IMPACT OF IRRIGATION WATER USE ON WATER QUALITY IN THE CENTRAL COLORADO WATER CONSERVANCY DISTRICT

by

Henriette Emond, Jim C. Loftis, and Terence Podmore

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Henriette Emond
Jim C. Loftis
Terence Podmore

Department of Agricultural & Chemical Engineering
Colorado State University

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COLORADO WATER RESOURCES RESEARCH INSTITUTE
Colorado State University
Fort Collins, Colorado 80523

Robert C. Ward, Director

Abstract

This paper presents the results of a two year study sponsored by the Colorado Water Resources Research Institute, the United States Geological Survey, and the United States Environmental Protection Agency on the impact of irrigation water use on water quality in the agricultural area near Greeley, Colorado. Data on water management techniques, consumptive use, irrigation application efficiency, deep percolation, surface runoff and nitrate levels were collected.

Results indicated a wide range of application efficiencies and deep percolation percentages. Nitrate levels in the pumped ground water often exceeded EPA drinking water standards, while nitrate levels of water from the South Platte River were generally below the drinking water standards.

There are opportunities for improving irrigation application efficiency in this area, but there may be repercussions for downstream water users. Decreasing the quantity of nitrate going into the ground water can occur through increased water conservation and through reducing the actual amount of nitrates applied in the irrigation water or fertilizers. There is currently little incentive for farmers to implement these measures

Table of Contents

Introduction

Sustainable agriculture, which is defined as minimizing the negative impacts by agriculture on the environment, has generated much attention in the past several years. There are concerns that return flows from irrigated agriculture are a source of pollution to ground water and surface water. In irrigated agriculture, excess irrigation water not stored in the root zone for beneficial crop use can result in deep percolation below the crop root zone or surface runoff. This excess water is free to transport fertilizers and pesticides to the ground water and surface water downstream of the irrigation, possibly contributing to the degradation of water quality.

The Central Colorado Water Conservancy District (CCWCD) of Greeley, CO has responded to this growing interest in sustainable agriculture by participating in a United States Environmental Protection Agency (EPA) funded study on the sustainability of agriculture in the CCWCD region. As part of that study, a field team from Colorado State University (CSU) conducted the on-farm monitoring of irrigation water use and water quality over the course of two irrigation seasons. This study conducted by the Colorado State University Team was also funded by the Colorado Water Resources Research Institute.

The Monitoring and Evaluation Strategy

Because agricultural return flows are believed to carry pollutants into ground water or surface water, a general improvement of water quality could result by controlling excess water from agriculture and increasing the water use efficiency. Before this can occur, it is important to identify the extent to which irrigated agriculture contributes to return flows as deep percolation and runoff in actual fields.

A mass balance approach was used to quantify the water inputs to the selected fields and the amount of water lost to deep percolation and surface runoff. This was done to determine irrigation application efficiency and the deep percolation ratio on a field by field basis in order to evaluate the potential for leaching nitrates and pesticides into the ground water. The amount of water applied to individual fields was monitored. The quantity of water required by the plants for growth was estimated from weather data using an evapotranspiration equation. This was supplemented by soil moisture assessment using gravimetric sampling at the head and tail of the fields.

Water quality of ground water and surface water was regularly analyzed for nitrates. The nitrate level in water is of concern for health considerations. In addition, it is a readily measured parameter and a good indicator of the ground water movement for other agricultural chemicals.

The irrigation monitoring and evaluation plan initially developed by the CSU team was based on conventionally accepted methods of surface irrigation. It was assumed that the farmers would irrigate their fields in sets of adjacent or alternating furrows every ten to fourteen days. The time between irrigations would allow the soil moisture to move from saturation to the desired level of management allowed soil water depletion. However, this proved to be very different from the way the irrigations were actually done and the monitoring strategy was adjusted accordingly. The final monitoring plan was developed using information from a variety of sources (ASAE, 1990; Merriam & Keller, 1978; Walker & Skogerboe, 1987; Podmore & Eynon, 1983).

During the 1992 irrigation season, the CSU team monitored three surface irrigated fields, denoted as field **4**, field **5**, and field **8**. In 1993, the CSU team monitored eleven surface irrigated fields (**1, 4, 4E, 5, 6, 7, 8, 9**) on seven different farms. These included the three fields which were studied in 1992. Two sprinkler irrigated fields, **2** and **3**, were monitored during both the 1992 and 1993 irrigation seasons. The location of these fields is shown on the map in Figure **1**.

On most of the surface irrigated fields, irrigations generally took place every three days to a week. The area covered during an irrigation set usually depended on the inflow rate and the size of the field. Sometimes one set would cover the entire field. In other cases, a field would be irrigated in several different sets with siphons running on a particular portion of the field or over the entire field but in alternating rows or every third or fourth furrow. The irrigation duration would range

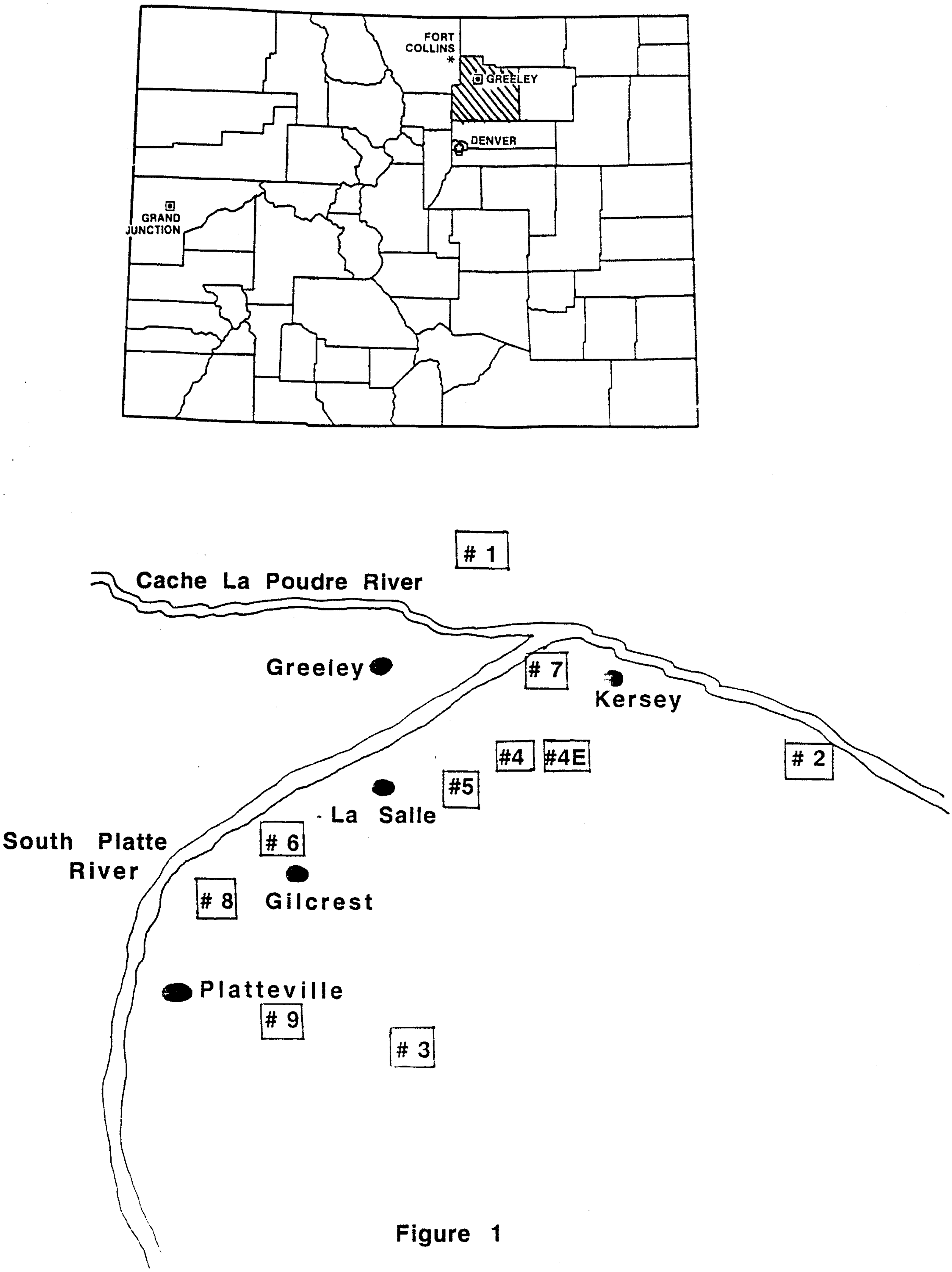
FORT COLLINS
GREELEY
DENVER
GRAND JUNCTION
1
Cache La Poudre River
Greeley
7
Kersey
#4
#4E
2
#5
La Salle
South Platte River
6
8
Gilcrest
Platteville
9
3

Figure 1

between 4 and 13 hours, depending on the soil type, field length, crop, and other farm constraints.

In 1992, water inflows and outflows for each of the monitored fields were carefully recorded for 4 to 6 weeks. The period of observation generally extended from the second or third irrigation to the end of the regular irrigation season. Each of these irrigations was either documented by direct observation or from discussions with the farmer or irrigator. In a few instances, particularly in field **5**, irrigation data were estimated based on observations made in the field after an irrigation event and matched to a previously documented event.

During the 1993 irrigation season, water inflows and outflows for each of the surface irrigated fields were monitored over the course of the entire irrigation season. Some fields were monitored daily while others were evaluated at periodic intervals. Depending on the crop, the period of observation generally extended from two to three months. For those fields monitored daily, each irrigation during this time period was either documented by direct observation or from discussions with the farmer or irrigator. In a few instances, such as when the irrigation occurred at night, missing irrigation data were estimated, when possible, based on observations made in the field after an irrigation event or discussion with the farmer and matched to a previously documented event.

Irrigation water applications to the surface irrigated fields were determined using a velocity/area/time approach where flow velocity was measured with a current meter (USBR, 1981). The velocity of water flowing in the head ditch was recorded during the irrigation event. This velocity, multiplied by the cross-sectional area of the head ditch, gives the flow rate coming onto the field. The flow rate is then multiplied by the duration of flow to give the total volume of water applied to the field. Outflows in the form of surface water runoff were determined using a cutthroat flume at the outlet of several of the irrigated fields. Flows through the flume were recorded manually in 1992 and, in 1993, with stage recorders. These flow rates were then multiplied by the duration time, at 15 minute intervals for the stage recorder, to determine the total volume of water flowing off the field. In those fields where the use of a flume was not practical, a current meter was used, when possible, to measure the outflow.

The amount of water applied to the sprinkler irrigated fields was determined by monitoring the amount of electricity used, the amount of water applied during one irrigation, and monitoring the number of revolutions made by the pivot over the course of the irrigation season. The uniformity of water distribution over the two fields was also determined using a catch can test.

Rain data were collected using rain gages installed in five of the fields. Rainfall on fields without rain gages was assumed to be the same as on the nearest field having a rain gage. Effective rainfall was estimated to be 100 percent for storms less than 5 mm and 50 percent for storms in excess of 5 mm since, in a heavy downpour, rain will fall at a rate greater than the infiltration rate (Zein Eldin, 1992). For the period of time before the rain gages could be installed, precipitation data were obtained from a weather station northeast of Greeley.

Water use by the plants over the course of the irrigation season was calculated using an evapotranspiration (ET) equation. Weather data for the determination of ET were obtained from a weather station near Peckham, Colorado located in the vicinity of the three most intensively monitored fields. These ET data, provided by the Colorado Onion Industry, were obtained for the months of May through August in 1992 and March through September for 1993. Reference ET was determined using the Penman combination equation. The weather variables required for Penman ET are temperature, solar radiation, relative humidity, and daily wind run. Appropriate crop coefficients (Jensen, 1980) were then applied to reference ET in order to obtain actual ET values for each crop.

The amount of water percolating down below the root zone and into the ground water was calculated for each surface irrigated field over the course of the irrigation season by determining the amount of water infiltrating into the soil. This infiltrated depth is the difference between the amount of water applied to the field and the amount of water running off the end of the field. The amount of infiltrated depth not stored in the root zone and not used by the plant through evapotranspiration is the quantity of water lost to deep percolation. The proportion of applied water moving down below the root zone is called the deep percolation ratio.

According to the Soil Conservation Service, soils in the monitored fields are fairly homogeneous and consist of deep, level and nearly level, well-drained, sandy loams or loamy sands formed in alluvium (USDA SCS, 1980). This is confirmed by the soil survey of the fields conducted in conjunction with the Sustainable Agriculture Project.

In 1992, variability of infiltration over each of the three fields was determined with advance and recession information. In general, results for the three surface irrigated fields indicated little variation in infiltration along the length of the furrows tested.

Water samples were taken for nearly every irrigation to determine the level of nitrate as nitrogen (NO_3-N). In 1992, these samples were analyzed in the field using a Hach test kit. In 1993, the water was usually analyzed by CCWCD's testing lab, although, when necessary, the water was analyzed for nitrates by the CSU field team. Samples were taken from the surface water in the head ditch above the pump, the ground water coming out of the pump, the mixed surface and ground water in the head ditch below the pump upstream and downstream of any chemicals being added to the irrigation water, and the water at the tail end of the field.

1992 Monitoring and Evaluation Results

Water Application:

Field **4** was planted with potatoes. The irrigations were monitored from June 30 until July 20, the last irrigation of the season. Irrigations were generally done every four days, with an average duration of 14 hours. The field was irrigated in four sets, with water running in every fourth furrow for 3 to 4 hours per set. Inflow volumes averaged about 4500 m^3 per irrigation, while outflows were generally in the range of 350 m^3. This translated into net water depth applications of 90 mm per irrigation on a field average basis, compared to the net ET requirements, adjusted for effective rain, of 24 mm per irrigation for field **4**.

Field **5** was planted in corn. This field was monitored from July 20 until August 30, the last full irrigation. During the evaluation, field **5** was irrigated every three days. Every second furrow or every fourth furrow on a third to a half of the field was irrigated during 6 to 12 hour sets. Field **5** had a relatively low priority for water on the farm and excess water from other fields was often applied to this field, resulting in an erratic irrigation schedule.

The average volume applied to field **5** was 6000 m^3 per irrigation. Outflow from the bottom of the field was blocked and all of the tail water and rain runoff ponded and infiltrated at the bottom of the field. The resulting depths of application averaged 100 mm compared to the average ET requirement per irrigation of 15 mm.

Field **8** was also planted with potatoes in 1992. Irrigations on field **8** were observed between June 15 and July 14, the last full irrigation. The irrigations generally occurred every three days. Water was applied in two sets, each to alternating furrows across the entire field, with a total irrigation duration of about 14 hours. In one instance the irrigation lasted 24 hours.

Average gross volume applied per irrigation on field **8** was 3500 m^3 while outflows averaged 1000 m^3 per irrigation. This translates to an average net depth applied of 18 mm per irrigation. This closely matches the average ET requirements for field **8** which, adjusted for effective rain, was 16 mm per irrigation.

While volumes of water applied to both fields **4** and **8** were roughly the same, field **8** is nearly four times the size of field **4**. Therefore, the average depth of irrigation water applied on field **8** was much less than for field **4**.

Application Efficiency:

The irrigation application efficiency over a given period is calculated as the amount of irrigation water required by the plant, divided by the depth of irrigation water applied, with the assumption that every irrigation event is a full irrigation. The amount of irrigation water required by the plant is calculated as ET minus the effective rain.

In field **4**, 24% of the water applied was actually required for plant use. The rest of the water applied either ran off the end of the field or was lost to deep percolation. For field **5**, individual application efficiencies ranged from 5% to 15% while the overall average irrigation application efficiency was calculated to be about 7%. In field **8**, the smaller depth of water applied translates to a higher level of irrigation application efficiency, calculated at 67%.

Deep Percolation:

The deep percolation ratio is the proportion of water which, applied to a field, percolates beyond the root zone. This provides an indication of the nitrate leaching potential that can result from irrigated agriculture. Deep percolation ratio is calculated as the net irrigation and rain depth applied minus the ET, divided by the total depth of irrigation water applied. All water, including rainfall, that is applied to a field and infiltrates into the soil is considered in the calculation of deep percolation.

The deep percolation ratio for field **4** was 68%. In field **5**, the large quantities of applied water compounded by the blocked outlet at the end of the field resulted in a deep percolation ratio of almost 94%. Conversely, the efficient use of water in field **8** is reflected in the relatively low deep percolation ratio of 8%. The high deep percolation ratios in field **4** and field **5** would indicates a large potential for leaching nitrates into the ground water compared to field **8**.

Infiltration Variability:

To determine the variability of infiltration along the length of the three fields, the advance rate of water down selected furrows and the rate of recession were monitored. In the three fields, observations of advance and recession indicated a low degree of variation in infiltration rate along the length of each field.

In field **4**, at full crop cover, it took about 1.5 hours for water to reach the end of the field, and the same amount of time to recede. Water intake opportunity time for field **4**, ie. the amount of time that water spends in the furrow, was 3 to 4 hours.

Advance in field **5**, under full cover, took a little over one hour while recession took slightly less than an hour. Intake opportunity time varied widely from irrigation to irrigation, depending on the length of the set. In addition, ponding of water at the bottom of field **5** resulted in greater infiltration at the tail than in the rest of the field.

In field **8**, under full plant cover, water both advanced to the end of the field and receded in about 3 hours, indicating a low amount of variability along the length of the field. The intake opportunity time between advance and recession in field **8** averaged 7 hours.

Nitrate as Nitrogen:

Nitrate as nitrogen levels were measured in the surface water above the pump, in the ground water coming from the pump, in the surface and ground water mixed in the head ditch below the pump and in the water at the tail end of the field. As a bench mark, the EPA drinking water standards have a maximum acceptable level of 10 mg/L as NO_3-N.

In field **4**, nitrate as nitrogen levels of the surface water upstream of the pump ranged from 5 to 7 mg/L. Ground water from the pump had nitrogen levels of 9 to 12 mg/L NO_3-N, while the tail water had levels of 10.5 to 11.8 mg/L NO_3-N. Nitrate levels in the head ditch below the pump were essentially the same as at the bottom of the field. Although the nitrate levels were reduced by mixing the pumped ground water with surface water in the head ditch, water being applied to field **4** still exceeded the EPA standards.

In field **5**, nitrate levels were primarily tested using the surface water in the head ditch. There was no pumped water for field **5**, and those tests conducted on the tail water indicated that the nitrate levels were essentially the same as at the head of the field. Nitrate as nitrogen levels in field **5** averaged 4.4 mg/L, all below the EPA drinking water standards of 10 mg/L NO_3-N.

In field **8**, NO_3-N levels in the surface water upstream of the pump ranged from 4 to 14 mg/L, with an average of 7.1 mg/L NO_3-N. Pumped ground water had nitrate as nitrogen levels in the range of 12 to 16 mg/L

NO_3-N, all above the drinking water standards. Tail water runoff reflected these high levels of nitrate as nitrogen, with an average NO_3-N content of 12.5 mg/L.

1993 Monitoring and Evaluation Results

Surface Irrigation Water Application:

Field **1** was planted in beans. Irrigations occurred from the beginning of July until the end of August. A combination of the irregular monitoring schedule and sporadic irrigations made results from this field difficult to obtain. Assumptions on flow rate and duration were made for all of the irrigations evaluated because there was some missing information for every evaluation.

Field **4** was planted with corn. The irrigations were monitored from June 1 until September 1, the last irrigation of the season. Irrigations generally occurred every 3 days, with most irrigations lasting about 8 hours. The field was irrigated in 2 sets, with water running in every fourth furrow for 4 hours per set. Net water depth applications generally ranged from 50 to 200 mm (2 to 8 inches) per irrigation, compared to the net ET requirements, adjusted for effective rain, of 20 to 40 mm (1 to 2 inches) per irrigation. These variations in depth indicate the wide range of application efficiency that resulted in the field over the course of the irrigation season.

Field **4E** was located just east of field **4** and was planted with lettuce. Irrigation depths generally ranged from 150 to 250 mm (6 to 10 inches). Irrigation sets generally lasted 6 hours with 2 to 4 sets per irrigation.

Field **5** was planted in potatoes. This field was monitored for nearly every irrigation of the season which lasted from May 23 to July 12. During this time, field **5** was irrigated every 3 days. The entire field was irrigated in three sets, where every third furrow was irrigated for a 3 to 4 hour set. The average volume applied to field **5** ranged from 2300 m^3 to 5300 m^3 per irrigation. Outflow from the bottom of the field ranged from 160 m^3 to 1200 m^3. The resulting depths of application ranged from 40 to

90 mm (2 to 4 inches) compared to the average ET requirement per irrigation of 10 to 30 mm (0.5 to 1 inch).

Field **6** was planted first with lettuce and then with beans. The lettuce irrigations were monitored periodically over the course of the irrigation season while the bean irrigations were monitored daily. The lettuce was irrigated and monitored from March 25 until June 9, while the beans were monitored from July 28 to August 25. The fields were irrigated perhaps once a week, with durations ranging from 10 to 30 hours per set. The fields were irrigated in an uneven pattern and for irregular periods of time. By the end of an irrigation, water had run in alternating furrows for 12 to 24 hours. Net water depth applications ranged from 10 to 40 mm (0.5 to 2 inches) per irrigation on a field average basis. Net ET requirements, adjusted for effective rain, also ranged widely, from 5 to 80 mm (0.2 to 3 inches) per irrigation, depending on the irrigation interval.

Field **7** was planted with alfalfa and was border irrigated. The irrigations were monitored from April 29 to September 5. Irrigations were generally done every 2 weeks, with durations of 5 to 10 hours per border. The field was irrigated in 5 sets, with water in one border per set. Net irrigation water depth applications ranged from 200 mm to 500 mm (8 to 20 inches).

In 1993, field **8** was divided into three fields, and planted with lettuce, onions, and corn. Irrigations on field **8** generally occurred once a week. Lettuce irrigations generally lasted 10 hours while onion irrigations ranged from 8 to 12 hours. Corn irrigations generally lasted from 10 to 25 hours.

Average gross volume applied per lettuce irrigation on field **8** was 1500 to 2000 m^3 while outflows averaged 100 to 350 m^3 per irrigation. This translates to an average net depth applied of 30 to 40 mm (1 to 2 inches) per irrigation. This was only slightly more than the average ET requirements for the lettuce on field **8** which, adjusted for effective rain, was 25 to 35 mm (1 to 1.5 inches) per irrigation. On the onion section of the field, gross applied volumes averaged 1500 to 2500 m^3 per irrigation. Adjusting for outflow, this equalled a net application of 20 to 35 mm (1 to 1.5 inches) per irrigation compared to a net irrigation requirement of 12 to 30 mm (0.5 to 1 inch). For the corn, the net irrigation depth applied was 10 to 175 mm (0.5 to 7 inches) per irrigation, compared to a net ET requirement of 15 to 60 mm (1 to 2.5 inches).

Field **9** was planted with sweet corn. The irrigations were monitored from July 2 until August 20. This field was divided into two parts due to the long length of run. Irrigations occurred nearly every day either at one end of the field or the other. Average total depths of irrigation water application ranged from 60 to 170 mm (2.5 to 7 inches).

Sprinkler Water Applications:

The sprinkler irrigated fields were monitored daily throughout the irrigation season, from the middle of May until the middle of September. A Collins meter was used on field **2** to determine the quantity of water supplied by the pump. In addition, catch can tests were performed on both of the fields to evaluate the depth of water applied and the uniformity of distribution of water over the fields. The monitoring enabled the CSU team to determine the number of revolutions made by the pivot over the course of the irrigation season. From this information, the total amount of water applied to the fields could be determined for each irrigation and over the entire irrigation season. For field **2**, the total depth applied per irrigation was 40 mm (1.6 inches), while for field **3**, the total depth of irrigation water application was 18 mm (0.7 inch).

The distribution uniformity of the fields was evaluated using the conventionally accepted parameter of the Christiansen Uniformity Coefficient (UCC). A UCC reading of over 80% is considered acceptable for a sprinkler irrigation system. Field **2** had a uniformity coefficient of 75%. The uniformity coefficient of field **3** was 83%. Both of these are within the range of acceptability, although the slightly lower figure for field **2** indicates an aging system.

Application Efficiency:

The data collected and described above provide the basis for the calculation of application efficiency. The irrigation application efficiency over a given period is defined as the amount of water available for the plant as a percent of the irrigation water depth applied. For this analysis, application efficiency is calculated as the amount of irrigation water required by the plant, divided by the depth of irrigation water applied, with the assumption that every irrigation event is a full irrigation over the given time period. In the analysis, the amount of irrigation water required by the plant is calculated as ET minus the effective rain.

For the beans grown in field **1**, individual application efficiencies ranged up to 20%. The overall application efficiency for this field is in the range of 10 to 20 percent.

The irrigation application efficiency of field **2**, the sprinkler irrigated field planted in corn, was 58% for the entire season. The irrigation application efficiency of field **3**, the sprinkler irrigated alfalfa field, ranged from 23% for an individual irrigation to 98% for all of the irrigations between the first and second cutting.

In field **4**, for the corn, 25% of the water applied was actually required for plant use. The rest of the water applied either ran off the end of the field or was lost to deep percolation. For the adjacent field **4E**, while lettuce was grown, individual application efficiencies ranged up to 40%. The overall average irrigation application efficiency was calculated to be about 19%. For field **5**, the overall average irrigation application efficiency was calculated to be about 25%.

The data for lettuce in field **6** were too inconclusive to calculate an application efficiency. The results appeared to indicate that there may have been irrigations which went unnoticed over the course of the irrigation season. This would change the application efficiency and deep percolation percentage. For the beans in field **6**, application efficiencies ranged from 22 to 50 percent. However, even these numbers may not represent efficiency levels for the entire season since a number of the irrigations occurred at night and were not monitored.

For field **7**, the border irrigated field of alfalfa, individual application efficiencies ranged up to 35% while the overall average irrigation application efficiency was calculated to be about 17%. In field **8**, the application efficiency of the lettuce field was calculated to be 70%.

The onion portion of field **8** had an application efficiency of 51% and the corn had an application efficiency of 28%.

For field **9**, individual application efficiencies ranged up to 37%. The overall average irrigation application efficiency was calculated to be about 11% for the lower section and 13% for the upper section. Application efficiency increased for both parts of the field over the course of the irrigation season.

Tail Water Percentage:

The tail water percentage was not affected by problems involving periodic monitoring because the data in this case only involve the amount of water applied for a given irrigation and the amount of water coming off the field. Average tail water percentages was 6% for field **4**, 19% for field **5**, and for field **8**, 12% for lettuce, 35% for onions, and 25% for corn.

Deep Percolation:

The deep percolation ratio is the proportion of water applied to a field which percolates beyond the root zone. This provides an indication of the nitrate leaching potential that can result from irrigated agriculture. For this analysis, the deep percolation ratio is calculated as the net irrigation and rain depth applied minus the ET, divided by the total depth of irrigation water applied. All water, including rainfall, that is applied to a field and infiltrates into the soil is considered in the calculation of deep percolation. Deep percolation was only calculated for those fields where reliable runoff information was also available.

As a percentage, the deep percolation for field **1** was as high as 85%. The deep percolation percentage for field **4** in 1993 was 69%. In field **5**, the excess quantities of applied water resulted in a deep percolation percentage of about 56%.

The efficient use of water in the onion and lettuce sections of field **8** is reflected in the relatively low deep percolation percentages of 14% and 17% respectively. The deep percolation of the corn section of field **8** was 41%.

The relatively high deep percolation percentage in field **4** indicates a large potential for leaching nitrates into the ground water as compared to field **8**.

Nitrate as Nitrogen:

Water samples were taken for nitrate analysis in each field over the entire irrigation season. These samples were taken in different parts of the fields to determine what, if any, changes in nitrate levels occurred as water moved across the field. Nitrate as nitrogen levels were measured in the surface water above the pump, in the ground water coming from the pump, in the surface and ground water mixed in the head ditch below the pump above and below the chemicals, and in the water at the tail end of the field. As a bench mark, the EPA drinking water standards have a maximum acceptable level of 10 mg/L as NO_3-N.

In field **1**, only surface water was applied to the field. Nitrate as nitrogen levels of the surface water at the head of the field averaged 4.2 mg/L, half the drinking water standards. Samples were not analyzed from the tail end of the field.

Water from the pumps supplying the sprinkler irrigated fields **2** and **3** exceeded the drinking water standards for nitrates. Nitrate as nitrogen in field **2** ranged from 10 to 13 mg/L while field **3** had levels of 22 to 32 mg/L.

In field **4**, nitrate as nitrogen levels of the surface water upstream of the pump averaged 5.4 mg/L. Ground water from the pump had nitrogen levels of 13 to 25 mg/L NO_3-N. Reflecting the combination of ditch water and pump water during the irrigation season, the tail water had levels of 3 to 18 mg/L NO_3-N. Nitrate levels in the head ditch below the pump were essentially the same as at the bottom of the field. Although the nitrate levels were reduced by mixing surface water with the pumped ground water, the water being applied to field **4** still exceeded the drinking water standards.

In field **5**, nitrate levels were sampled from the surface water in the head ditch and at the tail. There was no pumped water for field **5**, and those tests conducted on the tail water indicated that the nitrate levels were essentially the same as at the head of the field. Nitrate as nitrogen levels in field **5** ranged from 2.5 to 6 mg/L, all below the drinking water standards of 10 mg/L NO_3-N.

The nitrate levels in field **6** decreased over the course of the irrigation season. In field **6**, nitrate as nitrogen levels of the surface water upstream of the pump averaged 12 mg/L. Ground water from the pump had nitrogen levels of 31 mg/L NO_3-N, during the lettuce season and 12 mg/L during the bean season. The tail water reflected the addition of chemicals during the lettuce season because the NO_3-N content of lettuce tail water was 45 mg/L, while for the beans there was an average of 16 mg/L in the tail water.

All of the irrigation water for field **7** was supplied by surface water. The average NO_3-N content of water applied to the field was 5.3 mg/L.

For 1993, in field **8**, NO_3-N levels in the surface water upstream of the pump averaged 4 mg/L. Pumped ground water had nitrate as nitrogen levels of 14.5 mg/L NO_3-N. When chemicals were then applied to the head ditch, the average NO_3-N content was 35 mg/L, exceeding the drinking water standards. Tail water runoff reflected this addition of nitrogen to the irrigation water, with an average NO_3-N content of almost 20 mg/L.

In field **9**, nitrate as nitrogen levels of the surface water upstream of the pump averaged 6.2 mg/L. Ground water from the pump had nitrogen levels of 9 mg/L NO_3-N, while the tail water had levels of 7 mg/L NO_3-N.

Comparisons between 1992 and 1993 data

The 1993 study was more extensive than the comparable study conducted during the 1992 irrigation season. However, the same three fields studied in 1992 were also studied in 1993, permitting comparison of water use and nitrate levels between those fields over the two year period. Water use varied according to both the farmer and the crop type while nitrate levels of surface and pumped water for the three fields stayed roughly the same between the two years studied.

The irrigation application efficiencies in 1992 for fields **4**, **5**, and **8** were 24%, 7%, and 67% respectively. In 1993, these same fields had average application efficiencies of 25% for field **4**, 25% for field **5**, and in field **8**, 70% for lettuce, 51% for onions, and 28% for corn. The irrigation application efficiencies for the three fields were similar in 1992 and 1993, but had a slightly narrower range in 1993. When comparing the fields studied in 1992 with all of the fields evaluated in 1993, the range for both years is roughly the same.

A comparison of deep percolation percentages and tail water percentages in 1992 and 1993 again show a similarity between the two years. For fields **4** and **8**, the deep percolation and tail water runoff were roughly the same from one year to the next. In field **5**, the lower percentage of deep percolation in 1993 compared to 1992 was a result of the higher application efficiency and an increase in tail water runoff in 1993.

Based on the results from 1992 and 1993, summarized in the summary table found in the appendix, it appears that water management and nitrogen management are highly dependent on the value of the crop as well as on individual farmer techniques. Among the fields studied, it appeared that water applied to higher value crops was more carefully managed than that applied to the lower valued crops. Ultimately, the extent to which the water was managed on the individual fields was a function of both economics and the farmer's personal management style.

Conclusions

* The ranges of surface irrigation application efficiencies were 7% to 67% in 1992 and 10% to 70% in 1993.

* Overall average surface irrigation application efficiencies were 33% in 1992 and 28% in 1993.

* The ranges of deep percolation percentages were 8% to 94% in 1992 and 14% to 85% in 1993.

* Overall average deep percolation percentages were 56% in 1992 and 47% in 1993.

* In 1993, overall average sprinkler application efficiency was 60%.

* Overall average nitrate content of ditch water was 6 mg/L NO_3-N in both 1992 and 1993.

* Overall average nitrate content of pumped ground water was 13 mg/L NO_3-N in 1992 and 17 mg/L NO_3-N in 1993.

* There was no evidence of additional nitrate being picked up by water moving the length of the furrows in either year.

Prior to the study, we had anticipated that application efficiencies for surface irrigation systems in the study area would range from 15 to 50 percent. However, the range of irrigation application efficiencies measured for the surface irrigated fields during the two years of study was surprisingly wide, ranging from 10 to 70 percent. When low application efficiencies translate to high deep percolation percentages, there could be repercussions on nitrogen loading to the ground water, especially when nitrate levels in the applied irrigation water and/or nitrate fertilizer applications are high.

Application efficiencies below 50 percent would suggest an opportunity for improving irrigation system performance and reducing nitrate leaching. However, downstream users of the South Platte River are dependent upon irrigation return flows for late season irrigation. Therefore, from the perspective of water allocation, very high efficiencies might not necessarily be advisable in this region.

In general, the nitrate content found in the ditch water was below the drinking water standards, while pumped ground water exceeded the drinking water standards. We found no indication that nitrates were being picked up along the length of the furrow. The nitrate content of water at the tail end of the field was essentially the same as the nitrate content of water in the head ditch at the top of the field.

Recommendations

This study provides insight into the irrigation methods along the South Platte River and nitrate concentrations in applied irrigation water and runoff.

The next step to improving ground water quality, beyond this study, should be to identify the priorities in addressing the issue of nitrates. Decreasing the quantity of nitrates going into the ground water can occur through increased water conservation and through reducing the actual amount of nitrates applied in irrigation water and fertilizers. Both of these two approaches should be addressed. At the present time, there is little financial incentive for the farmer to implement more aggressive water conservation measures or to economize on chemical applications.

These factors must weigh heavily in the development of best management practices appropriate to the area. If implementation of these practices is to be successful, the practices must be developed in cooperation with the farmers who will use those techniques.

Activities and assistance that could support farmer efforts would be useful, particularly if they make financial sense to the farmer. One such activity might be to provide reasonable nitrogen use guidelines, taking into account the nitrogen found in surface and pump water, to supplement information the farmer receives from the chemical suppliers. (Fertilizer recommendations and fact sheets on water and fertilizer management are available from CSU). This could prove to be a money saving device for the farmer.

Another useful service might be to present ideas on how farmers could become more efficient managers of labor and resources, providing another fiscally advantageous avenue to water and chemical management. Regardless of the activities chosen to assist the farmers, farming techniques will only change when the farmers believe that it is in their best interests to do so.

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Appendix : Summary Table

Summary of Results : 1992

Field #	crop	Application Efficiency	Deep Percolation	Tail Water Runoff	ditch water NO3-N	pump water NO3-N
4	potatoes	24%	68%	8%	6 mg/L	11.8 mg/L
5	corn	6.5%	93.5%	0	4.4 mg/L	n/a
8	potatoes	67%	8%	25%	7.1 mg/L	14 mg/L

Summary of Results : 1993

Field #	crop	Application Efficiency	Deep Percolation	Tail Water Runoff	ditch water NO3-N	pump water NO3-N
1	beans	10%-20%	75%-85%	5%-10%	5.3 mg/L	n/a
2	corn	58%	*	*	n/a	12.2 mg/L
3	alfalfa	83%	*	*	n/a	30.4 mg/L
4	corn	25%	69%	6%	3 mg/L	15 mg/L
4E	lettuce	19%	*	*	5.2 mg/L	19.2 mg/L
5	potatoes	25%	56%	19%	4 mg/L	n/a
6	beans	22%	60%	17%	12.1 mg/L	26 mg/L
7	alfalfa	17%	*	*	5.3 mg/L	n/a
8	lettuce	70%	17%	12%	3.4 mg/L	15.2 mg/L
8	onions	51%	14%	35%	"	"
8	corn	28%	47%	25%	"	"
9	corn	11%	*	*	6.2 mg/L	8.9 mg/L

* = data not obtained