Irrigation water quality effects on soil salinity and crop production in the Powder River Basin, MT
by Kathryn S Thompson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Seience in Soils
Montana State University

Abstract:
Saline soils occur for the most part in arid or semi-arid regions. Low rainfall, high evapotranspiration, and inadequate leaching cause salts to accumulate in the root zone of soil profiles. Salinity problems of economic significance arise when cultivated soils become saline as a result of irrigation (U.S. Salinity Staff, 1969). One concern of irrigators in the Powder River basin of Montana is that an increase in irrigation water salinity will result in soil degradation and diminished crop production (Gallagher, 1986).

A greenhouse study was conducted to determine if crop yields and soil properties were affected under sustained irrigation with water quality of increasing salinity and sodicity. Twenty undisturbed soil columns were obtained from each of six soil sites and leached for 14 months with water quality treatments representing past, present, and future Powder River water quality. Columns were planted to alfalfa (Medicaqo sativa L.) or western wheatgrass (Agrgpyron smithii R.) and harvested on a monthly basis.

Soil water samples were periodically collected from soil columns and tested for salinity by EC (electrical conductivity), SAR (sodium adsorption ratio), and pH. Soil columns were then dismantled and sampled at the end of 14 months of continuous irrigation.

During the study period alfalfa yields did not significantly decline as a result of irrigation with water of past, present, or future water quality. However, long term irrigation and accelerated salt loading has resulted in significant amounts of salt and sodium accumulation in all soils of this study. All soils became saline or saline-sodic when irrigated with water assumed to be representative of future irrigation water quality. This will likely present a problem to future irrigation management, especially if present irrigation water quality deteriorates further.

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APPROVAL

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Kathryn S. Thompson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

12 July 1991
Date

James W. Bauder
Chairperson, Graduate Committee

Approved for the Major Department

14 July 1991
Date

Head, Major Department

Approved for the College of Graduate Studies

August 23, 1991
Date

Henry L Parsons
Graduate Dean

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Date June 7 1991

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Kathryn S. Thompson

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ABSTRACT

Saline soils occur for the most part in arid or semi-arid regions. Low rainfall, high evapotranspiration, and inadequate leaching cause salts to accumulate in the root zone of soil profiles. Salinity problems of economic significance arise when cultivated soils become saline as a result of irrigation (U.S. Salinity Staff, 1969). One concern of irrigators in the Powder River basin of Montana is that an increase in irrigation water salinity will result in soil degradation and diminished crop production (Gallagher, 1986).

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CHAPTER 1

INTRODUCTION

The amount of agricultural land in the United States under irrigation has been continually expanding, particularly in arid and semi-arid regions of the west (James et al., 1982). Crop production in these regions is often hampered by soil salinity and sodicity problems caused either by indigenous salts in the soil or by salts added with irrigation water. Salinity problems are expected to increase as more arid land is brought under irrigation. Salinity presently limits crop production on as much as one-forth of the seventeen western states and could potentially affect as much as one-half of all the irrigated western United States (James et al., 1982).

Fine-textured soils are particularly jeopardized by the salinity and sodicity of irrigation water. Irrigation water contains variable quantities of soluble salts that can accumulate in the soil profile as a result of evaporation, plant consumptive use and chemical precipitation (Hemb, 1984). Sodium in irrigation water can lead to clay dispersion and degradation of soil structure. This will cause soil water movement to be restricted throughout the soil profile.

The Powder River Basin in eastern Montana contains many irrigated, fine-textured soils. The Soil Conservation Service (SCS) soil survey for Powder River County (USDA, 1971) indicates that the soils in the Powder River Basin bottomland along the river consist mostly of silt loams, silty clay loams, and silty clays. These soils have been irrigated with Powder River water of increasing salinity since the 1920's (deMooy and Franklin, 1977). In the past two decades, reductions in irrigated crop yields have been attributed to prolonged irrigation with Powder River water (Gallagher, 1986).

Approximately 81% of the irrigated acreage in Powder River County from 1980 - 1983 was used for alfalfa production (Montana Agricultural Statistics, 1980 - 1983). Alfalfa is an important crop in arid and semi-arid areas because of its ability to symbiotically fix nitrogen and to root deeply. This latter characteristic of alfalfa enables it to continue extracting water deep in the soil after water has become limiting in surface soil layers. This makes alfalfa both environmentally suitable for this location and a crop of major economic agricultural importance.

The Powder River Conservation District (PRCD) and the Montana Department of Natural Resource and Conservation (DNRC) are concerned that oil well discharge in Wyoming is presently degrading water quality in the Powder River. Approximately 25% of the salt load in the Powder River comes from oil production discharges in the Salt Creek drainage in Wyoming (see map in Figure 1) (Wyoming Dept. Envir. Qual., 1984). Proposed developments in Wyoming, such as Middle Fork Reservoir on Middle Fork Creek (Figure 1), will likely further increase salinity levels in the Powder River by retaining good quality water. The DNRC estimated that the Middle Fork Reservoir would increase total dissolved salts (TDS) at Moorhead, Montana by 22% during the irrigation season (Gallagher, 1986). Powder River irrigators in Montana are concerned that water of deteriorated quality might result in diminished crop production by increasing salt and sodium concentrations in agricultural soils (deMooy and Franklin, 1977; Gallagher, 1986). In order for irrigation in this area to be successful, detrimental effects on the land due to water quality must be minimized.

The Powder River is inherently high in salt content because of the structural geology through which it passes (Figure 2). Geology consists mostly of Tertiary sandstones and shales in Montana. In the vicinity of Broadus, Montana, the concentration of dissolved solids in the river may exceed 2000 mg L^{-1} during an irrigation season (Hembree et al., 1952). Many of the Powder River tributaries are dominated by sodium and sulfate which have been leached from Tertiary and Cretaceous shales and sandstones south of Broadus (Hembree et al., 1952). The net result is a poor water quality with which producers are irrigating.

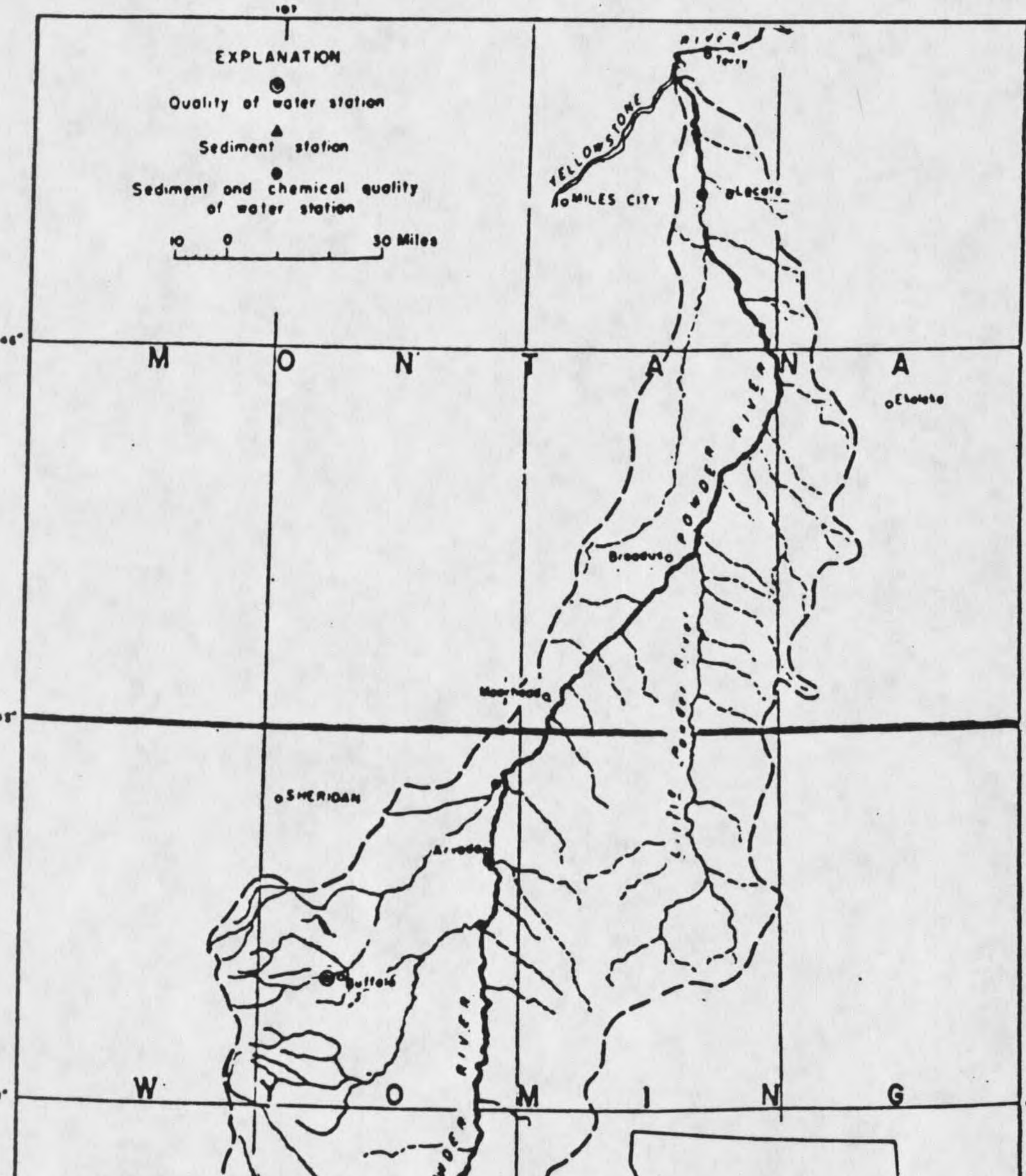

Figure 1. Powder River drainage basin, Wyoming and Montana. (From Hembree et al., 1952).

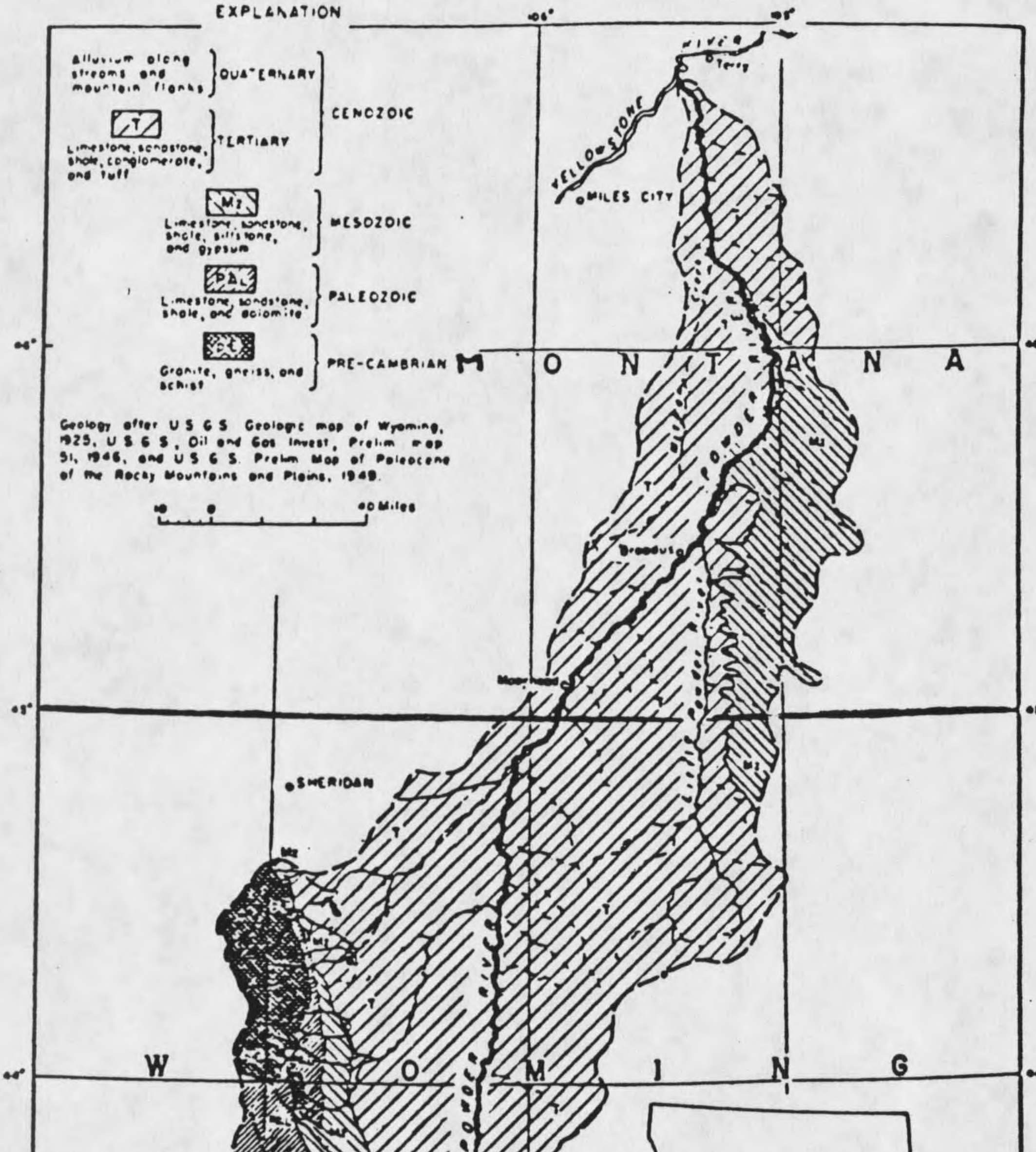

Figure 2. Structural geology of the Powder River basin. (From Hembree et al., 1952)

Furthermore, water quality modelling performed by the DNRC (Dalby, 1988) indicates that if the Middle Fork Reservoir were developed, continued degradation of the Powder River could be expected.

There are many research findings about the general effects of salinity and sodicity on soils and on plant growth (i.e., U.S. Salinity Staff, 1969). Guidelines for irrigation water quality have even been established for irrigators using water such as that from the Powder River (i.e., Maas and Hoffman, 1977; U.S. Salinity Staff, 1969). However, relatively little information is available concerning irrigation water quality effects on medium and fine textured soils in eastern Montana. Moreover, further refinement of our knowledge is required continuously in specific geographic areas, as more marginal lands are brought into production, and questionable water resources are used for irrigation. This project investigates problems associated with fine textured, salt- and sodium-affected soils in the Powder River Basin of Montana.

OBJECTIVES

The overall objective of this study was to evaluate the effects of irrigation water quality on soil chemical properties and on crop productivity, using soil representative of the irrigated acreage in the Powder River Conservation District. Water qualities used in this study were intended to be representative of past, present, and predicted future water quality conditions of Powder River water between Moorhead and Powderville, Montana. These levels were based on long term water quality trend analyses, conducted by the Montana DNRC and USGS (Dalby, 1988) using data from Moorhead, MT collection stations.

Specific objectives were:

1) to determine if and to what extent crop yields would be affected by prolonged irrigation with past, present, and future irrigation water qualities over extended periods of time;

2) to determine the extent to which salt and sodium accumulation would occur in various soils over time due to irrigation with past, present, and future water qualities;

3) to determine if sustained irrigation of selected soils with past, present, or future water quality would have a deleterious effect on soil and crop productivity.

CHAPTER 2

LITERATURE REVIEW

Criteria of Irrigation Water

Many problems associated with irrigated agriculture arise from the chemical composition of the water applied (James et al., 1982). Irrigation water contains varying amounts and different types of salts. Since water has no inherent quality except in the context for which it is used, specific use conditions dictate the suitability of a water. For purpose of this study, irrigation water is evaluated based on the potential to foster soil detrimental to crop growth. Four characteristics that are commonly used to evaluate irrigation water quality are: 1) salinity, 2) sodicity, 3) toxicity, and 4) suspended sediment.

Salinity

The salt effect of irrigation water is related to total salt concentration in irrigation water rather than specific constituents. Total salt concentration can be expressed as total dissolved solids (TDS) in mg L^{-1} or indirectly as electrical conductivity (EC) in dS m^{-1}. TDS can be obtained by evaporating to dryness an aliquot of filtered water and weighing the residue. The use of EC, however, has become the standard of comparison for water salinity. EC is based on the principle that the amount of electrical current transmitted by a salt solution under standardized conditions will increase as the salt concentration of the solution is increased (U.S. Salinity Staff, 1969). The conversion between TDS and EC for Powder River water is

$$TDS = 690(EC) \qquad \text{(eqn. 1)}$$

where TDS is in mg L^{-1} and EC is in dS m^{-1}. Equation 1 is based on 10 years of EC and TDS data collection at Moorhead, Montana (Gallagher, 1986).

When irrigation water is added to soil, salt precipitation in the soil occurs due to plant consumptive use of water. Many waters in semi-arid regions are partly or nearly saturated with respect to $CaCO_3$, and some contain high concentrations of SO_4^{2-}, which upon concentration could precipitate in the soil. Precipitation and dissolution of mineral salts, chiefly gypsum ($CaSO_4 \cdot 2H_2O$) or lime ($CaCO_3$), can reduce or increase salt concentration in soil solution (Rhoades et al., 1973).

Generally, a classification scheme to define a given salinity hazard is based on broad generalizations rather than on specifics such as crop type, climate, irrigation management, and soil properties (James et al., 1982). The result is a rather rigid classification, one that may not truly reflect the salinity hazard associated with irrigation water and type of crop grown.

Bernstein (1967) proposed a system, based on specific use factors, that takes into account soil and plant properties. The degree to which salinity develops in a nonsaline soil depends on the initial salinity of irrigation water and on the amount of water that moves through the root zone in excess of evapotranspiration demands. Adequate drainage allows excess water to carry salt water below the root zone. The fraction of applied, infiltrated irrigation water that passes the root zone is called the leaching fraction (LF) and is defined as

$$LF = \frac{D_d}{D_i} \qquad \text{(eqn. 2)}$$

where D_d is the depth of drainage water and D_i is the depth of irrigation water.

Since soil salinity is based on irrigation water salinity and leaching fraction, Bernstein (1967) developed the equation

$$EC_{iw} = LF\ (EC_d) \qquad \text{(eqn. 3)}$$

where EC_{iw} is the EC of irrigation water and EC_d is EC of drainage water. The permissible EC_{iw} that can be used under given conditions is calculated from equation 3. Table 1 shows some salinity tolerance thresholds for selected forage crops. These values are given for the average effective root