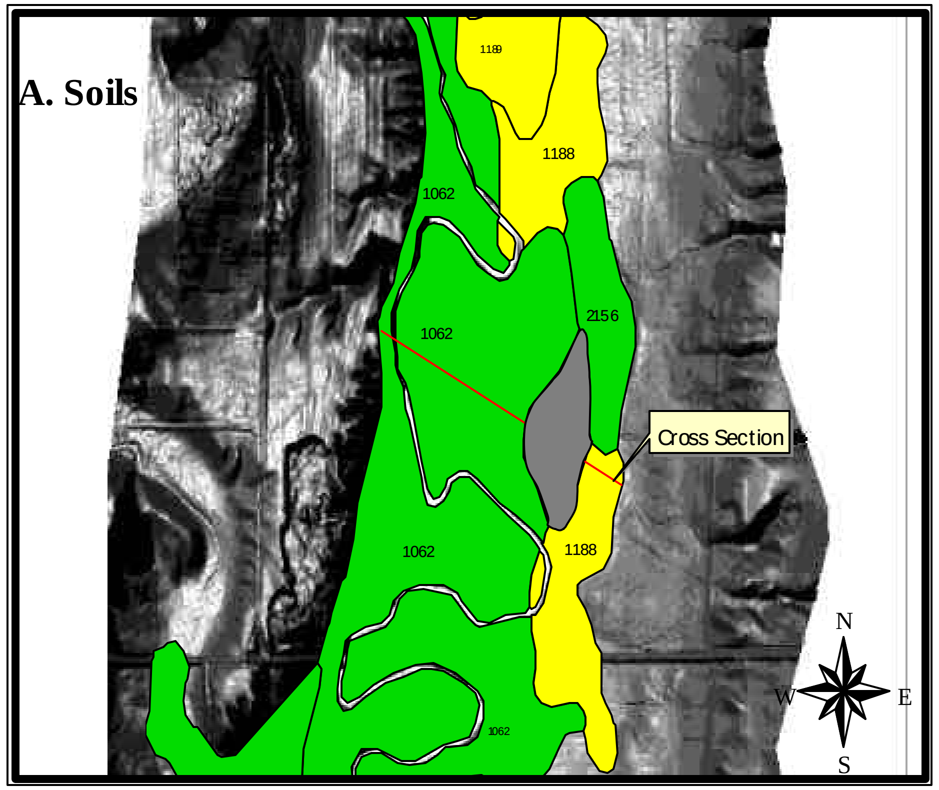
C. The shallow entrenchment of the Sheyenne River is apparent. Relief along the floor of the valley is less than 2 meters. Better drained Whapeton and LaDelle soils occupy the periphery of the floodplain and the natural levees. Low backswamp deposits are occupied by Lamoure, Ryan, Ludden, Rauville and other poorly drained soils. Under the outlet alternatives, saline soils could become more saline, and potentially saline soils with subsoil salinity could also experience a salinization hazard.

D. EM 38 salinity of a Ryan-Lamoure map unit shows high levels of salinity associated with the low active floodplain of the Sheyenne River. Note very high levels of salinity adjacent to the River.

E. Landscape view of low areas immediately adjacent to the Sheyenne. Soils in the photo were used used to develop the EM-38 data in (D).

# Figure 21

## Devils Lake Salinity: Sheyenne Valley
## LaDelle-Ludden-Whapeton Soil Association

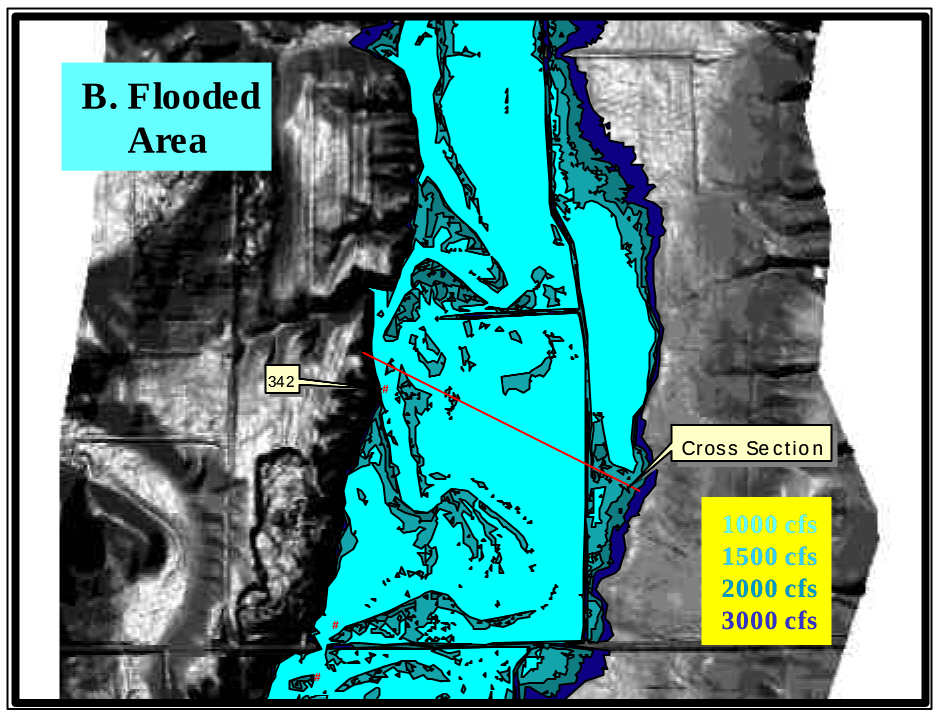


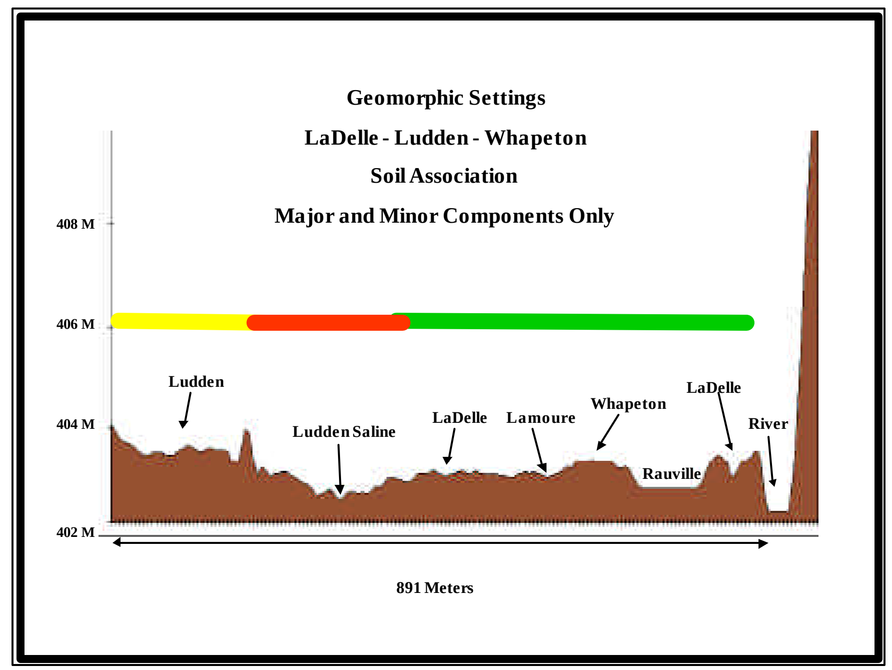

**Soil Legend**

1062 LaDelle
1188 Ludden
1189 Ludden Saline
2156 Lamoure-Rauville

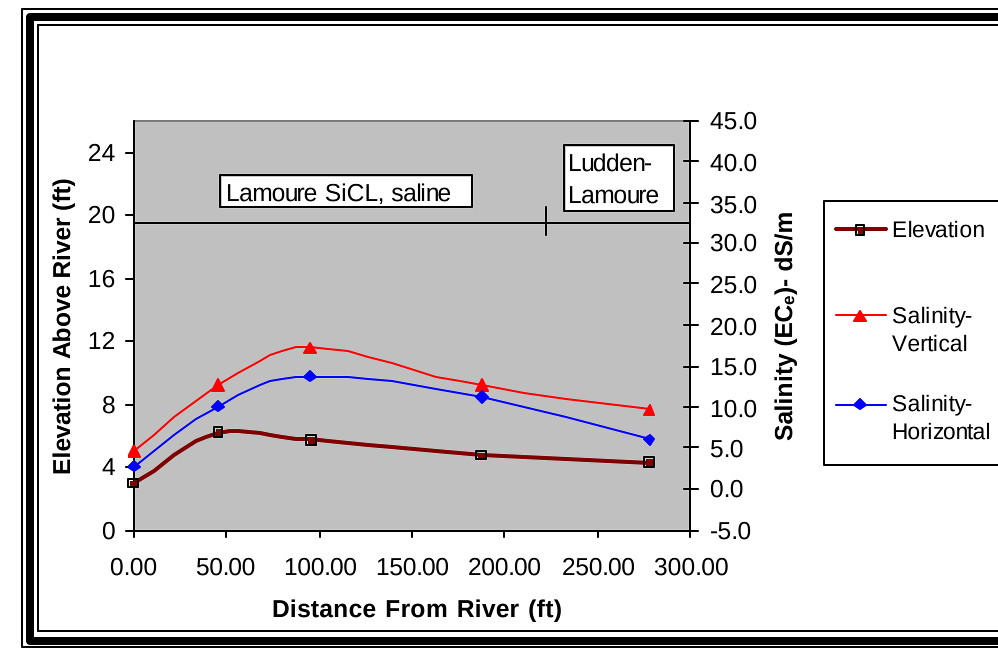
- Non-Saline Map Units
- Non-Saline Map Units with saline inclusions
- Complexes with saline major components
- Saline Map Units

E. Representative Landscape (Ludden/Lamoure)




C. Cross Section




D. EM-38 Salinity, Representative Landscape

Peterson Environmental Consulting, Inc.

**Location Data**

**Legal**: Sec. 12, T148N R59W

**County:** Griggs, North Dakota

**Soil Survey:** Griggs County

**River Mile:** 341 - 342

Discussion

A. Typical soils. The Association is contained within portions of the upper reaches of the Sheyenne in Griggs and Steele counties that are characterized by shallow entrenchment, a relatively broad active floodplain, and the presence of extensive poorly and very poorly drained soils adjacent to or near the river and in abandoned meanders. Poorly and very poorly drained soils comprise 23% of the Association. Saline soils are mapped as both major units and as inclusions.

B. Much of the valley floor would be flooded at 1000 cfs, which is considered by the USACE to be the normal flood stage for this reach of the river. Extensive overbank flooding coupled with high water tables and shallow Sheyenne River entrenchment provide significant salinization hazards for many of the soils in the association that would be affected by elevated water tables and more frequent flooding under the alternatives.

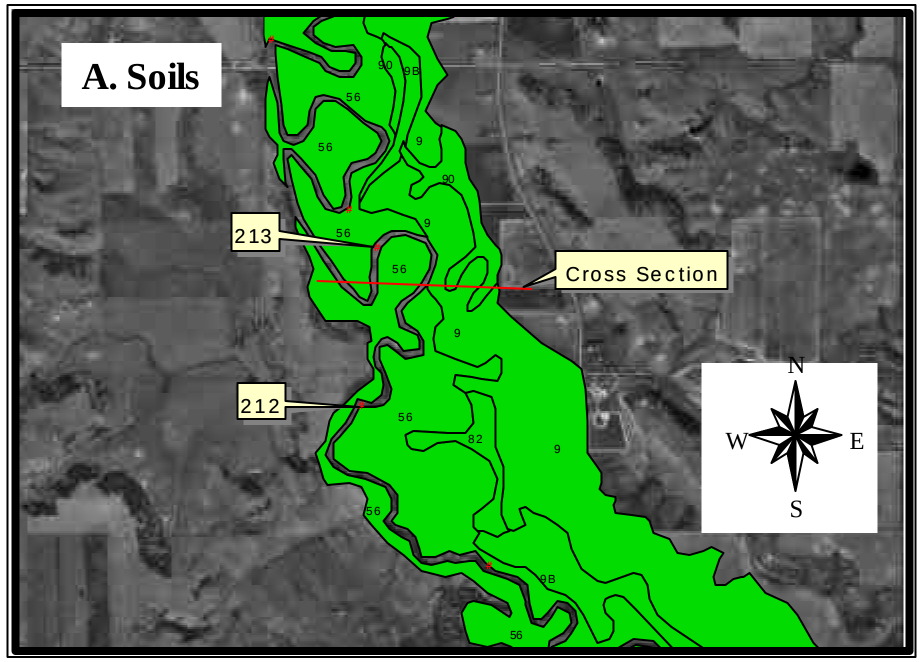
C. The shallow entrenchment of the Sheyenne river is apparent. Relief along the floor of the valley is about 2 meters. Better drained Whapeton and LaDelle soils occupy the periphery of the floodplain and the natural levees. Low backswamp deposits are occupied by Ludden and other poorly drained soils. Under the outlet alternatives, saline soils could become more saline, and potentially saline soils with subsoil salinity could also experience a salinization hazard.

D. EM 38 salinity of a Ludden (saline) and a Ludden-Lamoure map unit shows the increased levels of salinity associated with the low active floodplain of the Sheyenne River.

E. Backswamp areas and low areas immediately adjacent to the Sheyenne. Soils in the photo were used used to develop the EM-38 data in (D).

# Figure 22

## Devils Lake Salinity: Sheyenne Valley
## LaDelle-Nutley Soil Association

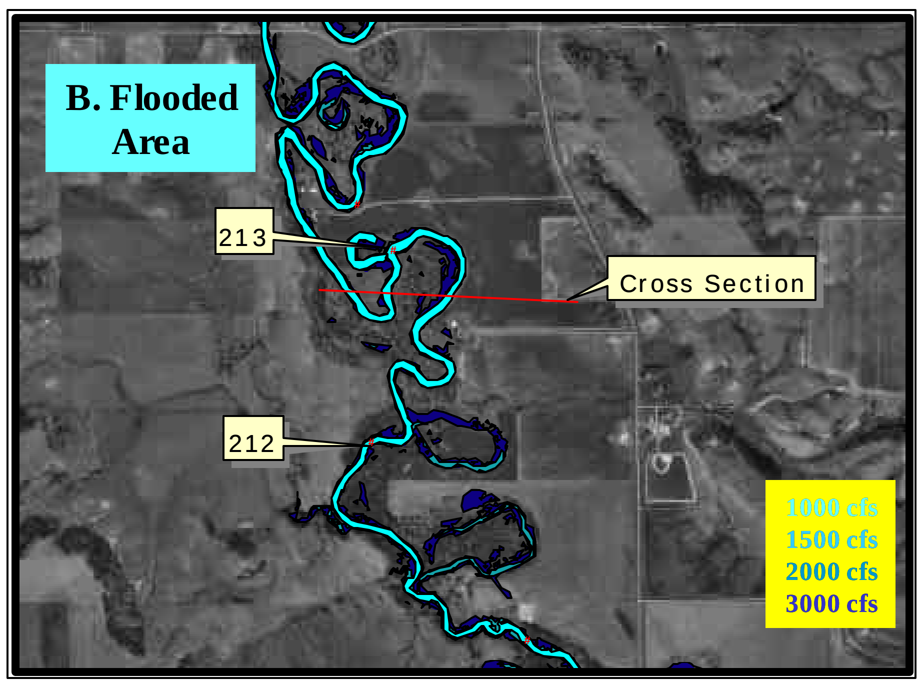


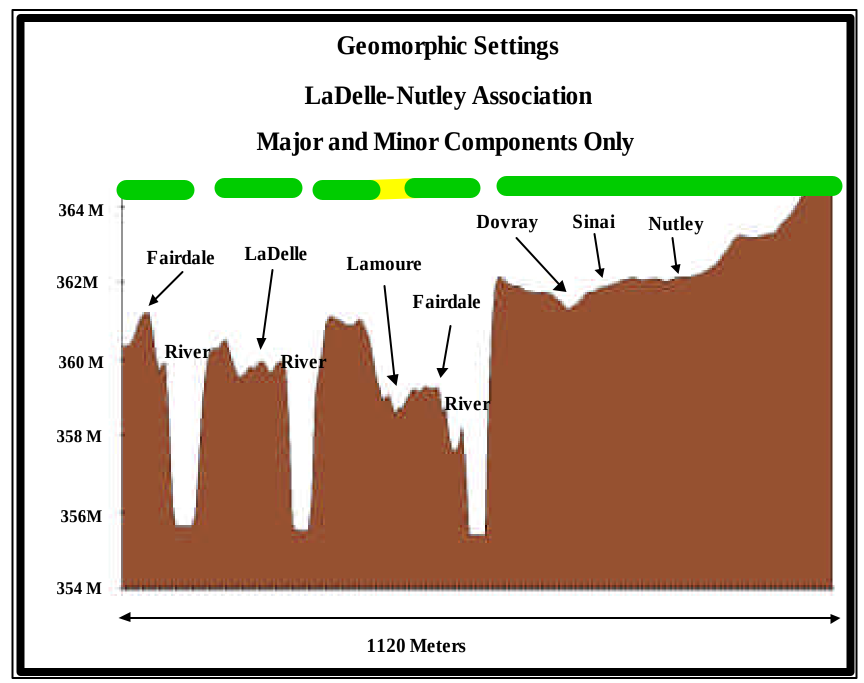

**Soil Legend**

| | |
|---|---|
| 9 | Nutley |
| 54 | Lamoure |
| 56 | LaDelle |
| 82 | Sinai |

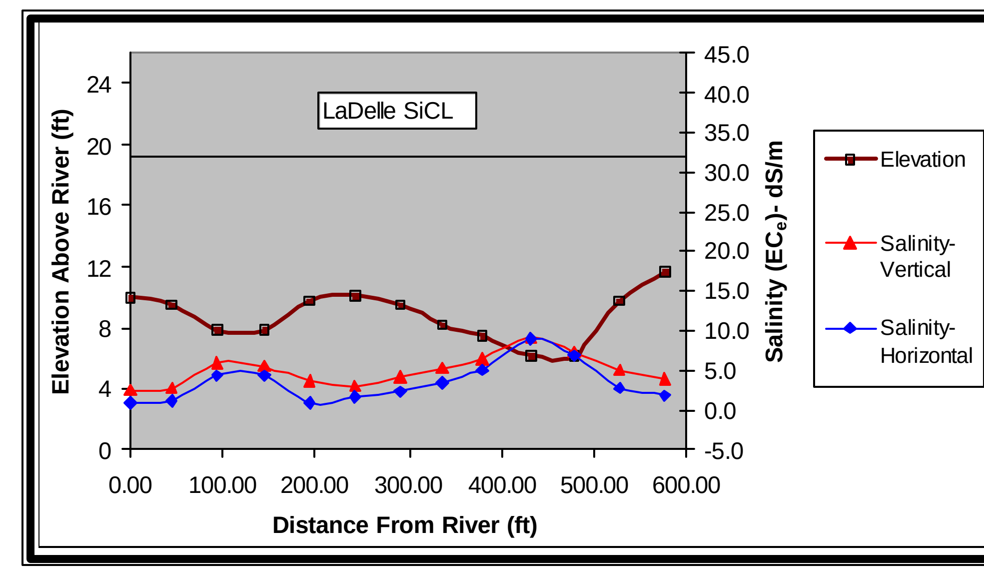
- Non-Saline Map Units
- Non-Saline Map Units with saline inclusions
- Complexes with saline major components
- Saline Map Units

E. Representative Landscape




C. Cross Section




D. EM-38 Salinity, Representative Landscape

Peterson Environmental Consulting, Inc.

**Location Data**

**Legal**: Sec. 3, 4 T139N R58W

**County:** Barnes, North Dakota

**Soil Survey:** Barnes County

**River Mile:** 236 - 237

Discussion

A. Typical soils in the LaDelle-Nutley Association . Most soils in this map unit are non-saline, moderately well drained soils with inclusions of poorly and very poorly drained Rauville and Lamoure soils in abandoned meanders.

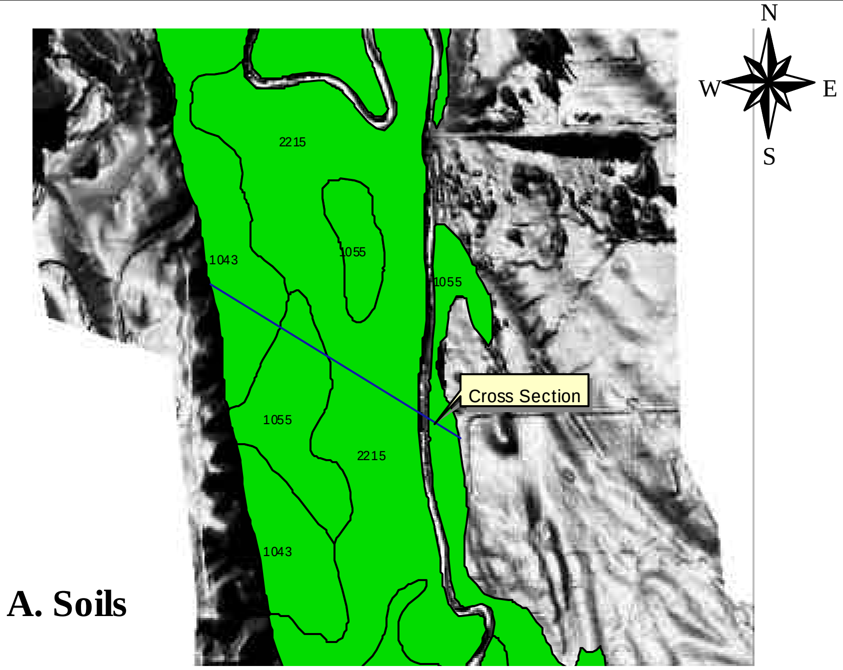
B. The flooded area outline data suggest that flood flows will be contained within the entrenched Sheyenne River and adjacent low abandoned meanders. Note the presence of an extensive abandoned meander system in the hillshaded DEM view. The USACE considers the 1500 cfs outline to be the normal flood flow for this area.

C. The valley of the Sheyenne is deeply entrenched (4 meters, 12 feet) and the active floodplain is relatively narrow. However, elevated terraces that are relict from periods when the Sheyenne was not a deeply entrenched are common. Well and moderately well drained Sinai and Nutley soils developed in colluvium/alluvium dominate the toeslope positions of the valley. Nutley and Sinai soil will not be affected by salinization under the alternatives given their topographic position relative to the river. Furthermore, it is unlikely that the LaDelle and Fairdale soils mapped on the higher terraces will be affected by salnization of the lack of significant overbank flooding and their elevated positions. However, LaDelle and Fairdale soils that are frequently hydrologically connected to river flooding could experience a salinization hazard.

D. EM-38 salinity data for a LaDelle soil containing an abandoned meander. Note the elevated salinity associated with the concave meander positions. A salinization hazard could exist both in the abandoned meanders and the immediately adjacent LaDelle soils if watertable elevations and flooding frequency increase.

# Figure 23

## Devils Lake Salinity: Sheyenne Valley
## Fairdale-LaPrairie-LaDelle Soil Association



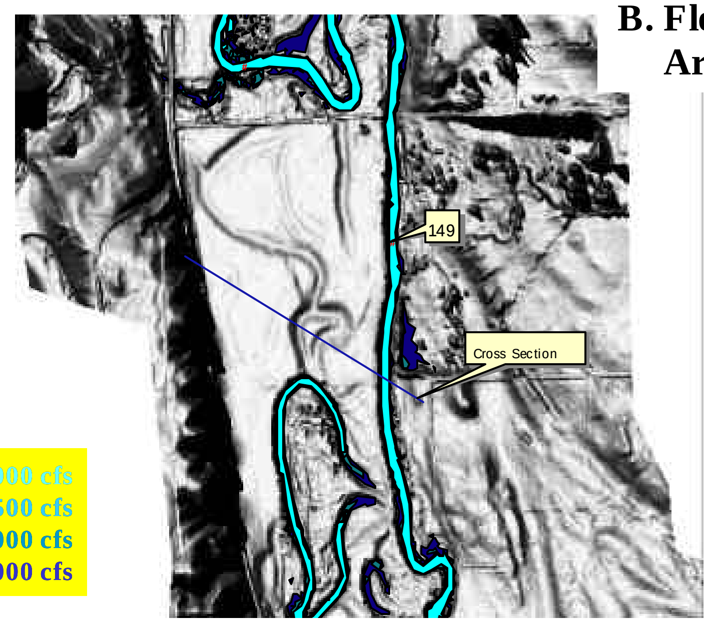

A. Soils

**Soil Legend**

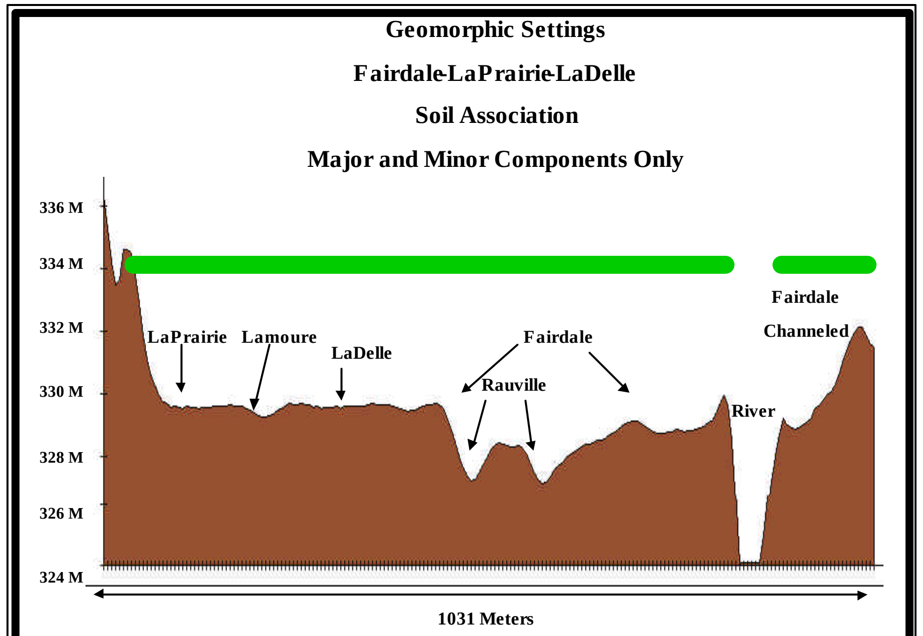
| | |
|---|---|
| 1043 | LaPrairie |
| 1055 | LaDelle |
| 2215 | Fairdale |

- Non-Saline Map Units
- Non-Saline Map Units with saline inclusions
- Complexes with saline major components
- Saline Map Units

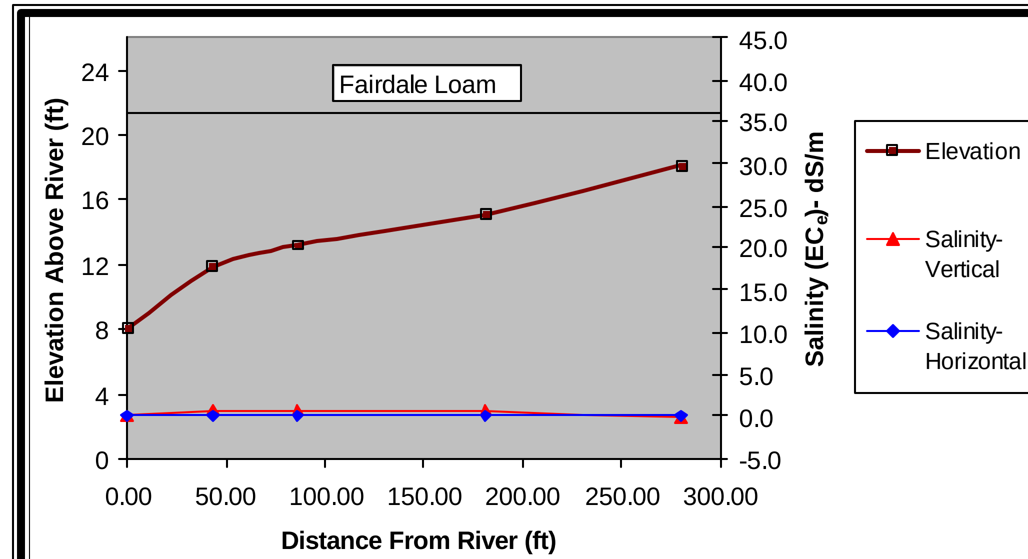
E. Representative Landscape (Fairdale)




B. Flooded Area




C. Cross Section




D. EM-38 Salinity, Representative Landscape (Fairdale)

Peterson Environmental Consulting, Inc.

**Location Data**

**Legal:** Sec. 23, 24, 25 T134N R56W

**County:** Ransom, North Dakota

**Soil Survey:** Ransom County

**River Mile:** 148 - 149

Discussion

A. Typical soils in the Fairdale-LaPrairie-LaDelle Association. Note very poorly drained Rauville soils occupying low abandoned meanders.

B. Flooded area outline data supplied by the USACE indicates that floodwaters are primarily confined to the channels, even at flow rates of 3000 cfs which is well above the 1500 cfs values considered normal flood stages for this reach of the river.

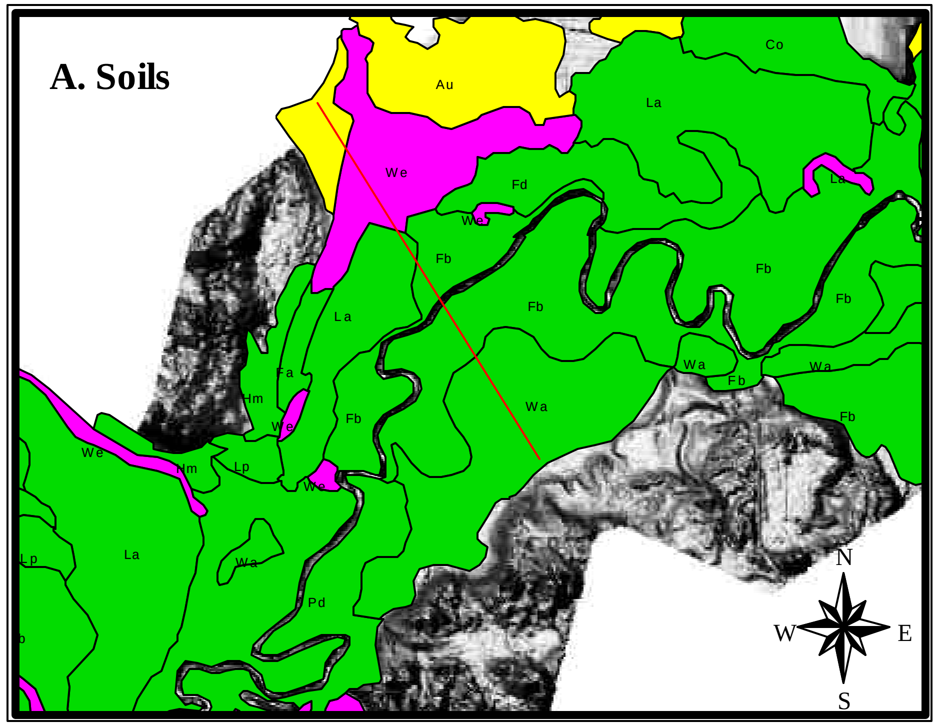
C. Note the entrenchment of the Sheyenne (3 meters, 10 feet) and the proximity and elevation of the soils in relation to the river. Rauville soils and similar Lamoure soils indicated in abandoned meanders may have the potential to become salinized given a mean water table rise of 1-3 feet, the presence of subsoil salts, and the additional of water as overbank flow. The higher LaPrairie and LaDelle soils that are more distant from the river and would likely not have a salinization hazard under the constructed outlet alternatives. These soils would not flood regularly and would not experience persistent elevated groundwater levels. However, LaDelle and LaPrairie soils nearer the river may have a salinization hazard if the mean stage rise under the alternatives is sufficient to mobilize subsoil salts to the surface.

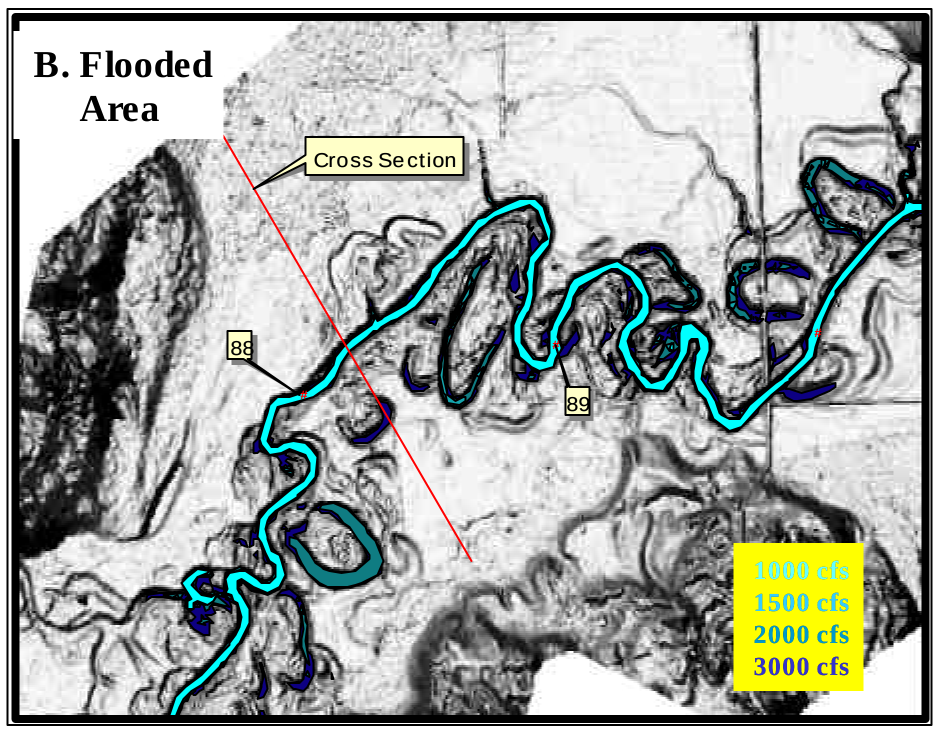
D. In a representative landscape, Fairdale soils were non-saline in an entrenched portion of the river similar to that shown in A-C. The river was deeply entrenched in this area with a nearly sheer 8 foot bank.

E. Typical landscape of nearly level to gently sloping Fairdale soils adjacent to the Sheyenne. The river is just beyond the trees. The field is in alfalfa, a common hay crop in the valley. The river was entrenched 8-12 feet into the surrounding area.

# Figure 24

## Devils Lake Salinity: Sheyenne Valley
## Fairdale-LaDelle-Whapeton-Delta Soil Association

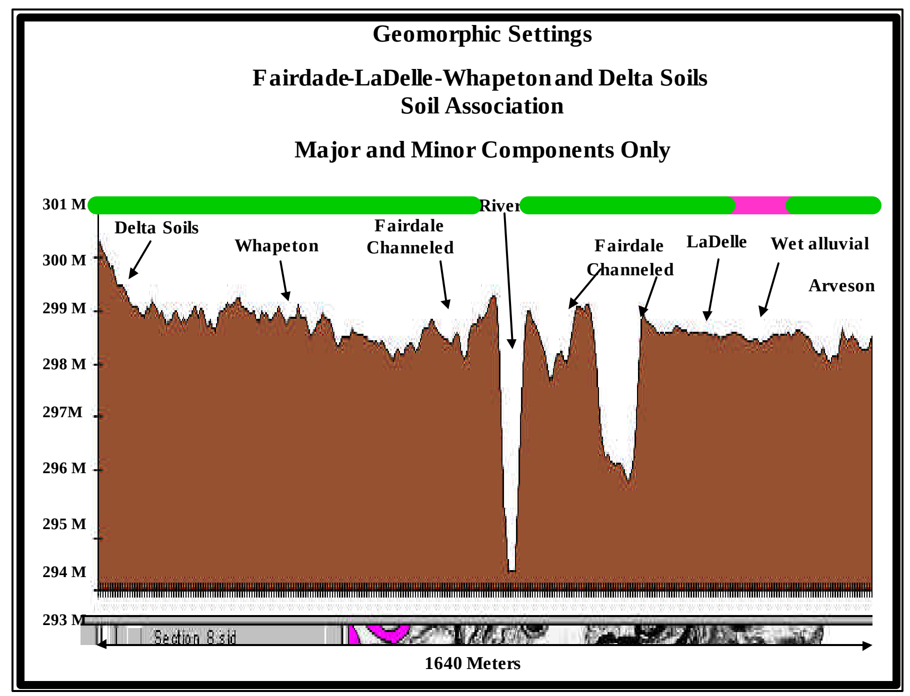



**Soil Legend**

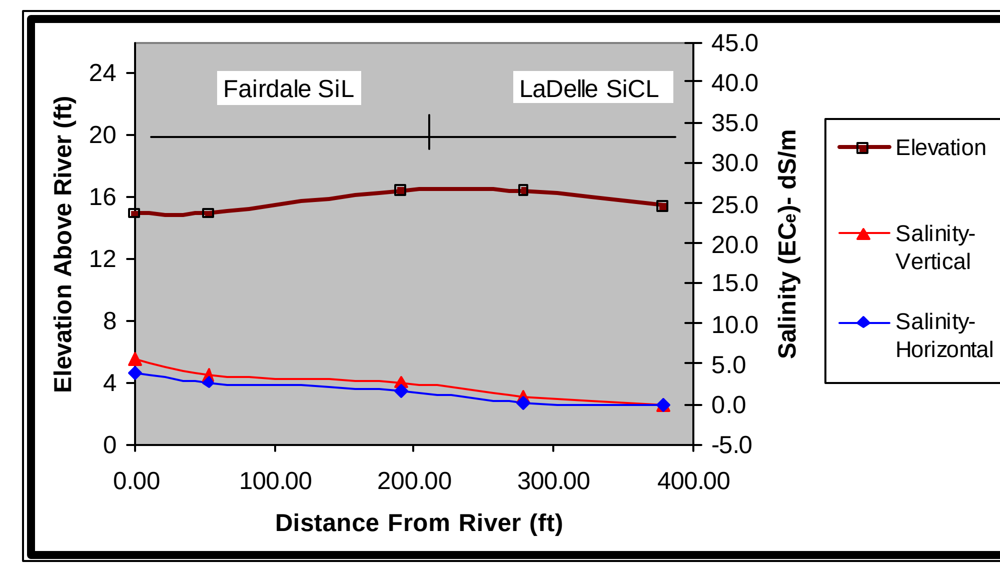
Au Arveson
Co Colvin
Fb Fairdale Channeled
Fd Fairdale
Hm Hecla
La LaDelle
Lp LaPrairie
Pd Parnell-Tonka
Wa Whapeton
We Wet Alluvial

- Non-Saline Map Units
- Non-Saline Map Units with saline inclusions
- Complexes with saline major components
- Saline Map Units




C. Cross Section

E. Representative Landscape (Fairdale/LaDelle)




D. EM-38 Salinity, Representative Landscape (Fairdale/LaDelle)

Peterson Environmental Consulting, Inc.

**Location Data**

**Legal**: Sec. 4T135N R52W

**County:** Richland, North Dakota

**Soil Survey:** Richland County

**River Mile:** 87-88

Discussion

A. Typical soils in the Fairdale-LaDelle-Whapeton-Delta Soils Association. Note Delta soils include Wet Alluvial Land, Arveson, and Hecla soils on the periphery of the valley. Wet Alluvial land likely represents groundwater seepage from the coarse textured uplands that would preclude a hydrologic affect from the Sheyenne River. In general, Delta soils are hydrologically upgradient from the Sheyenne River and would not be affected by salinization under the alternatives.

B. The channel essentially confines floodwaters up to 3000 cfs (HEC-RAS modeling) with flooding limited to abandoned meanders. It is unlikely that overbank flooding under the outlet alternatives will be a problem, as normal spring flood stages are approximately 1500 cfs in this stretch of the river.

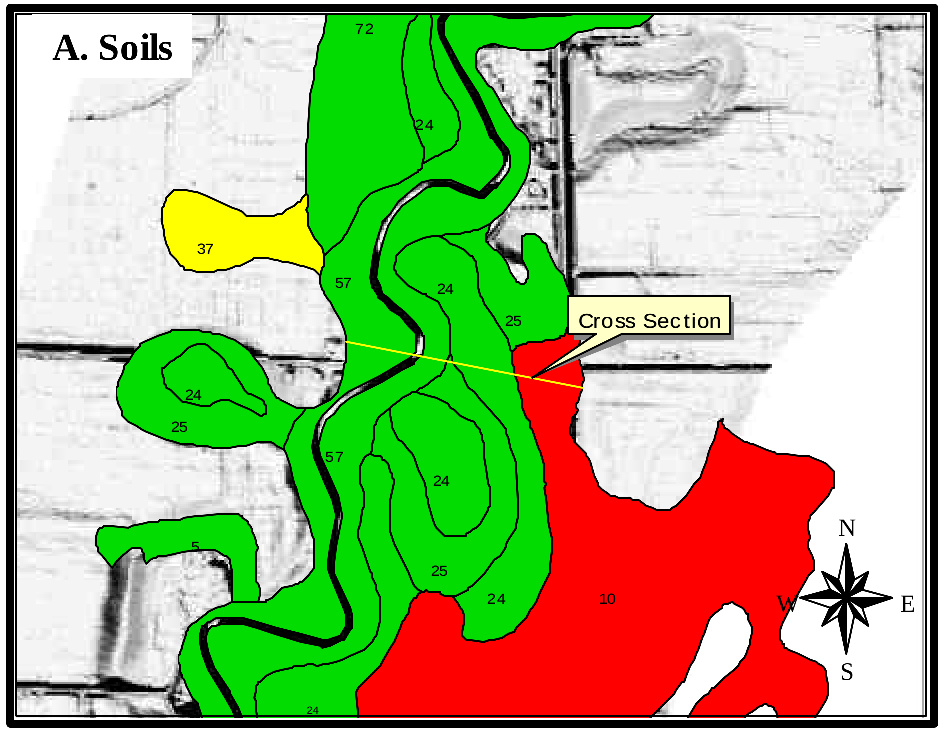
C. The Sheyenne River is deeply entrenched (6 meters, 20 feet). Several low, abandoned meanders (Fairdale Channeled) are hydrologically affected by flooding and groundwater intrusion from the river and may experience some salinization under the outlet alternatives. Poorly drained soils occupying the meanders are likely Lamoure, but were not indicated in the Soil Survey. The elevation above the river of the other moderately well and well drained soils suggests that salinization of these soils in this landscape setting would not be a significant hazard.

D. Low levels of salinity are indicated but are higher towards the river, suggesting that low-lying Fairdale/LaDelle soils hydrologically connected with the river could be subject to salinization under the outlet alternatives.

E. Typical landscape showing the deep entrenchment of the Sheyenne River.

# Figure 25

## Devils Lake Salinity: Sheyenne Valley Fairdale-Fargo Soil Association



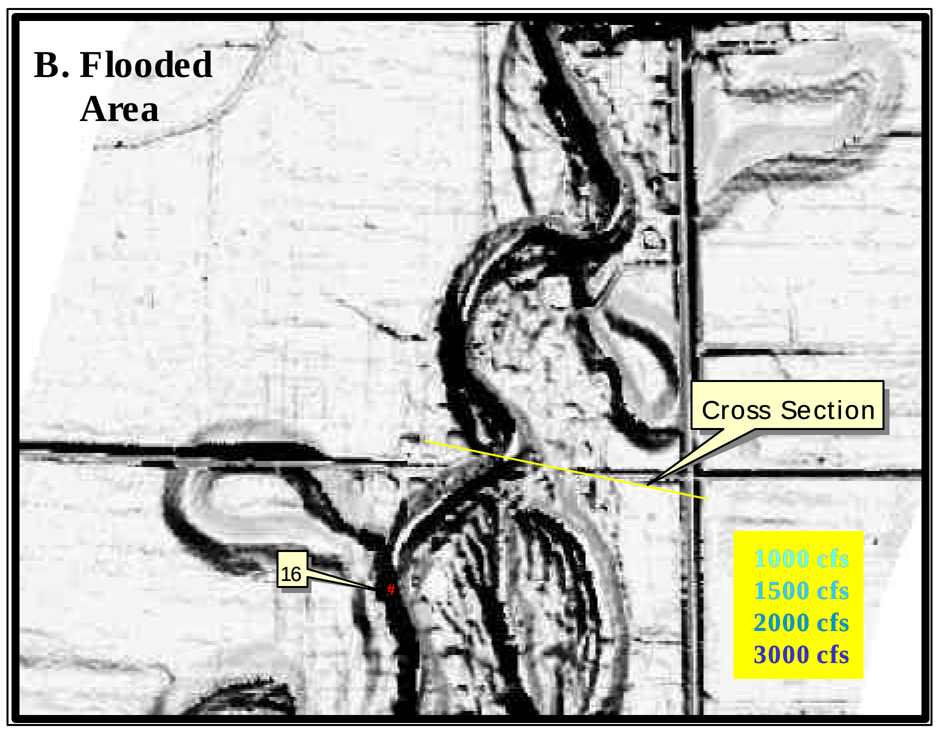

A. Soils

**Soil Legend**

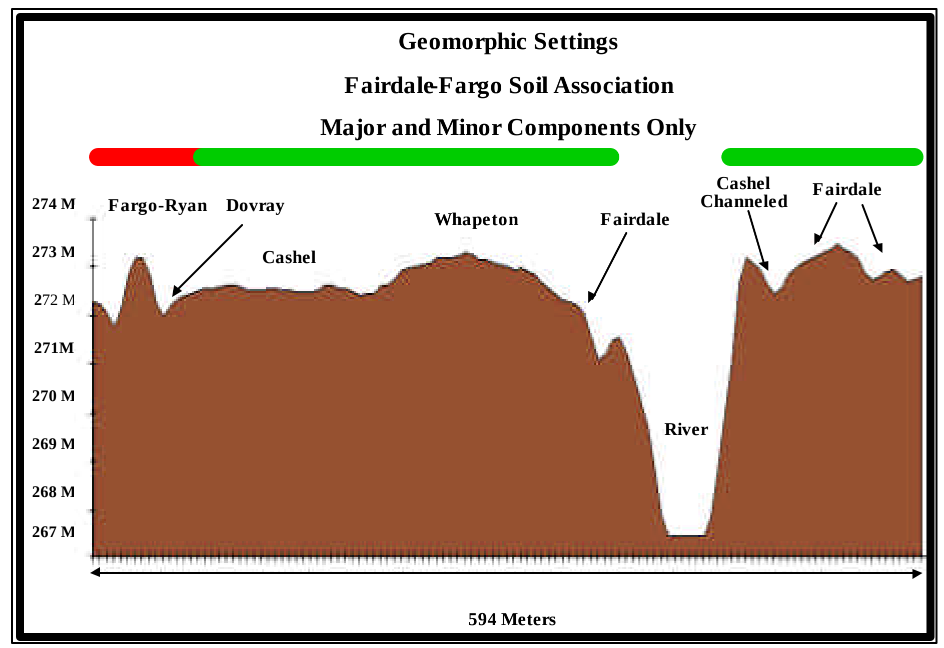
5 Dovray
10 Fargo-Ryan
24 Cashel
25 Cashel Channeled
37 Fargo Depressional
57 Fairdale
72 Whapeton

- Non-Saline Map Units
- Non-Saline Map Units with saline inclusions
- Complexes with saline major components
- Saline Map Units

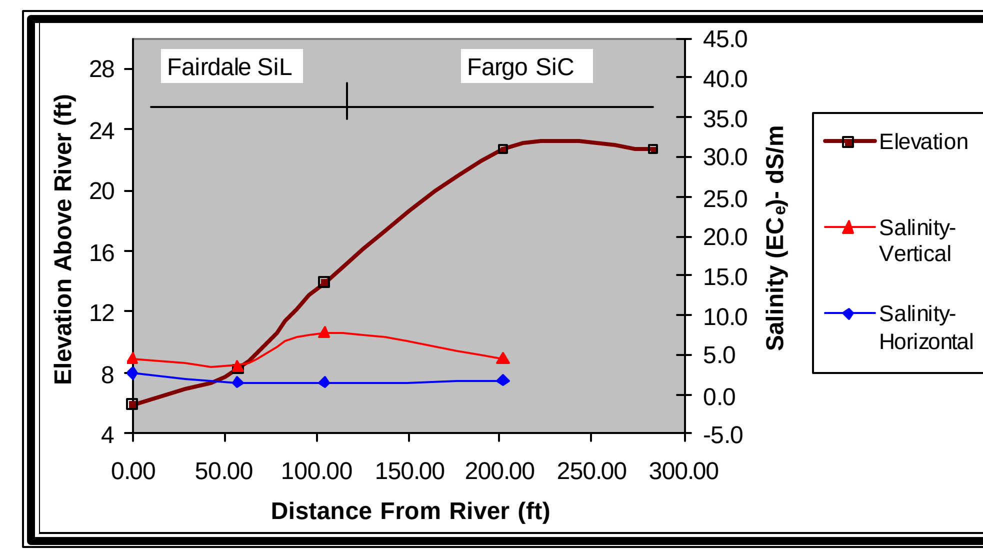
E. Representative Landscape (Fairdale/Fargo soils)




B. Flooded Area




C. Cross Section




D. EM-38 Salinity, Representative Landscape (Fairdale/Fargo)

Peterson Environmental Consulting, Inc.

**Location Data**

**Legal**: Sec. 7, T140N R49W

**County:** Cass, North Dakota

**Soil Survey:** Cass County

**River Mile:** 16-15

Discussion.

A. Ryan soils are separated from the river by Fairdale and Whapeton soils on better drained natural levees. Dovray soils in abandoned meanders.

B. No flooded area outlines were available. However, note that the Sheyenne River is entrenched 5 meters (16 feet). The Sheyenne River rarely rises out of its banks during the growing season (e.g. approximately the period of outlet operation) in the area of the Fargo-Fairdale Association.

C. Note the deep entrenchment of the Sheyenne River. Water tables in the area are relatively high in the somewhat poorly drained to poorly drained soils adjacent to the river. However, water movement is expected to be very slow (low permeability in Fargo/Ryan soils) and towards the river in this area.

D. EM-38 data indicate moderate levels of salinity expected in the Fargo-Fairdale association. An expected increase in salinity immediately adjacent to the river is due to transient evapotranspirative concentration of salts. Note the 24-foot rise in elevation between the river and the surrounding upland.

E. Slumping is evident and common along cut banks of the Sheyenne River in the Red River Valley. The geomorphic setting of the soils does not indicate a potential for additional salinization of the adjacent uplands under the outlet alternatives. Low flats and abandoned meanders immediately adjacent to the river may have a salinization hazard; however, these areas are within the channel and are not extensive, nor are they used for agriculture due to slope and frequent flooding.

Soil Salinization Hazards Associated with Devils Lake Flood Damage Reduction Alternatives:

Sheyenne River Valley

# Report Tables

Table 1. Selected distribution statistics for HEC5Q predicted TDS values, Wet7 climatic scenario dataset. All data represent predicted daily TDS values for the growing season extending from May 1 through September 30 for each year beginning with outlet operation May 1, 2005 and extending through September 30, 2050. Values for the 300 cfs Constrained (300) , the 480 cfs Unconstrained, (400) and the No Action ( NoPump) alternatives are further restricted to *Blended Water Only*. Baseflow values (Base) include the entire *Baseflow-plus-Blended-Water* dataset.

| Control Point | Alternative | Mean | Median | Standard Deviation | Minimum | Maximum | Count |
|---|---|---|---|---|---|---|---|
| Warwick | Base | 579 | 570 | 123 | 244 | 1067 | 7038 |
| | 300 | 964 | 1004 | 146 | 269 | 1237 | 7010 |
| | 480 | 938 | 938 | 150 | 253 | 1279 | 4786 |
| | NoPump | Upstream of Natural Spill | | | | | |
| Cooperstown | Base | 584 | 595 | 74 | 296 | 894 | 7038 |
| | 300 | 836 | 862 | 135 | 347 | 1094 | 6937 |
| | 480 | 884 | 898 | 157 | 296 | 1270 | 4779 |
| | NoPump | 1616 | 1581 | 607 | 410 | 2886 | 1611 |
| Valley City | Base | 467 | 463 | 68 | 314 | 653 | 7038 |
| | 300 | 610 | 620 | 120 | 328 | 967 | 7017 |
| | 480 | 681 | 697 | 162 | 329 | 1150 | 5944 |
| | NoPump | 1149 | 1158 | 465 | 387 | 2147 | 1519 |
| Lisbon | Base | 543 | 527 | 102 | 314 | 816 | 7038 |
| | 300 | 632 | 638 | 121 | 328 | 966 | 7012 |
| | 480 | 697 | 716 | 146 | 328 | 1143 | 5853 |
| | NoPump | 1002 | 808 | 414 | 467 | 2028 | 1929 |
| Kindred | Base | 537 | 534 | 82 | 287 | 737 | 7038 |
| | 300 | 610 | 622 | 103 | 304 | 904 | 7009 |
| | 480 | 673 | 687 | 138 | 301 | 1109 | 5756 |
| | NoPump | 972 | 869 | 379 | 389 | 1894 | 1708 |

Table 2. Selected distribution statistics for HEC5Q predicted SAR values, Wet7 climatic scenario dataset. All data represent predicted daily SAR values for the growing season extending from May 1 through September 30 for each year beginning with outlet operation May 1, 2005 and extending through September 30, 2050. Values for the 300 cfs Constrained (300) , the 480 cfs Unconstrained, (400) and the No Action ( NoPump) alternatives are further restricted to the *Blended-Water-Only* dataset. Baseflow values (Base) include the entire *Baseflow-plus-Blended-Water* dataset.

| Control Point | Alternative | Mean | Median | Standard Deviation | Minimum | Maximum | Count |
|---|---|---|---|---|---|---|---|
| Warwick | Base | 2.06 | 2.05 | 0.219 | 1.34 | 2.8 | 7038 |
| | 300 | 3.95 | 4.08 | 0.526 | 1.41 | 4.6 | 7010 |
| | 480 | 4.08 | 4.20 | 0.563 | 1.46 | 5.0 | 4786 |
| | NoPump | Upstream of Natural Spill | | | | | |
| Cooperstown | Base | 2.07 | 2.10 | 0.134 | 1.48 | 2.6 | 7038 |
| | 300 | 3.38 | 3.44 | 0.613 | 1.60 | 4.5 | 6937 |
| | 480 | 3.79 | 3.92 | 0.646 | 1.48 | 5.0 | 4779 |
| | NoPump | 6.98 | 7.25 | 2.449 | 1.79 | 11.0 | 1611 |
| Valley City | Base | 1.50 | 1.50 | 0.108 | 1.23 | 1.8 | 7038 |
| | 300 | 2.30 | 2.29 | 0.496 | 1.33 | 3.8 | 7017 |
| | 480 | 2.72 | 2.86 | 0.782 | 1.33 | 4.6 | 5944 |
| | NoPump | 5.78 | 6.03 | 2.112 | 1.69 | 9.8 | 1519 |
| Lisbon | Base | 1.62 | 1.60 | 0.150 | 1.23 | 2.0 | 7038 |
| | 300 | 1.95 | 1.91 | 0.344 | 1.26 | 3.3 | 7012 |
| | 480 | 2.89 | 2.87 | 0.878 | 1.29 | 4.8 | 5853 |
| | NoPump | 4.46 | 4.13 | 2.242 | 1.37 | 9.2 | 1929 |
| Kindred | Base | 1.61 | 1.61 | 0.123 | 1.18 | 1.9 | 7038 |
| | 300 | 2.07 | 2.00 | 0.386 | 1.27 | 3.3 | 7009 |
| | 480 | 2.71 | 2.67 | 0.831 | 1.01 | 4.5 | 5756 |
| | NoPump | 4.37 | 4.24 | 1.934 | 1.37 | 8.5 | 1708 |

Table 3. Mean predicted increases in river stage as a result of adding 300 and 480 cfs to mean May and August flows at selected control points along the Sheyenne River (data from Pat Foley, St. Paul District, USACE).

| **USGS Gauge** | **Mean Increase in May Average Stage** | | **Mean Increase in August Average Stage** | |
|---|---|---|---|---|
| | **300 cfs (ft)** | **480 cfs (ft)** | **300 cfs (ft)** | **480 cfs (ft)** |
| Warwick | 0.8 | 1.1 | 1.0 | 1.4 |
| Cooperstown | 0.9 | 1.3 | 1.0 | 1.5 |
| Valley City | 1.3 | 2.0 | 1.2 | 1.9 |
| Lisbon | 1.4 | 1.9 | 1.5 | 2.2 |
| Kindred | 1.8 | 2.7 | 1.7 | 2.8 |
| Horace | 2.3 | 3.5 | 2.8 | 4.3 |
| West Fargo | 2.0 | 3.0 | 2.9 | 4.2 |

Table 4. Acreage breakdown of salinization hazards by soil series for all soil associations.

| Soil Series | Acres | Hazard |
|---|---|---|
| **Lamoure-LaDelle-LaPrairie-Ryan Soil Association** | | |
| Walsh, Claire (channeled), Velva (channeled), Wamduska, Svea, Miranda variant | 627 | None |
| LaPrairie, Wahpeton, Embden, | 2803 | None to Slight |
| LaDelle | 3036 | Slight to Moderate |
| Lamoure, Ryan, Rauville, Ludden, Lamoure (saline), marsh, Cavour, Aberdeen, Cresbard, Minnewauken, Colvin, Exline, Borup, Marysland | 7674 | Moderate to Severe |
| Other Soils | 172 | Not Rated |
| **Totals** | **14312** | |
| **LaDelle-Ludden-Wahpeton Soil Association** | | |
| Wahpeton, Velva, Bearden, Parnell, Southam, Vallers | 1515 | None |
| LaPrairie | 510 | None to Slight |
| LaDelle, Fairdale, Marysland | 4923 | Slight to Moderate |
| Ludden, Lamoure, Rauville, Ryan, Ludden (saline), Colvin | 2366 | Moderate to Severe |
| Other soils | 50 | Not rated |
| **Totals** | **9364** | |
| **LaDelle-Nutley Soil Association** | | |
| Fargo, Overly, Dovray, Fordville, Bearden, Gardena, Nutley, Saini | 3006 | None |
| LaDelle | 3038 | None to Slight |
| Fairdale, Marysland | 752 | Slight to Moderate |
| Lamoure, Colvin channeled, Colvin (saline), Rauville, | 502 | Moderate to Severe |
| | 41 acres | Not Rated |
| **Totals** | **7339** | |

Table 4. Continued.

| Soil Series | Acres | Hazard |
|---|---|---|
| **Fairdale-LaPrairie-LaDelle Soil Association** | | |
| Eckman, Gardena, Fordville | 139 | None |
| LaPrairie, LaDelle | 5002 | None-to-Slight |
| Fairdale, Marysland | 7991 | Slight-to-Moderate |
| Lamoure, Rauville | 357 | Moderate-to-Severe |
| Other Minor Soils | 18 | Not Rated |
| **Totals** | **13507** | |
| **Fairdale-LaDelle-Wahpeton-Delta Soils Association** | | |
| Gardena, Towner, Embden, Fossum, Arveson, Hecla, Tiffany, Swenoda, Hamar, Glyndon, Galchutt, Perella, Ulen, Colvin | 1884 | None |
| Wahpeton, Wet Alluvial Land, LaPrairie, LaDelle | 2255 | None to Slight |
| Fairdale, Overly | 2676 | Slight to Moderate |
| Other Minor Soils | 17 | Not Rated |
| **Totals** | **6831** | |
| **Fargo-Fairdale Soils Association** | | |
| Fargo, Ryan, Hegne, Overly, Enloe, Bearden, Nahon, Perella, Nutley, Great Bend, Lindass | 6169 | None |
| Wahpeton, LaDelle, Fairdale variant | 2144 | None to Slight |
| Fairdale, Cashel, Dovray | 5201 | Slight to Moderate |
| Colvin, Colvin (saline), Lamoure, Ludden, Rauville | 228 | Moderate to Severe |
| **Totals** | **13742** | |
| **Grand Total** | **65095** | |

Table 5. Selected physical, hydrologic, chemical, and geomorphic characteristics of association soils identified along the Sheyenne River.

| Association, Included Counties and Applicable Soil Survey | Soil Series Name | Acres per Component | Taxonomic Classification/Drainage | Drainage | Seasonal High Groundwater | Annual Flooding/ Duration | Landscape Position | Salinity/Sodicity Characteristics | Comments: Salinity Hazards |
|---|---|---|---|---|---|---|---|---|---|
| **Lamoure-LaDelle-LaPrairie-Ryan Association**; Benson, Wells, Eddy, and Nelson Counties, North Dakota; Soil Survey of Eddy County and Parts of Benson and Nelson Counties, North Dakota (Wright and Sweeney, 1977; SSAID ND605), Soil Survey of Wells County, North Dakota (Seago et al., 1970; SSAID ND103), Soil Survey of Nelson County Area, North Dakota (Heidt et al., 1989; SSAID ND607) | Ladelle | 3036.1 | Fine-Silty, Mixed, Superactive, Frigid Cumulic Hapludolls | Moderately Well | Oct - Jun: 4 - 6 | Occas: Oct - Jun | Floodplain | Non-saline, non-sodic. Subsoil salinity up to 4 dS/m. SAR <1 in surface and subsoil. | **Slight to Moderate**. Slight in areas distant from the river to moderate in channeled areas near the river. |
| | Lamoure | 3255.7 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Poor | Oct - Jun: 0 - 1.5 | Freq: Mar - Oct | Active Floodplains and meanders | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR to 2 in the surface and 3 in the subsurface. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | Ryan | 1896.9 | Fine, Smectitic, Frigid Typic Natraquerts | Poor | -0.5 - 1.5 | Occas: Mar - Jun | Active floodplain | Saline/natric. Subsoil salinity to 16 dS/m. SAR to 2 in the surface and 4 in the subsoil. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | La Prairie | 2410.4 | Fine-Loamy, Mixed, Superactive, Frigid Cumulic Hapludolls | Moderately Well | Mar - Jun: 3.5 - 5 | Rare | Floodplains Terraces | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR to <1 in the surface and subsoil. | **None to Slight**. None in elevated positions distant from the river. Slight in positions adjacent to the river subject ot increased river stage and increased flooding. |
| | Rauville | 929.4 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Very Poor | Jan - Dec: 0 - 0.5 | Freq: Mar - Oct | Active Floodplain, abandoned meanders, swales | Non-saline, non-sodic. Surface salinity to 2 dS/m, subsurface salinity to 4 dS/m. SAR to 2 in the surface and 3 in the subsurface. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | Ludden | 542.4 | Fine, Smectitic, Frigid Typic Endoaquerts | Poor | Jan - Dec: -0.5 - 1.5 | Freq: Mar - Jun | Active Floodplain, abandoned meanders, swales | Non-saline, non-sodic. Surface salinity to 2 dS/m, subsurface salinity to 8 dS/m. SAR to 2 in the subsoil. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | Walsh | 393.1 | Fine-Loamy, Mixed, Superactive, Frigid Pachic Hapludolls | Well/ Moderately Well | Mar - Jun: 4 - 6 | None | Colluvium at the periphery of the Valley | Non-saline, non-sodic. Surface and subsoil salinity to <1 dS/m. SAR <1 in surface and subsoil. | **None**. Soils are associated with upper terraces and footslopes distant from the river . |
| | Wahpeton | 356.5 | Fine, Smectitic, Frigid Typic Hapluderts | Moderately Well | >6 | Occas: Mar - Jun | Natural Levees, stream terraces | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None to Slight** in areas near the river. Moderately well drained natural levee soil. |
| | Lamoure, Saline | 275.2 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Poor | Oct - Jun: 0 - 1.5 | Freq: Mar - Oct | Active Floodplains and meanders | Saline, non-sodic. Surface salinity ranges from 4-8 dS/m, subsoil salinity ranges from 8-16 dS/m. SAR to 2 in the surface and 4 in the subsoil. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | Marsh | 161.4 | No Classification | Very Poor | Jan - Dec: 0 - 0 | NA | Depressions, small lakes, oxbow lakes | No salinity given, should be similar to Southam (0-4 dS/m) | **Moderate to severe** in areas on the floodplain, |
| | Cavour | 120.9 | Fine, Smectitic, Frigid Calcic Natrudolls | Moderately Well | Apr - Jun: 4-6 | None | Till plains, flood plains, terraces | Saline/sodic. Subsoil salinity 8 to 16 dS/m. SAR to 5 in the surface, to 25 in the subsoil | **Moderate to Severe**. Low terrace approximately 1.5 m above river, channeled. |
| | Aberdeen | 110.0 | Fine, Smectitic, Frigid Glossic Natrudolls | Moderately Well | Apr - Jun: 4 - 6 | None | Alluvium on floodplains | Saline/sodic, Subsoil salinity to 8 dS/m. SAR to 15 in the subsoil. | **Moderate to Severe**. Immediately adjacent to the river in positions similar to Ryan. |

Table 5. Selected physical, hydrologic, chemical, and geomorphic characteristics of association soils identified along the Sheyenne River.

| Association, Included Counties and Applicable Soil Survey | Soil Series Name | Acres per Component | Taxonomic Classification/Drainage | Drainage | Seasonal High Groundwater | Annual Flooding/ Duration | Landscape Position | Salinity/Sodicity Characteristics | Comments: Salinity Hazards |
|---|---|---|---|---|---|---|---|---|---|
| Lamoure-LaDelle-LaPrairie-Ryan Association, continued. | Cresbard | 83.6 | Fine, Smectitic, Frigid Glossic Natrudolls | Moderately Well | Apr - Jun: 4-6 | None | Glacial till plain | Saline/sodic, Subsoil salinity 2 to 8 dS/m. SAR to 5 in the surface, and to 15 in the subsoil. | **Moderate to severe**. Low terrace approximately 1.5 m above river, channeled. |
| | Claire Channneled | 83.3 | Mixed, Frigid Typic Psammaquents | Excessively | >6 | NA | Outwash Plains and Terraces | Non-saline, non-sodic. Surface and subsoil salinity to <1 dS/m. SAR <1 in surface and subsoil. | **None**. Excessively drained. Mapped as inclusion in LaDelle. |
| | Minnewaukan | 83.3 | Mixed, Frigid Typic Psammaquents | Poor | Mar - Jul: -0.5 1.5 | Occas: Apr - Jun | Alluvium on floodplains | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR to 1 in the surface and 5 in the subsoil. | **Moderate to Severe**. Low terrace approximately 1.5 m above river. |
| | Colvin | 98.7 | Fine-Silty, Mixed, Superactive, Frigid Typic Calciaquolls | Poor/Very Poor | Mar - Jul: 0-1.5 | None | Glacial outwash plains, floodplains | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR to 2 in the surface, to 10 in the subsurface. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow. channeled areas very susceptible to salinization. Mapped in complex with LaPrairie soils in Wells county. |
| | Velva Channeled | 74.9 | Coarse-loamy, Mixed, Superactive, Frigid Fluventic Haplustolls | Excessively | >6 | None | Floodplains | Non-saline, non-sodic. Surface and subsoil salinity to <1 dS/m. SAR <1 in the surface and subsoil. | **None**. Well drained. Mapped as inclusion with LaDelle in Nelson County |
| | Exline | 49.0 | Fine, Smectitic, Frigid Leptic Natrudolls | Somewhat Poor | Apr - Jun: 1.5 - 3.5 | None | Outwash deposits | Saline/sodic. Surface salinity to 16 dS/m, subsoil salinity to 8 dS/m. SAR to 20 in the subsoil | **Moderate to Severe**. Low terrace approximately 1.5 m above river. |
| | Borup | 46.6 | Coarse-Silty, Mixed, Superactive, Frigid Typic Calciaquolls | Poor/Very Poor | Apr - Jun: 0-2.5 | None | Outwash deposits | Non-saline, non-sodic. Surface salinity to 4 dS/m, subsurface salinity to 8 dS/m. SAR <1 in the surface and subsoil. | **Moderate to Severe**. Low terrace 1.5 m above river. |
| | Embden | 35.8 | Coarse-Loamy, Mixed, Superactive, Frigid Pachic Hapludolls | Moderately Well | Apr - Jun: 3 - 5 | None | Outwash plains | Non-saline, non-sodic. Surface and subsoil salinity to 2 dS/m. SAR < 1 in the surface and subsoil. | **None to Slight** in areas adjacent to the river. Mapped as inclusion in Ladelle channeled in Nelson County Area. |
| | Wamduska | 30.0 | Sandy, Mixed, Frigid Typic Udorthents | Excessive | >6 | None | Beaches, outwash | Non-saline, non-sodic. Surface and subsoil salinity to <1 dS/m. SAR <1 in surface and subsoil. | **None**. Excessively drained. Mapped as inclusion in LaDelle. |
| | Svea | 24.6 | Fine-Loamy, Mixed, Superactive, Frigid Pachic Hapludolls | Moderately Well | Apr - Jun: 4-6 | None | Till plains, local alluvium | Non-saline, non-sodic. Surface and subsoil salinity to <1 dS/m. SAR < 1 in surface and subsoil. | **None**. Mapped as inclusion in Cavour Cresbard. |
| | Miranda Variant | 21.1 | Fine, Smectitic, Frigid Leptic Natrustolls | Somewhat Poor | Apr - Jul: 2 - 4 | None | Till Plains | Saline/sodic. Subsoil salinity to 16 dS/m. SAR to 25 in the subsoil. | **None**. Well drained on high terrace above river. |
| | Marysland | 20.9 | Fine-Loamy Over Sandy Or Sandy-Skeletal, Mixed, Superactive, Frigid Typic Calciaquolls | Poor/Very Poor | Nov - Jul: 0-2 | None | Lacustrine, alluvium, outwash | Non-saline, non-sodic. Surface and subsurface salinity < 1 dS/m. SAR <1 in surface and subsoil. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow. Mapped as inclusion in Rauville. |
| | Other Soils <20 acres Total | 172.1 | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|
| **LaDelle-Ludden-Whapeton Association**; Griggs and Steele Counties, North Dakota; Soil Survey of Griggs County (NRCS Staff, In Press; SSAID ND039), Soil Survey of Steele County, North Dakota (Murphy et al., 1997; SSAID ND091) | Ladelle | 4888.2 | Fine-Silty, Mixed, Superactive, Frigid Cumulic Hapludolls | Moderately Well | Oct - Jun: 4-6 | Occas: Apr - Jun | Floodplain, terraces | Non-saline, non-sodic. Subsoil salinity up to 4 dS/m. SAR to 1 in the subsoil. | **None to Slight. None** in areas distant from the river to slight in areas potentially affected by water table rise. |
| | Wahpeton | 1064.4 | Fine, Smectitic, Frigid Typic Hapluderts | Moderately Well | >6 | Occas: Mar - Jun | Natural Levees | Non-saline, non sodic. Surface and subsoil salinity <1 dS/m. SAR to <1 in the surface and subsoil. | **None to Slight** in areas near the river. Moderately well drained natural levee soil. |
| | Ludden | 1122.0 | Fine, Smectitic, Frigid Typic Endoaquerts | Poor | Jan - Dec: -0.5 - 1.5 | Occas: Mar - Jul | Active Floodplain | Non-saline, non-sodic. Surface salinity to 2 dS/m, subsurface salinity to 8 dS/m. SAR to 2 in the subsoil. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow. |
| | Lamoure | 511.1 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Poor | Oct - Jun: 0-1.5 | Freq: Mar - Oct | Floodplains, drainageways, abandoned meanders | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR to 2 in the surface and 3 in the subsurface. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | LaPrairie | 509.9 | Fine-Loamy, Mixed, Superactive, Frigid Cumulic Hapludolls | Moderately Well | Mar - Jun: 3.5 - 5 | Rare | Floodplains Terraces | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR to <1 in the surface and subsoil. | **None to Slight.** None in positions distant from the river. Slight in positions closer to the River. |
| | Rauville | 501.7 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Very Poor | Jan - Dec: 0 - 0.5 | Freq: Mar - Oct | Floodplains, drainageways, abandoned meanders | Non-saline, non-sodic. Surface salinity to 2 dS/m, subsurface salinity to 4 dS/m. SAR to 2 in the surface and 3 in the subsurface. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | Southam | 201.9 | Fine, Smectitic, Calcareous, Frigid Cumulic Vertic Endoaquolls | Very Poor | Jan - Dec: -5 - 1.0 | None | Concave slope in depressions on till plains | Non-saline, non-sodic. Surface and subsurface salinity ranges from 2 to 8 dS/m. SAR to 2 in the surface and subsurface. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | Velva | 177.8 | Coarse-Loamy, Mixed, Superactive, Frigid Fluventic Haplustolls | Well | >6 | None | Flood Palins, low terraces | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in the surface and subsoil. | **None.** Well drained. |
| | Colvin | 154.3 | Fine-Silty, Mixed, Superactive, Frigid Typic Calciaquolls | Poor/ Very Poor | Mar - Jul: 0 - 1.5 | None | Lake Plains | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR to 2 in the surface, and to 10 in trhe subsurface. | **None.** Not hydrologically affected by the river. Mapped as inclusion in Bearden. |
| | Ryan | 40.7 | Fine, Smectitic, Frigid Typic Natraquerts | Poor | Mar - Jun: 0.5 - 1.5 | Occas: Mar - Jun | Active Floodplain | Saline/natric. Subsoil salinity to 16 dS/m. SAR to 2 in the surface and 4 in the subsoil. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow. Mapped as inclusion in Ludden. |
| | Ludden, Saline | 36.0 | Fine, Smectitic, Frigid Typic Endoaquerts | Poor | Jan - Dec: -0.5 - 1.5 | Occas: Mar - Jul | Active Floodplain | Saline, non-sodic. Surface salinity ranges from 4-8 dS/m, subsoil salinity ranges from 8-16 dS/m. SAR to 2 in the surface and 4 in the subsoil. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | Parnell | 28.1 | Fine, Smectitic, Frigid Vertic Argiaquolls | Very Poor | Nov - Jul: -1.0 - 1.0 | None | Depressions on Till Palins | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in the surface and subsoil. | **None.** Not hydrologically affected by the river. |
| | Marysland | 24.6 | Fine-Loamy Over Sandy Or Sandy-Skeletal, Mixed, Superactive, Frigid Typic Calciaquolls | Poor | Nov - Jul: 0-2 | None | Lacustrine, alluvium, outwash | Non-saline, non-sodic. Surface and subsurface salinity to 2 dS/m. SAR <1 in the surface and subsoil. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow. Inclusion in Rauville. Less subsoil salinity. |

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|---|---|---|---|---|---|---|---|---|---|
| LaDelle-Ludden-Whapeton Association, continued. | Vallers | 19.8 | Fine-Loamy, Mixed, Superactive, Frigid Typic Calciaquolls | Poor | Apr - Jul: 0.5 - 1.5 | None | Outwash and till plains | Non-saline, non-sodic. Surface and subsurface salinity to 4 dS/m. SAR to 4 in the surface, to 10 in the subsoil. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow. Mapped as inclusion in Rauville Lamoure. |
| | Bearden | 23.0 | Fine-Silty, Mixed, Superactive, Frigid Aeric Calciaquolls | Somewhat Poor | Apr - Jun: 1.5 - 3.5 | None | Lake Plain | Non-saline, non-sodic. Subsoil salinity to 8 dS/m. Subsoil SAR to 10. | **None**. Not in a position to receive groundwater originating in the Sheyenne River. |
| | Fairdale | 11.0 | Fine-Loamy, Mixed, Superactive, Calcareous, Frigid Mollic Udifluvents | Moderately Well | Mar - Jun: 3.5 - 5 | Occas: Mar - Jun | Floodplains/ Terraces | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in the surface and subsoil. | **Slight to Moderate**. Slight in areas distant from the river to moderate in channeled areas near the river. |
| | Other Soils <10 acres Total | 50.2 | | | | | | | |

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| Association, Included Counties and Applicable Soil Survey | Soil Series Name | Acres per Component | Taxonomic Classification/Drainage | Drainage | Seasonal High Groundwater | Annual Flooding/ Duration | Landscape Position | Salinity/Sodicity Characteristics | Comments: Salinity Hazards |
|---|---|---|---|---|---|---|---|---|---|
| **LaDelle-Nutley Association**; Barnes County North Dakota; Soil Survey of Barnes County (Opdahl et al., 1990; SSAID ND003) | Ladelle | 3037.9 | Fine-Silty, Mixed, Superactive, Frigid Cumulic Hapludolls | Moderately Well | Oct - Jun: 4 - 6 | Occas: Oct - Jun | Floodplain | Non-saline, non-sodic. Subsoil salinity up to 4 dS/m. SAR to 1 in the subsoil. | **None to Slight.** None in areas distant from the river. Slight in areas near the river subject to mean increase in river stage. |
| | Nutley | 1666.0 | Fine, Smectitic, Frigid Chromic Hapluderts | Well | >6 | None | Colluvium on periphery of Valley | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil | **None.** Well drained |
| | Sinai | 864.1 | Fine, Smectitic, Frigid Typic Hapluderts | Well/ Moderately Well | >6 | None | Alluvium/ Colluvium periphery of Valley | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil | **None**. Moderately well and well drained. Not in a position to receive groundwater originating in the Sheyenne River. |
| | Fairdale | 725.4 | Fine-Loamy, Mixed, Superactive, Calcareous, Frigid Mollic Udifluvents | Moderately Well | Apr - Jun: 3 - 5 | Occas: Mar - Jun | Active Floodplain | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in the surface and subsoil. | **Slight to Moderate**. Slight in areas distant from the river to moderate in channeled areas near the river. |
| | Lamoure | 438.8 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Poor | Oct - Jun: 0 - 1.5 | Freq: Mar - Oct | Active Floodplains and meanders | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR to 2 in the surface and 3 in the subsurface. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | Fargo | 215.5 | Fine, Smectitic, Frigid Typic Epiaquerts | Poor | Sep - Jun: 0 - 3 | None | Lake Plains | Non-saline, non-sodic. Surface and subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil | **None.** Not in an area that would receive overflow and not in an area that would receive groundwater originating from the Sheyenne river. |
| | Overly | 84.3 | Fine-Silty, Mixed, Superactive, Frigid Pachic Hapludolls | Moderately Well | Apr - Jun: 3-5 | None | Lake Plains | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR <1 in surface and subsoil | **None**. Groundwater movement towards river. Mapped with Bearden on Lake Plain above river |
| | Dovray | 76.0 | Fine, Smectitic, Frigid Cumulic Vertic Epiaquolls | Poor/Very Poor | Jan - Dec: 0 - 0 | None | Lake Plains | Non-saline, non-sodic. Surface and subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil | **None.** Not in an area that would receive overflow and not in an area that would receive groundwater originating as Sheyenne river water. |
| | Fordville | 56.3 | Fine-Loamy Over Sandy Or Sandy-Skeletal, Mixed, Superactive, Frigid Pachic Hapludolls | Well | >6 | None | Outwash Plains and Terraces | Non-saline, non-sodic. Surface and subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil | **None.** Not in a position that would receive groundwater originating as Sheyenne River water (elevated terrace). Well Drained. |
| | Colvin Channeled | 40.3 | Fine-Silty, Mixed, Superactive, Frigid Typic Calciaquolls | Poor/ Very Poor | Mar - Jul: 0 - 1.5 | None | Lake Plains | Non-saline, non-sodic. Subsoil salinity up to 4 dS/m. SAR to 3 in the surface, 10 in the subsurface | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow. Channeled areas very susceptible to salinization |
| | Marysland | 26.9 | Fine-Loamy Over Sandy Or Sandy-Skeletal, Mixed, Superactive, Frigid Typic Calciaquolls | Poor/ Very Poor | Nov - Jul: 0-2 | None | Lacustrine, alluvium, outwash | Non-saline, subsurface salinity <1 dS/m. SAR <1 in surface and subsoil. | **Slight to Moderate**. Soil located in areas on the floodplain and in areas susceptible to overflow. Inclusion in Lamoure units. Non-saline with low surface and subsoil salinity. |
| | Bearden | 25.1 | Fine-Silty, Mixed, Superactive, Frigid Aeric Calciaquolls | Somewhat Poor | Apr - Jun: 1.5 - 3.5 | None | Lake Plains | Non-saline, non-sodic. Subsoil salinity to 8 dS/m. SAR to 2 in the surface, to 10 in the subsurface. | **None.** Not in an area that would receive overflow and not in an area that would receive groundwater originating as Sheyenne river water. |
| | Gardena | 19.2 | Coarse-Silty, Mixed, Superactive, Frigid Pachic Hapludolls | Moderately Well | Apr - Jun: 3 - 5 | None | Lake Plains | Non-saline, non-sodic. Surface and subsoil salinity to 2 dS/m. SAR to 2 in the subsoil. | **None.** Not in an area that would receive overflow and not in an area that would receive groundwater originating as Sheyenne river water. Inclusion in Bearden Unit. |
| | Rauville | 13.4 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Very Poor | Jan - Dec: 0 - 0.5 | Freq: Mar - Oct | Floodplains, drainageways, abandoned meanders | Non-saline, non-sodic. Surface salinity to 2 dS/m, subsurface salinity to 4 dS/m. SAR to 2 in the surface and 3 in the subsurface. | **Moderate to severe** in areas on the floodplain and in areas susceptible to overflow |

Table 5. Selected physical, hydrologic, chemical, and geomorphic characteristics of association soils identified along the Sheyenne River.

| Association, Included Counties and Applicable Soil Survey | Soil Series Name | Acres per Component | Taxonomic Classification/Drainage | Drainage | Seasonal High Groundwater | Annual Flooding/ Duration | Landscape Position | Salinity/Sodicity Characteristics | Comments: Salinity Hazards |
|---|---|---|---|---|---|---|---|---|---|
| LaDelle-Nutley Association, Continued. | Colvin, Saline | 9.0 | Fine-Silty, Mixed, Superactive, Frigid Typic Calciaquolls | Poor/ Very Poor | Mar - Jul: 0-1.5 | Occas: Mar - Jun | Floodplains, abandoned meanders | Saline, non-sodic. Surface and subsoil salinity varies from 4 to 16 dS/m. SAR to 2 in the surface, to 10 in the subsurface. | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | Other Soils <10 acres Total | 41.4 | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|
| **Fairdale-LaPrairie-LaDelle Soils Association**; Ransom County North Dakota; Soil Survey of Ransom County (NRCS Staff, In Press; SSAID ND073) | Fairdale | 7961.6 | Fine-Loamy, Mixed, Superactive, Calcareous, Frigid Mollic Udifluvents | Moderately Well | Apr - Jun: 1.5 - 3.5 | Occas: Mar - Jun | Active Floodplain | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil. | **Slight to Moderate**. Slight in areas distant from the river to moderate in channeled areas near the river. |
| | Ladelle | 2010.1 | Fine-Silty, Mixed, Superactive, Frigid Cumulic Hapludolls | Moderately Well | Apr - Jun: 3.5 -5 | Occas: Apr - Jun | Floodplain /terraces | Non-saline, non-sodic. Subsoil salinity up to 4 dS/m. SAR <1 in surface and subsoil. | **None to Slight.** None in areas distant from the river. Slight in areas near the river subject to mean increase in river stage. |
| | La Prairie | 2991.8 | Fine-Loamy, Mixed, Superactive, Frigid Cumulic Hapludolls | Moderately Well | Mar - Jun: 3.5 - 5 | Rare | Floodplains Terraces | Non-saline, non sodic. Surface and subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil. | **None to Slight**. None in positions distant from the river. Slight in positions adjacent to the River. |
| | Lamoure | 186.6 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Poor | Oct - Jun: 0-1.5 | Occas: Mar - Oct | Floodplains, abandoned meanders | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR to 2 in the surface, 3 in the subsurface | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow |
| | Rauville | 170.3 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Very Poor | Jan - Dec: 0-0.5 | Freq: Mar - Oct | Floodplains, abandoned meanders | Non-saline, non-sodic. Surface salinity to 2 dS/m, subsurface salinity to 4 dS/m. SAR to 2 in the surface, 3 in the subsurface | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow. |
| | Fordville | 83.8 | Fine-Loamy Over Sandy Or Sandy-Skeletal, Mixed, Superactive, Frigid Pachic Hapludolls | Well | >6 | None | Beach Ridges, Outwash Plains | Non-saline, non-sodic. Surface and subsoil salinity to 2 dS/m. SAR <1 in the surface and subsoil. | **None.** Well drained |
| | Gardena | 37.9 | Coarse-Silty, Mixed, Superactive, Frigid Pachic Hapludolls | Moderately Well | Apr - Jun: 3-5 | None | Lake Plains, Near shore sediments | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. Subsoil SAR to 2. | **None. No flooding, n**ot in a position to receive groundwater originating from the Sheyenne River.. |
| | Marysland | 29.1 | Fine-Loamy Over Sandy Or Sandy-Skeletal, Mixed, Superactive, Frigid Typic Calciaquolls | Poor/Very Poor | Mar - Jul: 0-1.5 | None | Lacustrine, alluvium, outwash | Non-saline, subsurface salinity to 2 dS/m. SAR <1 in surface and subsoil. | **Slight to Moderate** in areas on the floodplain and in areas susceptible to overflow. Inclusion in Rauville. Surface and subsoil salinity < 1 dS/m. |
| | Eckman | 17.1 | Coarse-Silty, Mixed, Superactive, Frigid Calcic Hapludolls | Well | >6 | None | Periphery of the Sheyenne Valley | Non-saline, non-sodic. Subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None**, well drained, not in a position to receive groundwater originating from the Sheyenne River.. |
| | Other Soils <10 acres Total | 18.0 | | | | | | | |

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| Association, Included Counties and Applicable Soil Survey | Soil Series Name | Acres per Component | Taxonomic Classification/Drainage | Drainage | Seasonal High Groundwater | Annual Flooding/ Duration | Landscape Position | Salinity/Sodicity Characteristics | Comments: Salinity Hazards |
|---|---|---|---|---|---|---|---|---|---|
| **Fairdale-LaDelle-Whapeton-Delta Soils Association**; Richland County North Dakota; Soil Survey of Richland County, and Sheyenne National Grassland area of Ransom County (Thompson and Joos, 1975; SSAID ND077) | Fairdale | 2562.5 | Fine-Loamy, Mixed, Superactive, Calcareous, Frigid Mollic Udifluvents | Moderately Well | Apr - Jun: 3 - 5 | Occas: Mar - Jun | Active Floodplain | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil. | **Slight to Moderate**. Slight in areas distant from the river to moderate in channeled areas near the river. |
| | Ladelle | 1004.1 | Fine-Silty, Mixed, Superactive, Frigid Cumulic Hapludolls | Moderately Well | Oct - Jun: 3.5 - 5 | Occas: Apr - Jun | Floodplain and low terraces | Non-saline, non-sodic. Subsoil salinity up to 4 dS/m. SAR <1 in surface and subsoil. | **None to Slight.** None in areas distant from the river. Slight in areas near the river subject to mean increase in river stage. |
| | Wahpeton | 739.3 | Fine, Smectitic, Frigid Typic Hapluderts | Moderately Well | >6 | Occas: Mar - Jun | Natural Levees | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None to Slight** in areas near the river. Moderately well drained natural levee soil. |
| | Gardena | 562.9 | Coarse-Silty, Mixed, Superactive, Frigid Pachic Hapludolls | Moderately Well | Apr - Jun: 3 - 5 | None | Lake Plain, nearshore sediments | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR to 2 in the subsoil. | **None.** Not hydrologically affected by the river. Gardena soils associated with places where the river transitions to the Lake Plain and cut through nearshore sedimments. Lidar data indicated that most Gardena soils are elevated 4-5 meters (15 feet) above the Sheyenne floodplain. |
| | Wet Alluvial Land | 321.5 | No Classification | Very Poor | Jan- Dec: 0 - 2 | Freq: April - Jul | Seeps, abandoned meanders, swales. | Non- to strongly saline, 2-16 dS/m. Sodicity not listed. | **None to Slight**. Most wet alluvial land map units are groundwater seeps at the valley toeslope. Some areas are mapped in elevated abandoned meanders and swales. The Sheyenne is strongly effluent (receives groundwater) in the area of the Sheyenne Delta. The majority of wet alluvial areas are groundwater fed and would not likely be affected by the alternatives. |
| | Towner | 222.0 | Sandy Over Loamy, Mixed, Superactive, Frigid Calcic Hapludolls | Well/ Moderately Well | Apr - Jun: 3 - 5 | None | Sheyenne Delta, sand mantled Till Plain | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil. | **None**. Not hydrologically affected by the river. Some units are close to the entrenchment, but are elevated 2-3 meters above the flood plain and are listed as having a perched watertable. |
| | Embden | 202.9 | Coarse-Loamy, Mixed, Superactive, Frigid Pachic Hapludolls | Moderately well | Apr - Jun: 3 - 5 | None | Lake Plain, Sheyenne Delta Uplands | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil. | **None**. Not hydrologically affected by the river. Most Embden units are on elevated terraces. Embden soils never flood, and the majority of the groundwater flow is towards the river. |
| | La Prairie | 190.2 | Fine-Loamy, Mixed, Superactive, Frigid Cumulic Hapludolls | Moderately Well | Mar - Jun: 3.5 - 5 | Occas: Mar - Jun | Floodplains/ Terraces | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None to Slight**. None in positions distant from the river. Slight in positions adjacent to the river subject to mean increased river stage and increased flooding. |
| | Fossum | 168.0 | Sandy, Mixed, Calcareous, Frigid Typic Endoaquolls | Poor | Nov - Oct: 0.5 - 1.5 | None | Lake Plain and Delta Uplands | Non-saline, non sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None**. Fossum soils are on elevated terraces above the river, never flood, and are groundwater fed. These soils are not hydrologically affected by the river. |
| | Arveson | 168.0 | Coarse-Loamy, Mixed, Superactive, Frigid Typic Calciaquolls | Poor | Apr - Jul: 0-2 | None | Lake Plain and Delta Uplands | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None**. Arveson soils are on elevated terraces above the river, never flood, and are groundwater fed. These soils are not hydrologically affected by the river. |
| | Hecla | 126.5 | Sandy, Mixed, Frigid Oxyaquic Hapludolls | Moderately Well | Apr - Jun: 3 - 5 | None | Lake Plain and Delta Uplands | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None**. Hecla soils are on elevated terraces above the river, never flood, and recharge the groundwater. Groundwater flow towards river. |
| | Tiffany | 115.0 | Coarse-Loamy, Mixed, Superactive, Frigid Typic Endoaquolls | Poor | Apr - Jun: 1 - 4 | None | Lake Plain and Delta Uplands | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None**. Not hydrologically affected by the river. Most Tiffany units are on elevated terraces. Tiffany soils never flood, and groundwater flow is towards the river. |

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|---|---|---|---|---|---|---|---|---|---|
| Fairdale-LaDelle-Whapeton-Delta Soils Association, cotinued. | Overly | 113.2 | Fine-Silty, Mixed, Superactive, Frigid Pachic Hapludolls | Moderately Well | Apr - Jun: 4 - 6 | None | Lake Plain and Delta Uplands | Non-saline, non-sodic. Surface salinity <1 dS/m, subsoil salinity to 4 dS/m. SAR <1 in surface and subsoil. | **Slight to Moderate** in areas near the river. Overly soils are present at elevations of 2-3 meters above the channeled floodplain, and may be subject to an elevated mean river stage. Overly soils never flood; but may receive overflows and have increased watertable elevations. Subsoil salts can be relatively high. |
| | Swenoda | 92.3 | Coarse-Loamy, Mixed, Superactive, Frigid Pachic Hapludolls | Moderately Well | Mar - Jun: 2.5 - 4 | None | Lke Plain, Sheyenne Delta, and mantled Lake Plains | Non-saline, non-sodic. Subsoil salinity to 4 dS/m. SAR <1 in surface and subsoil. | **None**. Groundwater flow towards river. Some units are close to the entrenchment, but are elevated 2-3 meters above the flood plain and are listed as having a perched watertable. |
| | Hamar | 89.4 | Sandy, Mixed, Frigid Typic Endoaquolls | Somewhat Poor/Poor | Oct - Jun: 0-2 | None | Lacustrine/ Aeolian deposits on Lake Plain and Delta | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil. | **None**. Hamar soils are mapped in complex with Hecla soils are on elevated terraces above the river and never flood. Not hydrologically connected to the river. |
| | Colvin | 56.8 | Fine-Silty, Mixed, Superactive, Frigid Typic Calciaquolls | Poor/Very Poor | Apr - JunA: 0 - 1 | None | Lake Plain, depressions and swales | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR to 2 in the surface, to 10 in the subsurface. | **None.** Map Unit is on an elevated position on the Lake Plain distant from the Sheyenne River. |
| | Tonka | 0.0 | Fine, Smectitic, Frigid Argiaquic Argialbolls | Poor | | | | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil. | **None.** Not hydrologically affected by the river. Associated with till inclusions. Possible mismap for Fairdale channeled (Fp). Acreage added to Fairdale |
| | Parnell | 0.0 | Fine, Smectitic, Frigid Vertic Argiaquolls | Very Poor | | | | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None.** Not hydrologically affected by to the river. Associated with till inclusions. Possible mismap for Fairdale channeled. (Fp). Acreage added Fairdale. |
| | Glyndon | 23.3 | Coarse-Silty, Mixed, Superactive, Frigid Aeric Calciaquolls | Moderately Well/Somewhat Poor | Apr - Jul: 2.5 - 6 | None | Lake Plain, Sheyenne Delta | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR <1 in surface and subsoil. | **None**. Glyndon soils are on elevated terraces above the river, never flood, and are groundwater fed. These soils are not hydrologically affected by the river. |
| | Galchutt | 22.3 | Fine, Smectitic, Frigid Vertic Argialbolls | Somewhat Poor | Apr - Jun: 1-3 | None | Lake Plain | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None**. Not hydrologically affected by the river. Mapped in association with Overly, listed as never flooding, with a perched watertable. |
| | Perella | 19.9 | Fine-Silty, Mixed, Superactive, Frigid Typic Endoaquolls | Poor | Apr - Jul: 0-2 | None | Abandoned meanders, swales, shallow flats on Lake Plain | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None**. Mapped in elevated meanders, no surface or subsoil salinity. No flooding indicated. Listed as having a perched watertable. This soil will not receive groundwater originating from the Sheyenne River. |
| | Ulen | 14.2 | Sandy, Mixed, Frigid Aeric Calciaquolls | Moderately Well/ Somewhat Poor | Apr - Jul: 2.5 - 6 | None | | Non-saline, non-sodic. Surface and subsoil salinity to 4 dS/m. SAR <1 in surface and subsoil. | **None**. Ulen soils are on elevated terraces above the river, never flood, and are groundwater fed. These soils are not hydrologically affected by the river. |
| | Other Soils <10 acres Total | 16.7 | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|
| **Fairdale-Fargo Association**; Cass County North Dakota; Soil Survey of Cass County (Prochnow et al., 1986; SSAID ND602) | Fairdale | 3723.2 | Fine-Loamy, Mixed, Superactive, Calcareous, Frigid Mollic Udifluvents, Moderately Well Drained | Moderately Well | Apr - Jun: 3 - 5 | Frequent: Mar-Jun | Active Floodplain | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil | **Slight to Moderate.** Slight in areas distant from the river. Moderate in channeled areas near the river subject to mean increase in river stage and increased flooding. |
| | Fargo | 3398.2 | Fine, Smectitic, Frigid Typic Epiaquerts | Poor | Sept - Jun: 0 - 3 | Occasional: Jan-Apr | Lake Plain | Non-saline, non-sodic. Surface and subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil | **None**. Distant from the floodplain. Not hydrologically affected by the river. Most soils on the floodplain are poorly drained due to slow permeability. Watertables are usually well above the level of the river. |
| | Ladelle | 1104.7 | Fine-Silty, Mixed, Superactive, Frigid Cumulic Hapludolls | Moderately Well | Oct - Jun: 4 - 6 | Occas: Oct - Jun | Floodplain-terraces | Non-saline, non-sodic. Subsoil salinity to 4 dS/m. Subsoils SAR up to 1 | **None to Slight.** None in areas distant from the river. Slight in areas near the river subject to mean increase in river stage. Most LaDelle areas are mapped upstream near the Sheyenne Delta. |
| | Cashel | 1097.6 | Fine, Smectitic, Calcareous, Frigid Aquertic Udifluvents | Somewhat Poor | April - Jul: 1 - 3 | Freq.: Mar May: Occas. Higher Positions | Lake Plain-abandoned meanders | Non-saline, non-sodic. Surface and subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil. | **Slight to Moderate.** Slight in areas above the entrenchment. Moderate in areas near the river subject to mean increase in river stage and overbank flooding. Cashel soils are associated with floodplain positions and abandoned meanders occupied by Cashel channeled and Rauville soils. |
| | Ryan | 841.6 | Fine, Smectitic, Frigid Typic Natraquerts | Poor | Mar. - Jul: 0 - 0 | Occas: Mar - Jun | Floodplain-lakeplain | Saline, non-sodic. Subsoil salinity to 16 dS/m. Subsoil SAR up to 4. | **None**. Distant from the floodplain. Ryan soils are associated with the Lake Plain in Cass County. Not hydrologically affected by the river. |
| | Fairdale Variant | 748.9 | Fine-Loamy, Mixed, Superactive, Calcareous, Frigid Mollic Udifluvents, Moderately Well Drained | Moderately Well | Apr - Jun: 2 - 4 | NA | Splays | Non-saline, subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil | **None to Slight**. Soil is described as occupying splays above the entrenchment and is rarely flooded. When flooded, soils quickly drain. |
| | Hegne | 695.4 | Fine, Smectitic, Frigid Typic Calciaquerts | Poor | Mar - Jul: 0 - 1.5 | NA | Lake Plain | Non-saline, non-sodic. Subsoil salinity up to 4 dS/m. Subsoil SAR to 2. | **None.** Distant from the floodplain. Not hydrologically affected by the river. |
| | Overly | 525.0 | Fine-Silty, Mixed, Superactive, Frigid Pachic Hapludolls | Moderately Well | Apr - Jun: 3 - 5 | NA | Lake Plain | Non-saline, non-sodic. Subsoil salinity to 4 dS/m. SAR <1 in surface and subsoil | **None**. Distant from the floodplain. Not hydrologically affected by the river. |
| | Dovray | 380.9 | Fine, Smectitic, Frigid Cumulic Vertic Epiaquolls | Very Poor | Jan - Dec: 0 - 0 | NA | Abandoned Meanders | Non-saline, non-sodic. Subsoil salinity < 1 dS/m. SAR <1 in surface and subsoil | **Slight to Moderate**. Mapped in abandoned meanders in complex with Ludden and Fargo. Subject to salinization in areas subject ot overflow and mean increase in river stage. Groundwater recharge position, however (epiaquic). |
| | Wahpeton | 289.9 | Fine, Smectitic, Frigid Typic Hapluderts | Moderately Well | >6 | Occas: Mar - Jun | Levees, Low Terraces | Non-saline, non-sodic. Subsoil salinty < 1 dS/m. SAR <1 in surface and subsoil | **None to Slight.** Moderately well drained on levees. |
| | Enloe | 153.6 | Fine, Smectitic, Frigid Argiaquic Argialbolls | Poor | Apr - Jun: 0 - 0 | NA | Lake Plain | Non-saline, non-sodic. Subsoil salinity < 1 dS/m. SAR <1 in surface and subsoil. | **None**. Distant from the floodplain. Not hydrologically affected by the river. |
| | Bearden | 145.2 | Fine-Silty, Mixed, Superactive, Frigid Aeric Calciaquolls | Somewhat Poor | Apr - Jun: 1.5 - 3.5 | NA | Lake Plain | Non-saline, non-sodic. Subsoil salinity to 8 dS/m. Subsoil SAR to 10. | **None**, Distant from the floodplain. Not hydrologically affected by the river. |
| | Nahon | 132.5 | Fine, Smectitic, Frigid Calcic Natrudolls | Moderately Well | Apr - Jun: 3.5 - 5 | NA | Lake Plain | Saline and sodic. Subsoil salinity to 16 dS/m. Subsoil SAR to 20. | **None.** Distant from the floodplain. Not hydrologically affected by the river. |

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|---|---|---|---|---|---|---|---|---|---|
| **Fairdale-Fargo Association; Continued.** | Rauville | 121.4 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Very Poor | Jan - Dec: 0 - 0.5 | Freq: Mar - Aug | Floodplains, abandoned meanders, seep areas | Non-saline, non-sodic. Subsoil salinity to 4 dS/m. SAR to 2 in the surface, 3 in the subsurface | **Moderate to Severe.** Soils are mapped in areas on the floodplain and in areas susceptible to overflow. Mapped in abandoned meanders and natural swales and seepy areas in complex with Lamoure and Colvin saline. Could salinize adjacent soils if flooded more frequently. |
| | Perella | 101.6 | Fine-Silty, Mixed, Superactive, Frigid Typic Endoaquolls | Poor | Apr - Jun: 2-4 | NA | Lake Plain | Non-saline, non-sodic. Subsoil salinity < 1 dS/m. SAR < 1 in surface and subsurface | **None**. Distant from the floodplain. Not hydrologically affected by the river. |
| | Fargo Sic | 93.4 | Fine, Smectitic, Frigid Typic Epiaquerts | Poor | Sept - Jun: 0-3 | Occas: Jan - April | Lake Plain | Non-saline, non-sodic. Surface and subsoil salinity to 2 dS/m. SAR <1 in surface and subsurface. | **None**. Distant from the floodplain. Not hydrologically affected by the river. |
| | Nutley | 39.4 | Fine, Smectitic, Frigid Chromic Hapluderts | Well | >6 | NA | Lake Plain | Non-saline, non-sodic. Subsoil salinity to 2 dS/m. SAR <1 in surface and subsoil | **None**. Distant from the floodplain. Not hydrologically affected by the river. Well drained |
| | Ludden | 39.1 | Fine, Smectitic, Frigid Typic Endoaquerts | Poor | Mar - Jul: 0 - 1.5 | Freq: Mar - Jul | Floodplains, abandoned meanders, seep areas | Non-saline, non-sodic. Subsoil salinity up to 4 dS/m. SAR <1 in the surface, to 3 in the subsurface | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow. |
| | Lamoure | 33.0 | Fine-Silty, Mixed, Superactive, Calcareous, Frigid Cumulic Endoaquolls | Poor | Oct - Jun: 0-1.5 | Occas: Mar - Oct | Floodplains, abandoned meanders | Non-saline, non-sodic. Subsoil salinity up to 4 dS/m. SAR to 2 in the surface, 3 in the subsurface | **Moderate to Severe** in areas on the floodplain and in areas susceptible to overflow. Mapped in abandoned meanders in complex with Rauville and Colvin Saline soils. |
| | Great Bend | 21.4 | Fine-Silty, Mixed, Superactive, Frigid Calcic Hapludolls | Well | >6 | None | Lake Plain | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None.** Distant from the floodplain. Not hydrologically affected by the river. Well drained |
| | Colvin | 18.5 | Fine-Silty, Mixed, Superactive, Frigid Typic Calciaquolls | Poor | Mar - Jul: 0-1.5 | Occas: Mar - Jun | Floodplains, abandoned meanders | Non-saline, non-sodic. Subsoil salinity up to 4 dS/m. SAR to 3 in the surface, 10 in the subsurface | **None**. Distant from the floodplain. Mapped as inclusions in several units distant from the river. |
| | Colvin, Saline | 16.4 | Fine-Silty, Mixed, Superactive, Frigid Typic Calciaquolls | Poor | Mar - Jul: 0-1.5 | Occas: Mar - Jun | Floodplains, abandoned meanders | Saline, non-sodic. Surface and subsoil salinity varies from 4 to 16 dS/m. SAR to 2 in the surface, to 10 in the subsurface. | **Severe** in areas adjacent to the river. Mapped in complex with Rauville in meanders. Mobilization of salts could salinize adjacent soils. |
| | Fargo, Channeled | 12.2 | Fine, Smectitic, Frigid Typic Epiaquerts | Poor | Jan - Dec: 0 - 0 | Occas: Mar - Jun | Lake Plain, channelled areas | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **Slight to Moderate** in areas near the river. Channel bottoms susceptible to salinization under increaased river stages. |
| | Lindaas | 9.8 | Fine, Smectitic, Frigid Typic Argiaquolls | Poor | Mar - Jun: 0 - 0 | None | Lake Plain | Non-saline, non-sodic. Surface and subsoil salinity <1 dS/m. SAR <1 in surface and subsoil. | **None**. Distant from the floodplain. Recharge wetland not groundwater fed. No flooding from river. |

Table 6. Acreage summary of soil salinization hazard class by soil association.

| Soil Association | None | None-to-Slight | Slight-to-Moderate | Moderate-to-Severe | Not Rated | Grand Total |
|---|---|---|---|---|---|---|
| **Soil Associations Upstream of Lake Ashtabula** | | | | | | |
| Lamoure-LaDelle-LaPrairie-Ryan | 627 | 2803 | 3036 | 7674 | 172 | 14312 |
| LaDelle-Ludden-Wahepeton | 1515 | 510 | 4923 | 2366 | 50 | 9364 |
| ***Subtotals (acreage)*** | ***2142*** | ***3313*** | ***7959*** | ***10040*** | ***222*** | ***23676*** |
| ***Subtotals (percent)*** | ***9.0*** | ***14.0*** | ***33.6*** | ***42.4*** | ***0.9*** | ***100.0*** |
| **Soil Associations Downstream of Baldhill Dam** | | | | | | |
| LaDelle-Nutley | 3006 | 3038 | 752 | 502 | 41 | 7339 |
| Fairdale-LaPrairie-LaDelle | 139 | 5002 | 7991 | 357 | 18 | 13507 |
| Fairdale-LaDelle-Wahpeton-Delta | 1884 | 2255 | 2676 | - | 17 | 6832 |
| Fargo-Fairdale | 6169 | 2144 | 5201 | 228 | - | 13742 |
| ***Subtotals (acreage)*** | ***11198*** | ***12439*** | ***16620*** | ***1087*** | ***76*** | ***41420*** |
| ***Subtotals (percent)*** | ***27.0*** | ***30.0*** | ***40.1*** | ***2.6*** | ***0.2*** | ***100.0*** |
| **Grand Totals (acreage)** | **13340** | **15752** | **24579** | **11127** | **298** | **65096** |
| **Grand Totals (percent)** | **20.5** | **24.2** | **37.8** | **17.1** | **0.5** | **100.0** |