GROUND-WATER QUALITY STUDY
OF SEVERANCE BASIN, WELD COUNTY, COLORADO

Prepared for

Office of Water Resources Research
U. S. Department of Interior
Public Law 88-379
Allotment No. 14-01-0001-726

Civil Engineering Department
Engineering Research Center
Colorado State University
Fort Collins, Colorado

April 1966

CER66NFW-DKS5
GROUND-WATER QUALITY STUDY
OF SEVERANCE BASIN, WELD COUNTY, COLORADO

by

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with special section on Geology
by Murray McComas

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FORT COLLINS, COLORADO

April 1966

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ABSTRACT

Pollution of ground-water aquifers in the United States is becoming a problem of increasing importance. To study this problem, a small aquifer was selected near Windsor, Colorado. This aquifer had as pollution sources: cattle feedlots, fertilizers, oil field brine pits, geologic strata, and irrigation water.

The analysis of the problem consisted of a study of the individual pollution sources in the basin and an overall study of the basin using a mass balance technique. It was found that each of the above sources at a single entity contributed very little to the contamination of the aquifer. The primary cause of pollution was the high evapotranspiration rate as opposed to a low ground-water and surface water discharge from the area. This ratio of evapotranspiration to ground-water and surface water outflow produced an increase in the total dissolved solids of 173 ppm/year.
ACKNOWLEDGMENTS

The writers would like to express their appreciation to Murray McComas whose geologic work in the area produced much of the necessary information needed for the basin analysis. The writers are also indebted to Robert Longenbaugh for his guidance and assistance in initiating the study. Also, appreciation is extended to the land owners in the Severance Basin who gave permission for the use of their property in this study.

The investigation was supported by the United States Department of the Interior as authorized under the Water Resources Research Act of 1964, Public Law 88-379.
ORGANIZATION OF INVESTIGATION

This investigation was sponsored by the United States Department of Interior from funds authorized under the Water Resources Research Act of 1964, Public Law 88-379. The research was conducted under the supervision of R. A. Longenbaugh, Assistant Civil Engineer and D. K. Sunada, Assistant Professor of Civil Engineering. Mr. N. F. White, Graduate Assistant, was responsible for conducting the investigation.

This study, conducted at the Foothills Research Center, is part of a continuing program of research in ground-water hydrology.
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INTRODUCTION

The problem of ground-water pollution is continually gaining more attention. As potential water supplies are being better defined, the problem of water pollution is becoming more important. As a domestic source, untreated water from contaminated aquifers is of little value unless it can be rehabilitated. In many instances, the problems involved in reclaiming contaminated aquifers have been so great that no attempt has been made, and the rehabilitation of the contaminated aquifers has been left to nature's forces which could be a process lasting thousands of years. Considering this eventuality, it is extremely important to find a means of evaluating and preventing further contamination of the aquifers.

In connection with the increasing pollution of aquifers in Colorado, Colorado State University initiated (May 1965) a field study on a ground-water basin showing increasing contamination. This basin is located about 2 miles northeast of Windsor, Colorado. The ground water in this basin is primarily a result of percolation losses from irrigation and this ground water flows into the water bearing material associated with the Cache la Poudre River.

The increasing contamination in the basin can be attributed to several factors. These factors are: 1) leaching of applied fertilizer, 2) leaching contaminants from silage pits and feed lots, 3) percolation from oil-field brine pits, 4) application of irrigation water, and 5) geologic contamination of the aquifer.

To analyze this basin, both a geologic and hydrologic study were made. Due to the complex nature of contamination in this area, only general relationships were found between the aquifer and the contamination sources. In this report a discussion of these relationships will be presented.
BASIN DESCRIPTION

Physiographic Description

The location of this ground-water basin referred to as "Severance Basin" is shown in Figure 1. A detailed map of the basin is shown as a base to several of the figures in the text (i.e., Figures 3, 4, etc.).

The Severance Basin is rectangular in shape, approximately 2 miles wide by 5 miles in length. The basin encompasses 8.4 square miles of which 95 percent is farm land. Topographically, this is an area of gently rolling hills.

The basin is drained by a small slough which removes approximately 2700 acre-feet of water a year. There are three reservoirs in the basin, these being Law Reservoir, Gress Reservoir, and Loop Lake. These bodies of water act as sources of irrigation water during the summer months. On the eastern side of the basin there are five small lakes. In total, these lakes cover an area of approximately 200 acres and store about 1500 acre-feet of water.

The economy of this area consists of farming and cattle feeding. The primary crops grown are corn and sugar beets, while alfalfa, wheat, and other grains are grown to a lesser amount. Corn represents about 70 percent of the crop and the harvest is primarily used by the cattle feeders within the basin.

Almost every farm in the basin feeds cattle. There are three farms which have large feed lots handling from 500 to 2000 cattle a year. The large feed lot operations are not completely self-sustained and some corn must be imported. Associated with all the feed lots in the basin are silage pits in which the ensiled corn is stored.

The town of Severance is located in the central part of the basin and has a population of approximately 200 people. Most of
GENERAL LOCATION OF SEVERANCE BASIN IN COLORADO

FIGURE 1
the homes in the basin use septic tanks for lack of a central sewage disposal system.

In the northwestern part of the basin, California Oil Company, a subsidiary of Standard Oil of California, operates the New Windsor Oil Field. In the basin, this field has four pumping wells and three brine pits that collect brine from separating units. The pits are unlined and are thus potential sources of contamination to the aquifer.

**Climatological Description**

The climate in the area of the Severance Basin may be classed as semi-arid. Over the last 11 years, the average annual precipitation (1) was 11.12 inches while, during the period of November 1964 to October 1965, the precipitation was 14.15 inches. Temperatures over the last 11 years have averaged 48.2°F, with extremes of -32°F and 106°F. During the period from November to March the evaporation will range from 1 to 2 inches per month while from April to October the evaporation will range from 3 to 6 inches per month. The mean annual evaporation varies from 35 to 39 inches a year.

In general, the area is one of warm summers and cold winters. Snow is the main form of precipitation during the winter months. During the summer months precipitation occurs in the form of rain and hail. Summer thunderstorms are common and sometimes cause large surface runoffs.
Geologic Description

(by Murray McComas)

The Severance Basin is underlain by the Fox Hills sandstone. Several types of unconsolidated deposits rest on the Fox Hills in the basin. Figure 2, a surficial geology map of the basin, shows the location of these deposits in the Severance Basin. In the text below all the geologic units present on the surface are discussed in detail.

Bedrock Geology

The Fox Hills sandstone of Cretaceous age is the bedrock formation in the Severance Basin. In the basin the Fox Hills is gently dipping eastward and is covered by Quaternary alluvium and colluvium except for man-made cuts.

In the exposed sections of bedrock the strata is characterized by a massive yellow-brown sandstone interbedded with thin, discontinuous dark gray gritty shale. Locally, the Fox Hills contains thin, well indurated, highly calcareous dark brown sandstone layers and zones of large limonite concretions.

Unconsolidated Deposits

The unconsolidated deposits in the Windsor-Severance study area consist of Quaternary alluvium and colluvium, terrace and pediment deposits, and wind-blown sand.

Terrace Deposits:

Terrace deposits of the Cache la Poudre River and of its ancient tributary the "Slough", are found in the area. The Poudre River terrace trends in a northwest-southeast direction approximately paralleling the present course of the river. This terrace averages
1 mile in width and has deposits up to 20 feet in thickness. The "Slough" terrace is covered by a veneer of alluvium about 5 feet thick and parallels the course of the "Slough" from above Loop Lake to 1 mile south of Severance. The materials of larger grain size in both terraces are made up of granitic and metamorphic rocks. Abundant caliche is present in deposits of both terraces, while cobbles and boulders of the terraces are typically coated with calcium carbonate. In two areas of the Severance Basin, the "Slough" terrace is composed of a highly cemented matrix which forms an impermeable ground-water boundary.

Pediment Deposits:

Two pediment remnants capped with unconsolidated rock material are present. These remnants comprise Antelope Hill (sec. 13, T. 6N., R. 67W.) and Lind Hill (sec. 3, T. 6N., R. 67W.).

On Antelope Hill deposits have a maximum thickness of 7 feet and contain all sizes of material ranging from boulders to clay, with the larger sizes being dominant. The pediment deposits are similar to those of the terraces in that most of the material is derived from the predominantly granitic and metamorphic rocks of the Front Range. The pediment remnants contain no ground water and neither pediment is irrigated nor cultivated.

Wind Blown Deposits:

East of the "Slough" terrace, the Quaternary deposits are largely eolian in origin, and are considered to be relict Pleistocene sand dunes. The dunes trend in a general northwest-southeast direction, reflecting a possible prevailing wind direction in the late Pleistocene. Sediments of the dunes are comprised mainly of quartz and potash feldspar with some thin interbedded lenses of loess. The soil on the dunes is not heavily weathered and is probably recent in age.
The caliche which is abundant in the terrace and pediment deposits is lacking in the dunal deposits.

Alluvium and Colluvium:

Alluvium in the area is differentiated from the overlying colluvium principally on the basis of size and mineralogical content. The colluvium consists of quartz sand and caliche clay with minor amounts of feldspar. The alluvium consists of larger material predominately of feldspathic composition.

The trend of the alluvial deposits generally follows the present course of the "Slough". Several small tributary valleys cut into the Fox Hills sandstone on the western side of the valley. Thin deposits of alluvium are present in the vicinity of the mouths of these tributaries. On the eastern side of the valley there is a large abandoned stream channel, presently filled with alluvium, which heads in SW 1/4 sec. 25, T. 7N., R. 67W. and empties into the main stream channel in sec. 1, T. 6N., R. 67W.

The alluvium ranges in thickness from 0 to 30 feet and averages approximately 10 feet. In general, the depth of the alluvium thickens southward with maximum thicknesses occurring at the mouth of the buried channel and at the mouth of the "Slough".

The alluvium is a reddish, coarse grained, poorly stratified deposit consisting of pink feldspar, quartz, sandstone fragments, limonite concretions, and minute gypsum crystals.
GROUND-WATER QUALITY

This ground-water basin, like many others in Colorado, has shown increasing contamination in recent years. One of the wells in the basin, yielding poor quality water, showed an increase in total dissolved solids from 6060 ppm in 1961 to 6960 ppm in 1965. This is an increase of 900 ppm in a 4.5 year span. Generally, contamination of the aquifer is to the point where the water is no longer used for cattle. If the contamination of the aquifer continues, it will only be a matter of time until the ground water will be of marginal value for use on crops. Figure 3, an electrical conductivity map of the ground water in the basin, shows the general areas of relatively high and low contamination. The values for electrical conductivity may be approximately converted to total dissolved solids by the following conversion factor (2)

\[
\text{Electrical conductivity} \times 0.65 = \text{dissolved solids}
\]

where

- electrical conductivity is in micromhos/sq cm and dissolved solids is in parts per million.

Ground-Water Monitoring System

To analyze the different factors contributing to the contamination of the aquifer, it was necessary to determine the movement of the water in the aquifer. This was accomplished by setting up a ground-water monitoring system which consisted of 54 observation wells (Figure 4). Water levels, electrical conductivity and pH were measured periodically in the wells during the summer and fall of 1965. Several water samples of both well water and surface water were taken for complete chemical analyses.
Electrical Conductivity Map
August 17, 1965
Severance Basin, Weld County, Colo.

Civil Engineering Section
Colorado State University
March, 1966

Legend
Data Collection Points

1 mile 1/2 0 1
1000 0 2000 4000 6000 feet

Conductivity Contour Interval
1000 Micromhos per Centimeter

FIGURE 3
Sources of Contamination

Feed Lots

Feed lots are a possible source of contamination due to the accumulation of waste products and silage in and around the lots. Following rainfall, the feed lots often become mires, and manure water ponds in the lots. Thus, there is a possibility of percolation of manure water to the ground-water table. A measure of this contamination is the concentration of nitrate ($\text{NO}_3^-$) ion, nitrite ($\text{NO}_2^-$) ion, and ammonia ($\text{NH}_3^-$) in the surrounding ground water. These constituents were measured in and around various feed lots in the basin.

Nitrate was the most common constituent measured and the concentrations ranged from 1 to 7 ppm with an average of 4 ppm in areas removed from the feed lots. This, of course, would be areas which were under farming and subject to the effect of fertilizers. Generally, in and adjacent to the feed lots the nitrate concentration ranged from 10 to 18 ppm. This is a distinguishable difference from the average concentration of the nitrate ions in the aquifer, indicating that feed lots do contribute to the contamination.

Silage Pits

Silage pits are another possible source of contamination. Several test holes were drilled in and adjacent to silage pits in the ground-water basin. One test hole in a silage pit showed a dark brown organically odoriferous shale which extended to a depth 5 feet beneath the pit. Below this zone was a clayey sand which is common in the basin. A water sample taken from a test hole in another silage pit gave a chloride ion concentration of 780 ppm and a sulfate ion concentration of 2750 ppm.
These concentrations are considerably higher than the concentration of the same ions in the aquifer waters. In the aquifer the chloride ion concentration averages about 50 ppm while the sulfate ion concentration averages about 800 ppm. Although the ion concentrations seem to be greater directly beneath the silage pits it does not appear that these are major sources of contamination. Most of the pits are covered and there does not appear to be a means of leaching the contaminants to the ground-water table.

Brine Pits

Three brine pits are located in the Severance Basin. These pits range in volume from approximately 5000 cubic feet to 25,000 cubic feet. Two of these pits were sampled for water content and their analyses are shown in Table I.

Brine waters are being discharged into these pits at rates varying from approximately 20 gal/hr to 340 gal/hr. Test holes were drilled around the periphery of the pits to determine the movement of the water from the pits. In the case of brine pit S2 three holes were drilled. All three holes which were drilled to bedrock at a depth of about 6 feet, were dry.

Brine pit S1 presented another picture. A test hole was drilled 50 feet down gradient from the pit. A log of the hole showed 7 feet of sand with pea gravel lenses above the Fox Hills which was at a depth of 11.0 feet. A water sample was taken from this test hole and an analysis showed high concentrations of sodium (400 ppm), chloride (340 ppm), and sulfate (2110 ppm). These ion concentrations seem to indicate communication between the brine pit and the ground water.

Saline water is discharged into the brine pit S1 at the rate of approximately 340 gallon per hour. This saline water contains oil and is an emulsion. Due to the oil film on the water surface the evaporation losses from this emulsion should be very low. Assuming little or no
Table I

Brine pit water analyses* 

<table>
<thead>
<tr>
<th>Sample</th>
<th>Calcium</th>
<th>Magnesium</th>
<th>Sodium</th>
<th>Potassium</th>
<th>Carbonate</th>
<th>Bicarbonate</th>
<th>Chloride</th>
<th>Sulfate</th>
<th>Nitrate</th>
<th>E.C. x10^6**</th>
<th>TDS</th>
<th>PH</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>76.1</td>
<td>124</td>
<td>13,300</td>
<td>900</td>
<td>516</td>
<td>390</td>
<td>2980</td>
<td>24,400</td>
<td>1.7</td>
<td>37,400</td>
<td>40,600</td>
<td>9.0</td>
</tr>
<tr>
<td>S2</td>
<td>116</td>
<td>80.3</td>
<td>10,900</td>
<td>700</td>
<td>312</td>
<td>1100</td>
<td>4580</td>
<td>16,300</td>
<td>0.9</td>
<td>32,100</td>
<td>31,900</td>
<td>8.2</td>
</tr>
</tbody>
</table>

* Cations and anions in parts per million.
** (E.C.) Electrical conductivity in micromhos per centimeter.
evaporation, the brine pit would add about 27 ppm dissolved solids to the basin as a whole per year. This is about 3 percent of the total dissolved solids added to the basin in a year's time.

Fertilizers

Fertilizers are used extensively in this basin. The fertilizers used consist primarily of nitrogen and phosphate soluble compounds. One type of fertilizer consists basically of 2 parts nitrate and 1 part phosphate, while another type consists of 18 percent nitrate and 46 percent phosphate.

These fertilizers are applied in amounts ranging from 200-300 pounds per acre fertilized. Over the whole basin, the average is about 100 pounds per acre. The amount of fertilizer that percolates to the ground-water table is difficult to determine since there is no easy means of determining the amount of fertilizer used by the plants and the amount that eventually percolates down to the ground-water table. Although it is reasonable to expect that the fertilizers are contributing to the contamination of the aquifer, there is no readily available means of calculating the extent of the contamination.

Surface Water

The main source of surface water in the Severance Basin is irrigation water from Eaton Canal. The irrigation water is supplied from the Cache la Poudre River, Horsetooth Reservoir, Windsor Lake, Terry Lake, Gray Lake, and Long's Pond. Over the irrigation period of about 5 months, this water averaged about 225 ppm total dissolved solids.

There are several lakes in the basin. In the area of major contamination, Loop Lake and Law Reservoir have a total dissolved solids content of 2250 ppm and 1760 ppm respectively. Based on water
analyses from 23 wells in the basin the average total dissolved solids was 2200 ppm. The lake water appears to have the same basic ppm concentration as the ground water.

As a single factor, the irrigation water would tend to lower the contamination by its dilution effect. However, the contamination sources cannot be effectively analyzed as single entities. To gain a better understanding of the contamination of an aquifer, all the possible sources of pollution must be correlated with each other and to the aquifer as a whole. In the next section, this will be done and a general analysis of the basin will be made.

ANALYSIS OF WATER QUALITY FROM A HYDROLOGIC STUDY

The general approach used in the study of the Severance Basin was a water balance and total dissolved solids balance applied to the entire basin. These two mass balances proved quite effective in analyzing the contamination problems in the basin.

Water Balance

A water balance calculation is based on the principle of conservation of mass and may be expressed as

\[ Q_i = Q_o + \Delta S \]

where \( Q_i \) is the total volume of fluid that comes into an area in unit time, \( Q_o \) is the total volume of water that leaves an area in unit time, and \( \Delta S \) is the change in storage in unit time. Now

\[ Q_i = Q_{swi} + Q_p + Q_{gwi} \]

and

\[ Q_o = Q_e + Q_{swo} + Q_{gwo} \]
where \( Q_{swi} \) is the total surface water inflow, \( Q_p \) is the total precipitation, \( Q_{gwi} \) is the total ground water inflow, \( Q_{swg} \) is the total surface water outflow, \( Q_e \) is the total evapotranspiration, and \( Q_{gwo} \) is the total ground water outflow.

The water balance presented in this report is based on data gathered over a one-year period.

**Ground-Water Flow**

The evaluation of the ground-water movement in the basin was based upon Darcy's Law which can be stated as

\[
Q = KIA
\]

where \( Q \) is the flow rate, \( K \) is the permeability, \( I \) is the hydraulic gradient, and \( A \) is the cross-sectional area normal to the gradient.

The ground-water gradient in the aquifer was determined from the water-table contour map while the area normal to the flow was determined from the isopach map of the saturated thickness. Figure 5 shows the water table elevation on August 17, 1965 while Figure 6 is the isopach map of the saturated gravels and sands.

The permeability was determined using drawdown versus time data (3) from several well pumping tests, and applying a technique by R. Theodore Hurr (4). Hurr's technique permitted the computation of permeability from data collected on the pumping well. The results based on this technique appeared reasonable and an average permeability in the gravels of 4740 gpd/ft\(^2\) was calculated.

Knowing the permeability, ground-water gradient, and the saturated area normal to flow, flow rates were calculated throughout the basin. Assuming a relatively constant saturated thickness, the ground-water flow into the basin from November 1964 to October 1965 was computed to be 8,650,000 gpd while the outflow was 2,750,000 gpd for the same period.
Water Table Contour Map
August 17, 1965
Severance Basin, Weld County, Colo.

Civil Engineering Section
Colorado State University
March, 1966

Legend
Water Table Contours
Data Collection Points

1 mile

Contour Interval - 10 ft.

FIGURE 5
Saturated Thickness Map
August 17, 1965
Severance Basin
Weld County, Colorado

Civil Engineering Section
Colorado State University
March, 1966

Legend:
- Saturated Thickness
- Contours
- Data Collection Points

Contour Interval - 5 ft.

FIGURE 6
Precipitation

Precipitation from November 1964 through October 1965 totaled 14.2 inches. Over the entire study area this represented 6360 acre-feet of water.

Evapotranspiration

The computation of evapotranspiration was broken into two parts due to the climatic conditions in Northeastern Colorado. During the months of May through October, evapotranspiration was computed as the total water loss due to evaporation and transpiration. However, from November through April it was assumed that there was no effective plant life and the water loss was due only to evaporation.

For the period of May through October, evapotranspiration was estimated by the Blaney and Criddle (5) technique. This technique is empirical and can be formulated by the equation:

\[ U = KF \]

where \( U \) is the consumptive use of the crop in inches for any period, \( F \) is the consumptive use factor for the area, and \( K \) is the consumptive use coefficient of the crop for the growing season or period.

Consumptive use incorporates both the crop transpiration and the evaporation from the soil around the crops. Thus, consumptive use is the total water loss from a field. In computing consumptive use, a very important factor is the consumptive use coefficient. This term has been empirically estimated by Blaney and Criddle. Various values which apply to the Severance Basin are shown in Table II.

The term \( F \), the consumptive use factor, is the sum of the monthly consumptive use factors for any period.

\[ F = \Sigma f = \Sigma \frac{txp}{100} \]
Table II

Consumptive use coefficients in irrigated areas, Severance Basin, Colorado.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Growing Season or Period</th>
<th>Consumptive Use Coefficient (K) Growing Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated Land</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td>Frost-free period</td>
<td>0.85</td>
</tr>
<tr>
<td>Grass, hay and pasture</td>
<td>Frost-free period</td>
<td>0.75</td>
</tr>
<tr>
<td>Small Grains</td>
<td>Three months</td>
<td>0.75</td>
</tr>
<tr>
<td>Corn and other annuals</td>
<td>Four months</td>
<td>0.75</td>
</tr>
<tr>
<td>Orchard</td>
<td>Frost-free period</td>
<td>0.65</td>
</tr>
<tr>
<td>Incidental Areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water surfaces</td>
<td>Frost-free period</td>
<td>0.95</td>
</tr>
</tbody>
</table>

where $t$ is the mean monthly temperature in degrees Fahrenheit, and $p$ is the monthly percent of daytime hours of the year.

Table III presents the calculations for evaluating consumptive use. As seen from Table III the total consumptive use for the basin from May through October was 12,334 acre-feet.

The above value for evapotranspiration was checked by using the Penman Method (6) for estimating evapotranspiration. This method resulted in a value of evapotranspiration about 20 percent lower than the Blaney-Criddle technique. However, the Penman Method lacks the ability to differentiate between crop types. Thus the Blaney-Criddle technique was accepted as being a better estimate of evapotranspiration.
Table III

Consumptive use calculation for Severance Basin, 1965

<table>
<thead>
<tr>
<th>Month</th>
<th>Monthly consumptive use factor $f_i = \frac{txp}{100}$ (inches)</th>
<th>Crop</th>
<th>Area $A_i$ (acres)</th>
<th>Consumptive use coefficient $K_i$</th>
<th>Consumptive use (ac-ft) $U_i = K_i A_i F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>5.89</td>
<td>Alfalfa</td>
<td>143</td>
<td>0.85</td>
<td>368</td>
</tr>
<tr>
<td>June</td>
<td>6.87</td>
<td>Pasture</td>
<td>287</td>
<td>0.75</td>
<td>650</td>
</tr>
<tr>
<td>July</td>
<td>7.69</td>
<td>Grains</td>
<td>71</td>
<td>0.75</td>
<td>161</td>
</tr>
<tr>
<td>August</td>
<td>6.81</td>
<td>Corn</td>
<td>4230</td>
<td>0.75</td>
<td>9580</td>
</tr>
<tr>
<td>September</td>
<td>4.64</td>
<td>Water surface</td>
<td>155</td>
<td>0.95</td>
<td>433</td>
</tr>
<tr>
<td>October</td>
<td>4.29</td>
<td>Orchard</td>
<td>42</td>
<td>0.65</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>$F = \sum f_i = 36.19$</td>
<td>Sugar beets</td>
<td>467</td>
<td>0.75</td>
<td>1060</td>
</tr>
</tbody>
</table>

$U = \sum K_i A_i F = 12,334$

* $f_i$ = individual monthly consumptive use factor

* $A_i$ = individual crop area

* $K_i$ = individual crop consumptive use coefficient
In order to determine completely the water loss during the year, evaporation loss during the non-growing season must be considered. During the winter months no evaporation data is available for the northeastern section of Colorado. Therefore, data was taken from Montrose, Colorado (1) and correlated to Fort Collins based on comparative data available for the summer months. An 11 year correlation showed an average evaporation rate in Fort Collins to be 0.70 of the evaporation rate in Montrose. Thus, knowing the evaporation in Montrose from November through April permitted the computation of evaporation in the Fort Collins-Windsor area for the same period. The evaporation from November 1964 through April 1965 was estimated to be 10 inches and accounted for 3070 acre-feet of water.

Surface Water Flow

The major source of surface water supplied to the basin comes from Eaton Canal, an irrigation canal that traverses the northern part of the basin. The Collins Lateral supplies irrigation water to a few farms in the basin lying north of the Eaton Canal. These two ditches supplied 3517 acre-feet (7, 8) of water between May and September 1965.

Storage

Based on data (3) extending back to 1959 the ground-water level appears to be dropping at the rate of 0.2 ft/yr. Considering the areal extent of the basin, this is a decline in storage of 200 acre-feet per year. Knowing the change in storage along with the other factors mentioned previously it is possible to calculate a water balance. The results of this calculation are presented in Table IV.
Table IV
Water and total dissolved solids balance
November 1964 - October 1965

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount of water (ac-ft)</th>
<th>Average total dissolved solids (ppm)</th>
<th>((2) \times (3)) ppm-ac-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water in</td>
<td>3520</td>
<td>225</td>
<td>792,000</td>
</tr>
<tr>
<td>Ground-water in</td>
<td>9680</td>
<td>1090</td>
<td>10,500,000</td>
</tr>
<tr>
<td>Precipitation</td>
<td>6360</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Brine pit*</td>
<td>9</td>
<td>40,600</td>
<td>365,000</td>
</tr>
<tr>
<td><strong>TOTAL Inflow</strong></td>
<td><strong>19,560</strong></td>
<td><strong>11,657,000</strong></td>
<td></td>
</tr>
</tbody>
</table>

| Evaporation (Nov-Apr)   | 3270                    | 0                                   | 0                            |
| Consumptive use (May-Oct)| 12,300                 | 0                                   | 0                            |
| Ground water out        | 3080                    | 1850                                | 5,700,000                    |
| Surface water out       | 2720                    | 1330                                | 3,620,000                    |
| **TOTAL Outflow**       | **21,370**              | **9,320,000**                       |                              |

| Change in Storage       | -200                    |                                     |                              |

Water balance: Total inflow - Total outflow = Change in storage
Error = 1610 ac-ft
Percent error = 7.5 percent**

Ion balance: Total ion inflow - Total ion outflow = change in ions in basin
Change in ions in basin = 2,337,000 ppm-ac-ft

Ion increase per year = \(\frac{\text{Change in ions in basin}}{\text{Total volume}***}\) = 173 ppm/yr.

* Flow from brine pit is already taken into account in the ground-water flow in.
** Percent error based upon assumption that the value for total outflow from the basin is correct.
*** Total volume refers to the volume of water in the aquifer. This was assumed to be 0.30 of the bulk volume of the saturated aquifer.
Total Dissolved Solids Balance

A total dissolved solids balance may be calculated from the water balance. For a given time interval, this balance may be expressed as

Total dissolved solids flowing into basin - Total dissolved solids flowing out of basin = Change in total dissolved solids in basin.

To determine the total dissolved solids flowing into and out of the basin during a given period of time, the volume of each of the flow components, such as surface water and ground water, is multiplied by the total dissolved solids content of that component. The difference in these values for the inflow and outflow divided by the volume of water in the aquifer will give the change in the total dissolved solids content for a given period. If this period is a year, the units will be ppm/yr.

The different components in the water balance have varying concentrations of dissolved solids. The ground water flowing into the basin has two distinct waters of varying ion concentration. One water was associated with the gravels and the other was associated with the wind blown sand in the eastern half of the basin. The water flowing through the gravels has an average total dissolved solids content of 1280 ppm while the water flowing in the sand has an average total dissolved solids content of 970 ppm. A weighted average based upon relative flow rates through the sand and gravel is 1060 ppm.

The ground water flowing out of the basin several miles away had a total dissolved solids of 1880 ppm which is an increase of approximately 700 ppm in the direction of flow.

The surface water inflow from the irrigation canals had an average total dissolved solids content of about 225 ppm while the surface water outflow had an average total dissolved solids content of about 1330 ppm. Evapotranspiration and evaporation losses were assumed to have no dissolved solids. Thus, with a knowledge of the
total dissolved solids content and flow contributed by each of the 
water balance components, the total dissolved solids balance was 
computed. This balance plus the water balance are shown in Table IV. 
The water balance yields a difference of about 8 percent 
between the outflow and inflow of water in the basin. Based on this 
result it should be safe to assume that the total dissolved solids 
balance has approximately the same error. 
The total dissolved solids balance in the aquifer indicated 
an increase in contamination of about 173 ppm/yr. If the brine pit 
were removed from consideration the increase in total dissolved 
solids would still be about 146 ppm/yr. This means that the ground-
water inflow and irrigation water are contributing enough dissolved 
solids to make this increase. 
This result may seem paradoxical, since the ground-water 
inflow has an average total dissolved solids content of 1060 ppm and 
the irrigation water only 225 ppm, as opposed to the surface water 
outflow which has a total dissolved solids content of 1330 ppm and 
ground-water flow with 1850 ppm. This result can be explained if 
one refers to Table IV. 
During the period from November 1964 to October 1965 the 
inflow water contributed 11,657,000 ppm-ac-ft while the outflow 
water relieved the basin of only 9,320,000 ppm-ac-ft. This was an 
increase of 2,337,000 ppm-ac-ft in a year's time. This increase 
appears to be caused by the combination of high rates of evapotrans-
spiration in the crops and the low rate of ground-water and surface 
water discharge from the basin. Water loss by evapotranspiration 
and evaporation accounted for 73 percent of the water loss from the 
basin. Realizing that this is pure water leaving the basin, it seems 
that this combination of high evapotranspiration to low ground-water 
and surface water flows could effect an increase in salt content in the 
aquifer water.
Well W 21 gives the only historic record of increasing salt contamination. This well, in 4.5 years, has shown an average increase in total dissolved solids of 200 ppm/yr. The ion balance gave an average basin increase in contamination of 173 ppm/yr which indicates that the ion balance results are fairly reasonable.

CONCLUSIONS

In this study, due to data limitations, it was difficult to effectively analyze the contribution to the contamination from various isolated sources. The contribution of organic material from feed lots, silage pits, and fertilizers appears to be relatively small. Although geologic formations probably produced the initial contamination when the basin was supplied a ground-water zone by the application of irrigation water, there does not appear to be sufficient evidence that the geologic formations are currently contributing any major pollution to the aquifer.

The brine pits seemed to be contributing about 3 percent of the total dissolved solids. Except for possible local effects, the brine pits do not appear to be a major contributor to the contamination of the aquifer.

The major cause of contamination in this aquifer appears to be the combination of a high rate of evapotranspiration and relatively low surface and ground-water flow from the basin. The total dissolved solids in the basin is increasing at the rate of 173 ppm/yr.

This problem in the Severance Basin probably has areal ramifications. The possibility of pollution due to high evapotranspiration rates in semi-arid and arid regions subjected to irrigation is highly probable. This could be a major contributor to contamination of many aquifers in this area which are showing increased dissolved solids content in the ground-water.
RECOMMENDATIONS

To stabilize the contamination increases in the Severance Basin it is necessary to increase the ground-water flow out of the basin. However, any increase in ground-water outflow also necessitates an increase in surface water application if the ground-water levels are to be maintained. One method of increasing the ground-water outflow would be to put in a series of wells at the lower end of the aquifer and pump the higher salt concentration water out of the area. The increased surface water applications could be made up from irrigation water application.

Future study on the amount of contamination from feed lots, silage pits, brine pits, and geologic formations is highly recommended. Only when these individual factors are completely understood will a complete analysis of the water quality in an aquifer be possible.
BIBLIOGRAPHY


6) Schulz, E. F., A Graphical Procedure to Estimate Potential Evapotranspiration by the Penman Method; Civil Engineering Department, Colorado State University, Fort Collins, Colorado, August, 1962.

