Potential Effect of Northern Integrated Supply Project Water Exchanges on Irrigation Water Quality

Submitted to:

W. R. Fischer, Esq.
Fischer, Brown & Gunn, P.C.
1319 East Prospect
Fort Collins CO 80525

T. J. Dow, Esq.
#7 Clocktower Square
323 S. College Ave.
Fort Collins, CO 80524

Executive Summary

The Northern Colorado Water Conservancy District (NCWCD) is coordinating the Northern Integrated Supply Project (NISP), which includes thirteen water-serving districts; to accommodate future water needs of the region (NISP, 2004). The NISP proposes the construction of two reservoirs to increase water storage. The proposed Glade Reservoir would be located northwest of the City of Fort Collins and the Galeton Reservoir would be constructed near Galeton, Colorado and would be used as a partial supply for the New Cache and Larimer and Weld Irrigation Companies.

Under NISP, diversions to Glade Reservoir would occur from the Cache la Poudre River near the Poudre canyon mouth and would occur primarily during spring snowmelt runoff (i.e., May and June). Diversions to Galeton Reservoir would occur from the South Platte River below the confluence with the Cache la Poudre River, upstream from Kersey, CO. These transfers are expected to occur primarily during winter and early spring months. Galeton Reservoir would be used as an irrigation supply for the New Cache and Larimer and Weld (Eaton) ditches. Transfers from Galeton Reservoir to the canals are expected to occur simultaneously (i.e., May and June) with supply transfers from the Cache la Poudre River to Glade Reservoir. Galeton Reservoir would supply approximately 22,000 acre-feet of water per year to the New Cache and Eaton ditches, or about one-third of the needed 60,000 acre-feet per year.

There has been a variety of research efforts on using treated municipal wastewater as irrigation water, but perhaps surprisingly, there are few water quality standards or recommendations for agriculture using non-wastewater as a water supply. Most irrigation recommendations relate to soil salinization, the addition of salts over time through irrigation. The United Nations Food and Agriculture Organization (FAO) and the State of California have both developed a set of recommendations for irrigation water quality. There are recommendations, not standards, for irrigation water quality for the state of Colorado. These recommendations were used to assess the suitability of water for irrigation use.

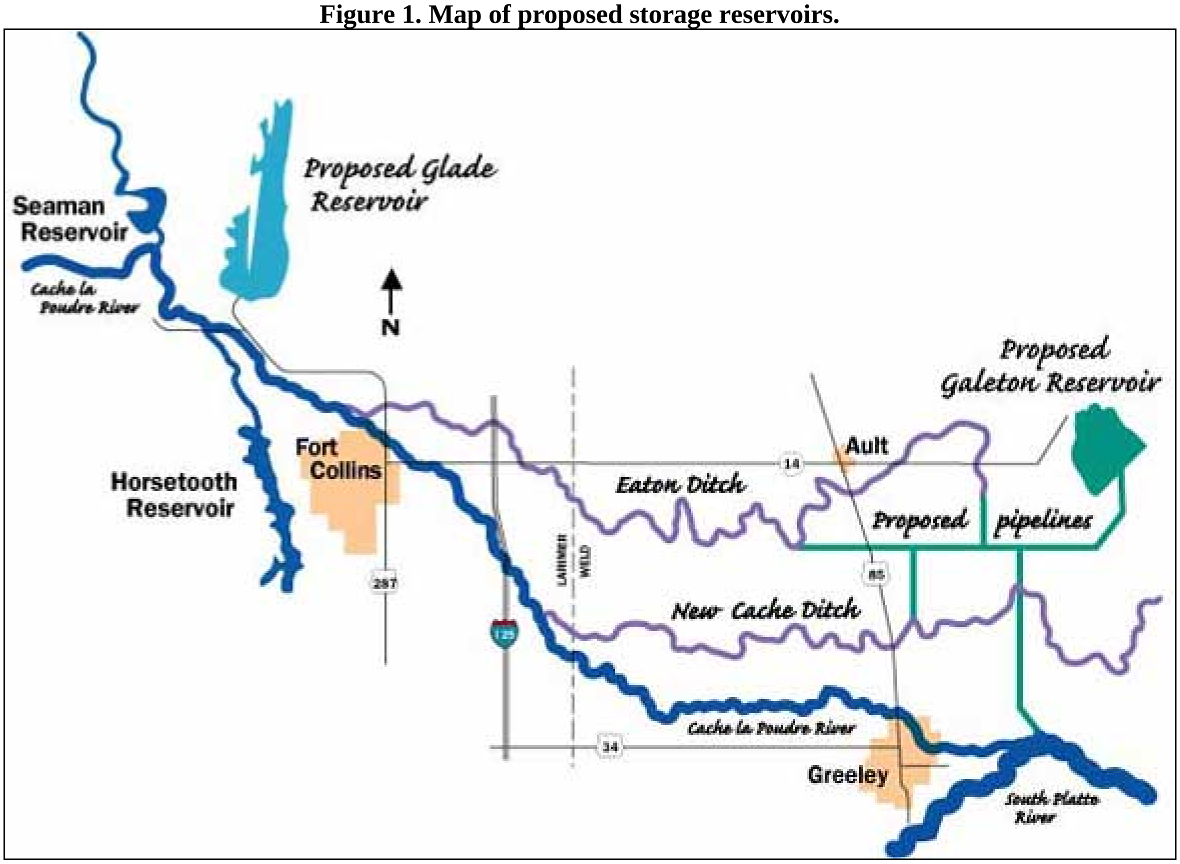
The guidelines for irrigation water quality were used to determine potential effects of the proposed water exchanges. Water quality at the two sites, Cache la Poudre River at canyon mouth and South Platte River at Kersey, was compared to the guidelines to determine whether water quality could potentially affect crop yields. The South Platte River at Kersey tended to have higher concentrations when compared to the Cache la Poudre River. Most constituent concentrations were below the recommended levels for irrigation use, but the salt concentrations, as measured by electrical conductivity, exceed the irrigation guidelines. The salt load to the field (salts in the irrigation water) will be increased under the exchange scenario. Expected yields of salt sensitive crops would be reduced if irrigated with this water.

Table of Contents

Introduction

The Northern Colorado Water Conservancy District (NCWCD) is coordinating the Northern Integrated Supply Project (NISP), which includes thirteen water-serving districts; to accommodate future water needs of the region (NISP, 2004). This project includes the construction of two reservoirs to increase water storage volumes. The proposed Glade Reservoir would be located northwest of the City of Fort Collins with storage of 230,000 acre feet and would be used to supply various water needs for each of the thirteen NISP participants (Figure 1). The Galeton Reservoir would be constructed near Galeton, Colorado to accommodate agricultural water uses while transfers occurred to Glade Reservoir. The Galeton Reservoir would have an active storage capacity of approximately 22,000 acre-feet.

Figure 1. Map of proposed storage reservoirs.



http://www.ncwcd.org/project&features/nisp_main.asp

The South Platte River basin, located in Northeastern Colorado, contains productive farmland that contributes a large proportion of the nation's crops. The region has a semi-arid climate and agricultural crop production is often irrigation dependent. The success and sustainability of irrigated agriculture depends largely on the usability of available water supplies. Poor water quality can lead to decreased crop production and can directly influence crop quality (Ayers and Westcot, 1985).

Water quality refers to the characteristics of a water supply that will influence its suitability for a specific use (Ayers and Westcot, 1985). For agriculture, certain constituents are regarded as limiting crop production capabilities. Total dissolved solids (estimated from electrical conductivity or EC) may lead to long-term salinization problems on irrigated lands having poor drainage (Gates et al., 1993). Excess nutrients, such as nitrates and phosphates, may directly affect crop yields and contribute to algal growth, potentially causing eutrophication of water supplies (Stednick, 1991). Other chemical constituents may contribute to the degradation of soil structure and prove toxic to crops and/or livestock (Gates et al., 1993).

Water suitability for irrigation has been defined by its affect on soils and crops (Ayers, 1977). Water quality evaluations, conducted by the Food and Agriculture Organization of the United Nations (FAO), have been grouped into four categories based on problem areas and include salinity, water infiltration rate, specific ion toxicity, and nutrients (Ayers and Westcot, 1985). These present general guidelines for evaluating water quality for irrigation.

Northern Integrated Supply Project (NISP) proposes exchanging water from the Cache la Poudre River with the South Platte River and/or the lower Cache la Poudre

River. Due to different land use activities, water uses, and water sources, the South Platte River water quality constituent concentrations are higher than in the Cache la Poudre River. The South Platte River is often dominated by wastewater effluent, especially in the winter months. Increased nutrient concentrations may be considered beneficial for crops as nitrogen and phosphorous are often added to soils as fertilizer, although the timing of the application is important based on the plant phenology (stage of plant development). Irrigation waters may include other constituents such as salts, which are not considered beneficial for crop production. Point and nonpoint source inputs of water quality are greater along the South Platte River as this basin includes the highest population density in the Rocky Mountain region (NAWQA, 2004). The South Platte River from Denver to Kersey consists principally of treated municipal wastewater especially in the winter months. Although treated municipal wastewater is generally considered an acceptable water source for irrigation use, careful consideration must be given to water quality in order to evaluate effects from added salts, nutrients, and trace elements on soils and plants (Ayers and Westcot, 1985).

Water quality in the Cache la Poudre River at the canyon mouth were compared to that of the South Platte River near Kersey, CO. Water quality data were downloaded from the US Geological Survey (USGS) for the streamflow gauging station at each location. These stations were selected based on the available long-term water quality database (32 and 56 years respectively). Other stations are located on the Cache la Poudre River, but the canyon mouth station was selected, since this represents water quality that is minimally affected by human activities, and better represents water quality associated with the date of the water rights. Water quality at each station was evaluated for irrigation suitability based on recommendations for irrigated agriculture to determine if crop yields would be affected through proposed water exchanges under the Northern Integrated Supply Project (NISP). In this report Cache la Poudre refers to the water quality at the canyon mouth, and the South Platte River designation refers to the river near Kersey, unless otherwise noted.

Watershed Description

The region is dominated by a continental type climate, where large spatial mean annual temperature and precipitation variations occur. Temperatures generally increase from west to east in mountainous areas, and north to south on the plains. Precipitation in mountainous areas of the South Platte and Poudre basins is dominated by snowfall. Snowfall may exceed 300 inches annually (approximately 30 inches of rainfall). In contrast, precipitation on the plains is primarily rainfall and ranges between 7 to 15 inches annually (NAWQA, 2004).

The Cache la Poudre River basin drains into the South Platte basin southeast of Greeley, Colorado. The Poudre River has a watershed area of 1,055 square miles above the USGS stream gage (NWIS, 2004). Elevations range from approximately 13,000 feet above mean sea level on the continental divide to 5,220 feet at the gage. Land use is primarily rangeland followed by agriculture, forested, urban and other land use. This basin includes the cities of Fort Collins and Greeley.

The South Platte River basin drains 9,659 square miles above the USGS stream gage near Kersey, Colorado (NWIS, 2004). Basin elevations vary from approximately

14,000 feet at Mt. Lincoln on the continental divide to 4,600 feet near Kersey. Land uses are rangeland, followed by agriculture, forested, and urban use. Major urban centers along the South Platte River include Denver and its many suburbs, Boulder, Golden, Longmont, and Loveland. Although both watersheds have similar land uses and hydrology, water quality in the South Platte River below Denver is often wastewater effluent dominated, especially during the winter months, resulting in higher constituent concentrations than the Poudre River.

Methods

Water quality data were downloaded from the USGS National Water Information System website (http://waterdata.usgs.gov/nwis). Data from the stream gage located at the mouth of the Poudre canyon (USGS 06752000 Cache La Poudre River at Mouth of Canyon, Near Fort Collins) were used to determine upstream water quality conditions (Table 1). Cache la Poudre River to Glade Reservoir transfers will occur at this location. The Poudre canyon gage included a 32-year period of record (1970–2002).

Data from the Kersey stream gage (USGS 06754000 South Platte River near Kersey, CO) were used to characterize downstream water quality. This gage is located on the South Platte River near the proposed Galeton Reservoir. The Kersey gage had a 56-year period of record (1948-2003).

Table 1. Study site comparison

Location	Poudre canyon	Kersey
Elevation range (ft)	8400	9710
Contributing area (sq mi)	1,055	9659
Period of record (yrs)	32	56

Research has been done on using treated municipal wastewater as irrigation water, but there are few water quality standards or recommendations for agriculture using non-wastewater for irrigation. The United Nations Food and Agriculture Organization (FAO) (Ayers and Westcot, 1977) and the state of California (Ayers, 1985) have developed recommendations for irrigation water quality. Recommendations have also been proposed for the state of Colorado (Gates et al., 1993). These recommendations were compiled and used to assess the suitability of water for irrigation.

Constituents evaluated included pH, dissolved oxygen, electrical conductivity, calcium, magnesium, potassium, sodium, sodium adsorption ratio, phosphorous, sulfate, and nitrate-nitrogen. Summary statistics were calculated for comparative purposes. Data for each constituent were plotted as frequency and cumulative percent frequency. Water diversions are planned for the winter months. Concentrations may be lower during spring melt runoff, but the relatively short runoff period, and given the few concentration differences between runoff and other months, all data were compiled and annual means used for comparison. Crop tolerances to salinity were assessed as potential percent crop yield reduction (Ayers, 1977), to determine potential effects under the NISP.

Irrigation Water Quality Guidelines

A conservative recommendation of the potential water quality effect on irrigation uses for each constituent was determined as the lower value for each constituent (based on Ayers, 1977: FAO, 1985; and Gates et al., 1993), (Table 2). Also included in this table are constituent ranges usually found in irrigation water (from Ayers, 1977).

Salinity

Salinity is defined as the presence of salts in soil or water that reduces water availability to a crop to the extent that crop yields may be affected (Ayers and Westcot, 1985). Electrical conductivity (EC) data were used to estimate total dissolved salt concentrations within the water supply. This is considered the most important parameter in determining the suitability of water for irrigation use (Environmental Protection Board, 2004).

Table 2. Recommended irrigation water quality concentrations for various parameters.

Problem and Related Constituent	Units	Usual range in irrigation water	Ayers (1977)[1]			FAO (1985)[2]			Gates (1993)[3]	
			Water Quality Guidelines			Degree of restriction on use			Current Colorado Standard	Proposed Criteria for Irrigation
			No Problem	Increasing problems	Severe problems	None	Slight to Moderate	Severe		
Salinity										
EC_w	uS/m	0 - 3	< 750	750 - 3000	> 3000	< 700	700 - 3000	> 3000		
(or)										
TDS	mg/L	0 - 2000				< 450	450 - 2000	> 2000	no standard	< 450
Infiltration										
SAR = 0-3 **and Ecw** =	uS/m					> 700	700 - 200	< 200		
= 3 - 6 =						> 1200	1200 - 300	< 300		
= 6 - 12 =						> 1900	1900 - 500	< 500		
= 12 - 20 =						> 2900	2900 - 1300	< 1300		
= 20 - 40 =						> 5000	5000 - 2900	< 2900		
Specific Ion Toxicity										
Sodium (Na) - Surface irrig.	SAR		< 3	3 - 9	> 9	< 3	3 - 9	> 9	no standard	< 3
	mg/L	0 - 920	< 69	> 69						
Chloride (Cl) - Surface Irrig.	meq/L		< 4	4 - 10	> 10	< 4	4 - 10	> 10		
	mg/L	0 - 1050	< 106	> 106		< 140	140 - 350	> 350	no standard	< 140
Boron (B)	mg/L	0 - 2	< 0.5	0.5 - 2.0	2.0 - 10.0	< 0.7	0.7 - 3.0	> 3.0	0.75 (30 day)	< 0.5
NO_3 - N	mg/L	0 - 10				< 5	5 - 30	> 30	no standard	< 5 (total N)
DO	mg/L								3.0	no standard
PO_4	mg/L	0 - 2							no standard	no standard
Ca	mg/L	0 - 400								
Mg	mg/L	0 - 60								
K	mg/L	0 - 2								
SO_4	mg/L	0 - 780								
NH_3 as NH_4	mg/L									
pH	S.U.	normal range = 6.5 - 8.4								

[1] Adapted from Ayers, 1977. Quality of water for irrigation. Jour. Of Irrig. and Drain., Vol 103, IR2 pp135-154

[2] Adapted from Ayers and Westcott, 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper. 29 Rev. 1

[3] Gates, Sanders, and Podmore, 1993. Recommended water quality criteria for agricultural diversions in Colorado. Project Tech. Report No. 1

Water Infiltration Rate

A high portion of sodium in relation to calcium and magnesium can result in dispersion of clay particles, decreasing the water infiltration capacity. A measure of this salinization is by the sodium adsorption ratio (SAR) (Bauder, et al., 2003) defined as the ratio between sodium relative to calcium and magnesium (Figure 2).

Figure 2. SAR equation, where concentrations are in meq/L.

$$SAR = Na / ((Ca + Mg) /2)^{0.5}$$

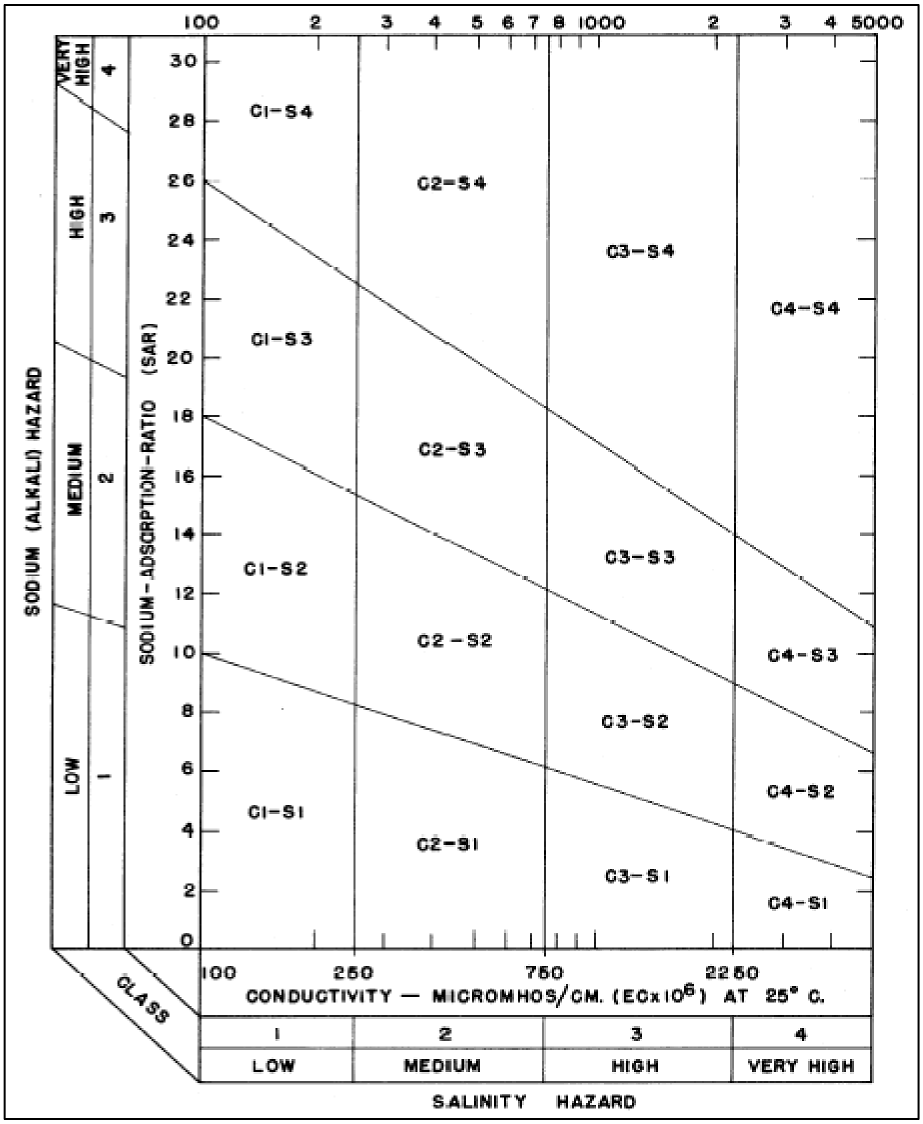
Other work on water infiltration rates incorporates both the sodium adsorption ratio (SAR) and electrical conductivity, as infiltration problems concern both salinity and relative sodium concentration in irrigation water (USSSL, 1954), (Figure 3). This figure will be explained more later. Infiltration rates generally increase with increasing salinity and decrease with either decreasing salinity or increasing sodium adsorption ratios (Ayers and Westcot, 1985).

Specific Ion Toxicity

This category includes sodium, chloride, and boron. Specific ion toxicity is defined by the FAO as accumulations of ions from soil or water in sensitive crops to the extent that crop damage and reduced yields occur (Ayers and Westcot, 1985).

Sodium toxicity has been recorded as a result of relatively high sodium concentrations in irrigation water. It appears as leaf burn and dead tissue along the outside edges of leaves. Sodium toxicity usually occurs after prolonged exposure of higher than normal sodium concentrations (Ayers and Westcot, 1985).

Figure 3. Diagram for the classification of irrigation water



http://www.ussl.ars.usda.gov/hb60/offset/Hb60ch5.pdf

Chloride toxicity is the most common toxicity found in crops. Crops readily adsorb chloride. The result is the accumulation of chloride in plant leaves. Symptoms of chloride toxicity include leaf burn or dying tissue if concentrations exceed crop tolerances (Ayers and Westcot, 1985).

Boron is an essential micronutrient for plant growth, but can become toxic at higher concentrations. Boron toxicity appears as a yellowing, spotting, or drying of leaf edges but there is a wide range of boron tolerances among crops (Ayers and Westcot, 1985).

Nutrients

The nutrient category is defined as excessive nutrients in soil or water that reduce crop yield or quality and may cause excessive corrosion of irrigation equipment (Ayers and Westcot, 1985). Nitrogen is essential for crop production and its limited availability usually limits plant growth, thus nitrogen is often added as fertilizer to increase crop production. When nitrogen concentrations are relatively high in irrigation water, root crop yields may decrease. Sensitive crop tolerances may be as low as 5 mg/L nitrate-nitrogen but can be up to as much as 30 mg/L (Ayers and Westcot, 1985).

The pH is a measure of hydrogen ion activity (Stednick, 1991). This is an indicator of potential problems associated with water. The usual range for pH for irrigation water is usually 6.5 – 8.4. An abnormal pH value denotes potential problems with toxic ions or nutritional imbalances (Ayers and Westcot, 1985).

Other nutrients (not included in the FAO guidelines for irrigation water quality) are dissolved oxygen, phosphorous, calcium, magnesium, potassium, and sulfate. These constituents are considered acceptable at low concentrations but may reduce crop yields when excessive concentrations are reached in soil or water.

Dissolved oxygen is related to the available oxygen for biological demand within a water supply. Dissolved oxygen is important for biological processes to occur within soil to benefit plant production. Phosphorous, like nitrogen, is essential for plant growth but may be toxic in high concentrations. Calcium and magnesium are important in terms of the sodium adsorption ratio in soils. As mentioned previously, decreased infiltration may occur when SAR is high in applied water as compared with specific conductivity. Other compounds essential for plant growth in small concentrations are potassium and sulfate, and both are considered macronutrients.

Water Quality Data Analysis

Streamflow values and constituent concentrations were compiled for the period of record for the Poudre canyon and Kersey gages. In both cases, constituent concentrations tended to decrease with increased streamflows. The lower concentrations were often not statistically different than the other months, so mean annual values were used for comparative purposes, rather than trying to arbitrarily separate by season. The constituent concentrations were compared between locations using summary statistics and frequency and cumulative percent frequency plots. Frequency bins were calculated between one-half to one-third of the constituent standard deviation to determine concentration ranges between the minimum and maximum values for each data set.

Results

Average annual concentrations for the Cache la Poudre River were compared with the same at the Kersey gage. Comparisons with the irrigation recommendations were made to determine the potential effect on crop production. Results for each constituent are discussed below.

pH

The mean pH at Poudre canyon was 7.5 and 7.9 at Kersey (Table 3) both within the FAO guideline of 6.5 – 8.4 (Table 2). The pH is slightly more alkaline at Kersey.

Dissolved Oxygen

Dissolved oxygen is acceptable and above the current Colorado standard of not less than 3.0 mg/L (Figure 5). There are no FAO recommendations for dissolved oxygen (Table 2). The mean values were 9.5 mg/L at the Poudre canyon site and 9.2 mg/L at the Kersey gage (Table 4).

Figure 4. pH (standard units)
Frequency and Cumulative Percent Frequency

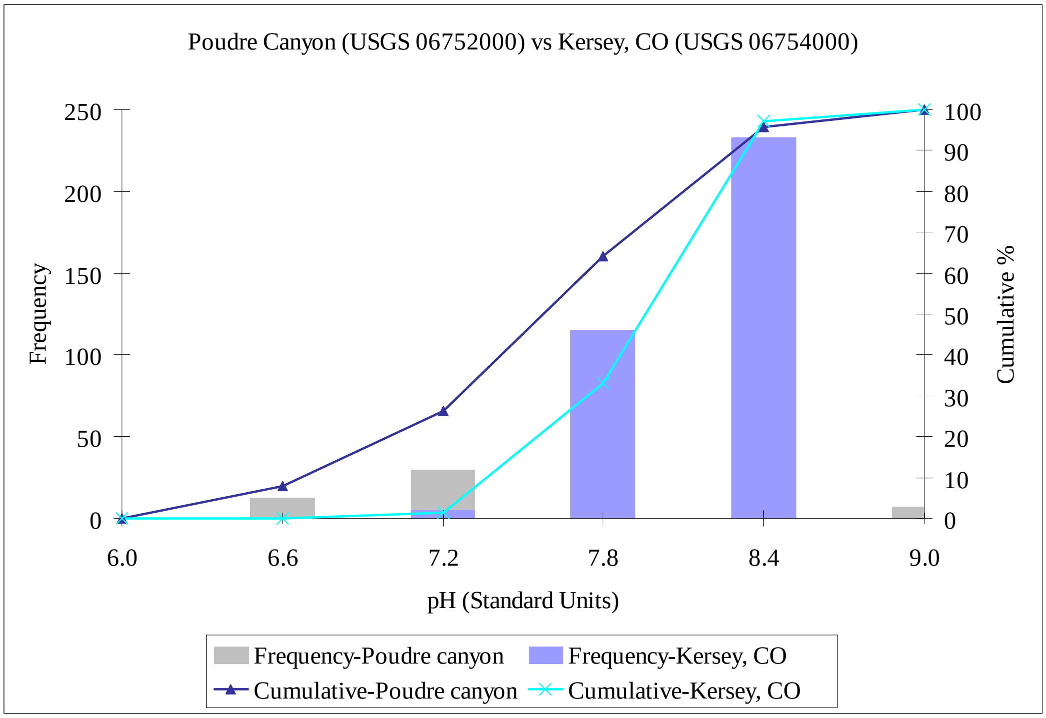


Table 3. pH (standard units)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	7.48	7.87
Mode	7.80	8.00
Median	7.60	7.90
Standard Deviation	0.55	0.31
Minimum	6.10	7.00
Maximum	8.50	8.70
Number of Samples	164	363
Variance	0.30	0.10

Figure 5. Dissolved Oxygen (mg/L)
Frequency and Cumulative Percent Frequency

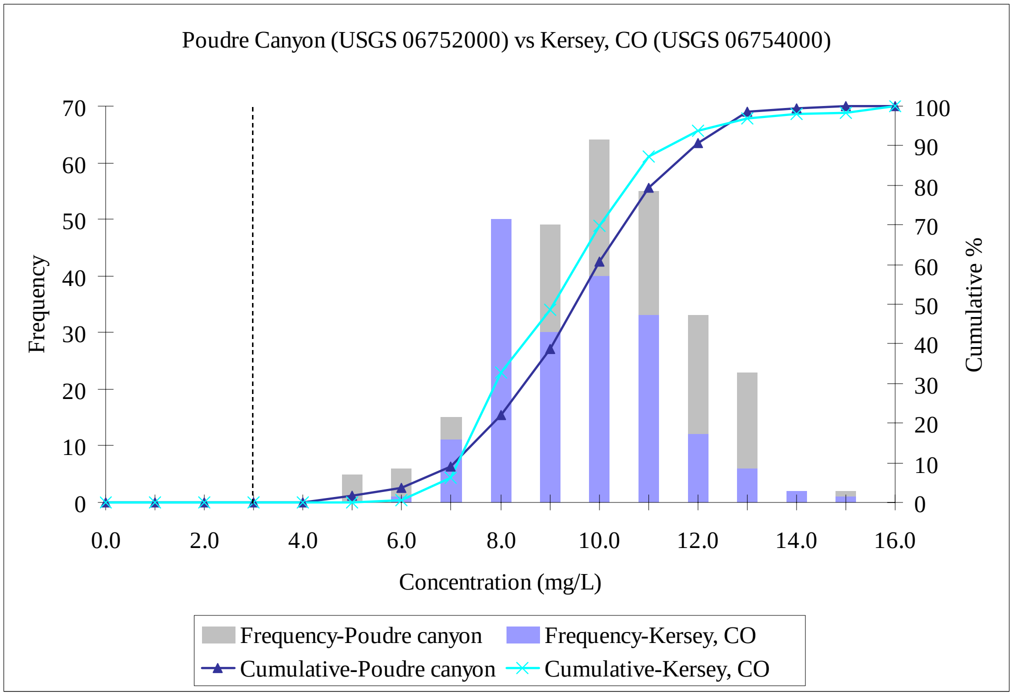


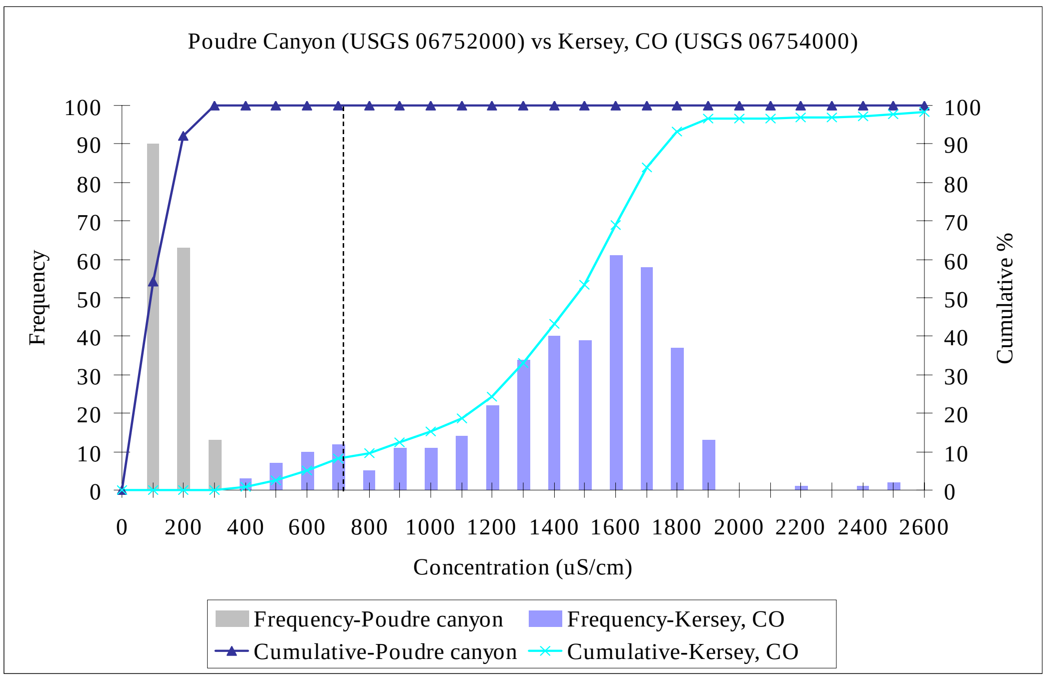
Table 4. Dissolved Oxygen (mg/L)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	9.52	9.24
Mode	10.20	7.80
Median	9.80	9.10
Standard Deviation	1.85	1.81
Minimum	4.80	6.00
Maximum	14.30	15.90
Number of Samples	292	189
Variance	3.41	3.26

Electrical Conductivity (EC)

The mean electrical conductivity values at the Poudre canyon gage was 107 uS/cm (Table 5), well below the FAO guideline (Table 2) while approximately 92 percent of EC at the Kersey gage exceeded the recommended value of 700 uS/cm (Figure 6). All of the Poudre canyon EC levels were less than or equal to 300 uS/cm while EC levels at the Kersey gage begin at 400 uS/cm and increase to approximately 2500 uS/cm.

Figure 6. Electrical Conductivity (uS/cm)



Frequency and Cumulative Percent Frequency

Table 5. Electrical Conductivity (uS/cm)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	107.49	1386.10
Mode	50.00	1600.00
Median	98.00	1490.00
Standard Deviation	57.20	364.41
Minimum	27.00	315.00
Maximum	291.00	2520.00
Number of Samples	166	390
Variance	3272	132793

Calcium

The usual range of calcium concentrations found in irrigation water is between 0 and 400 mg/L. There are no FAO standards for calcium (Table 2). The highest calcium concentrations at the Poudre canyon and Kersey gage were 36 mg/L and 240 mg/L, respectively (Figure 7), both within acceptable limits.

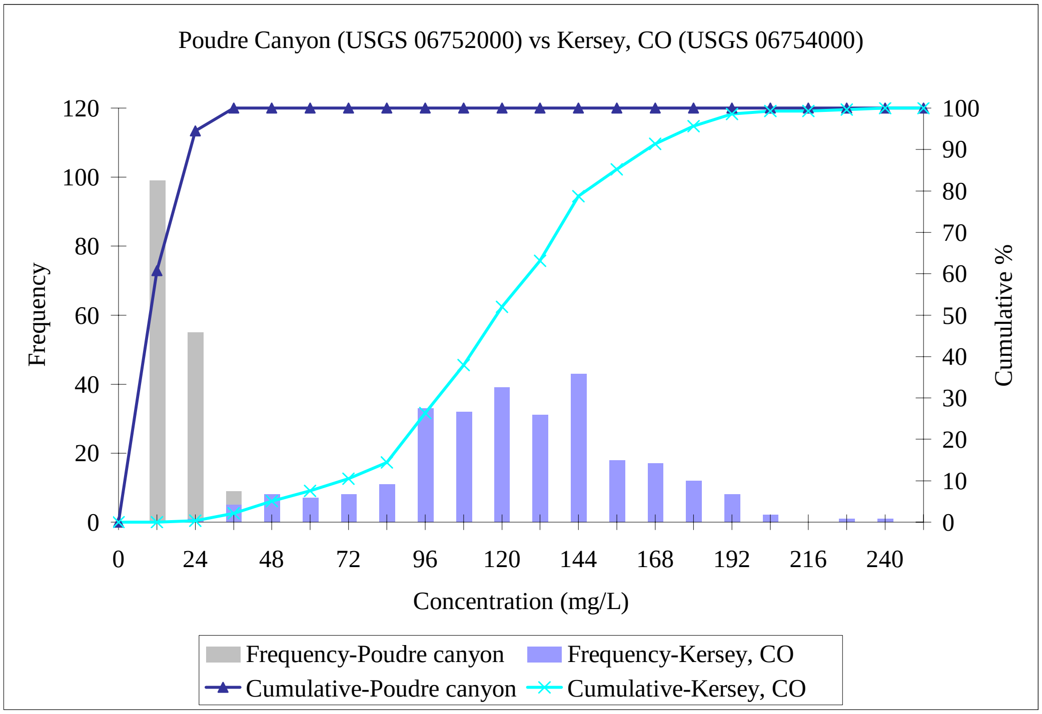


Figure 7. Calcium (mg/L)

Frequency and Cumulative Frequency

The mean concentrations were significantly different between locations (Table 6) with concentrations of approximately 10 mg/L and 120 mg/L at the Poudre canyon and Kersey gages, respectively.

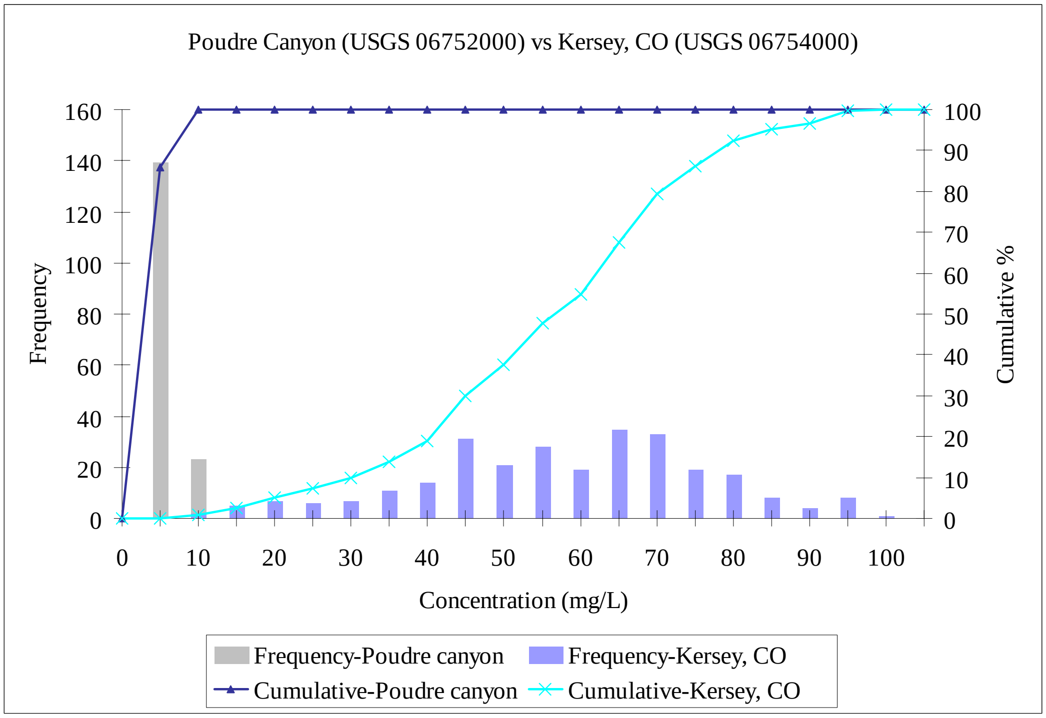
Table 6. Calcium (mg/L)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	12.09	119.20
Mode	16.00	120.00
Median	9.80	120.00
Standard Deviation	6.62	37.46
Minimum	3.20	20.80
Maximum	36.00	236.00
Number of Samples	163	277
Variance	43.76	1403.11

Magnesium

Magnesium concentrations were within the usual range in irrigation water (0-60 mg/L) for both the Poudre canyon and Kersey sites. There are no FAO recommendations for this constituent (Table 2). All of the magnesium concentrations were less than or equal to 10 mg/L at the Poudre canyon gage compared to a maximum of 100 mg/L at the Kersey gage (Figure 8).

Figure 8. Magnesium (mg/L)



Frequency and Cumulative Percent Frequency

Summary statistics for magnesium show large differences in mean values between the Poudre canyon and Kersey sites at 3.0 mg/L and 56 mg/L, respectively (Table 7).

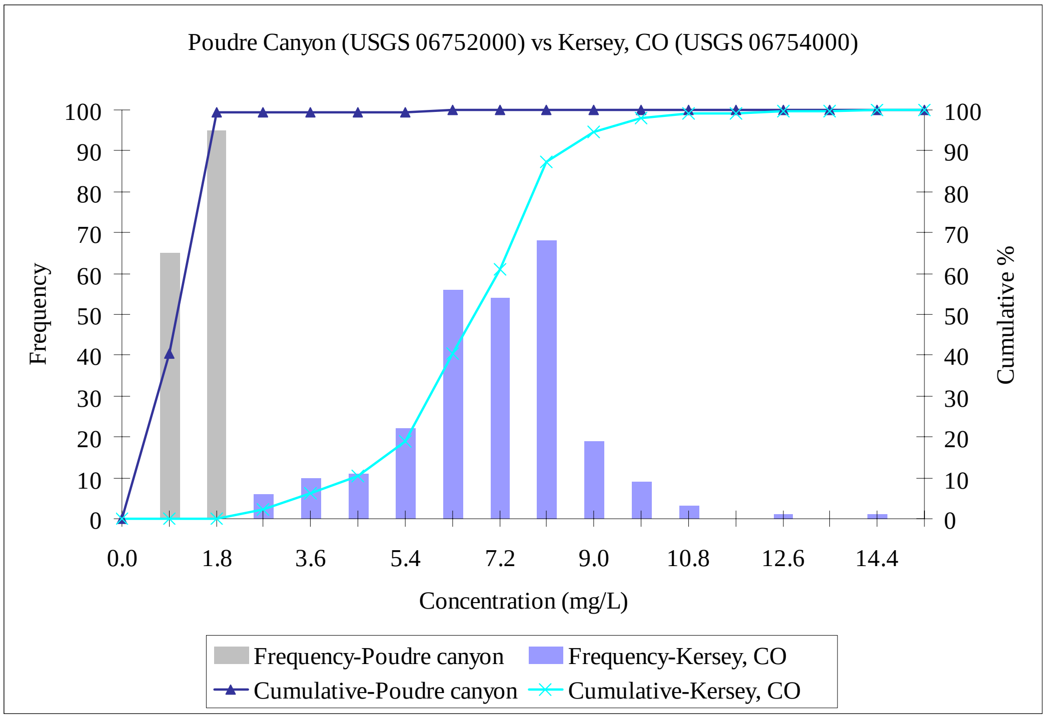
Table 7. Magnesium (mg/L)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	3.07	55.62
Mode	2.20	63.00
Median	2.60	57.00
Standard Deviation	1.86	18.64
Minimum	0.60	7.53
Maximum	9.40	100.00
Number of Samples	162	276
Variance	3.45	347.51

Potassium

Potassium concentrations were above the usual range of 0 to 2 mg/L found in irrigation water at the Kersey site (Table 2). The mean potassium concentration is within the expected range at the Poudre canyon site. All of the potassium concentrations were below 6.0 mg/L at the Poudre canyon gage and 14.4 mg/L at the Kersey gage (Figure 9). Approximately 99 percent of the Poudre canyon data were at or below 1.8 mg/L. At Kersey, approximately 99 percent of the data are above 1.8 mg/L (Figure 9).

Figure 9. Potassium (mg/L)
Frequency and Cumulative Percent Frequency



Summary statistics for potassium show mean and median values of 1.0 mg/L at the upper gage and 7.0 mg/L at the lower gage (Table 8). The standard deviation is approximately three times higher at the Kersey gage than the Poudre canyon gage.

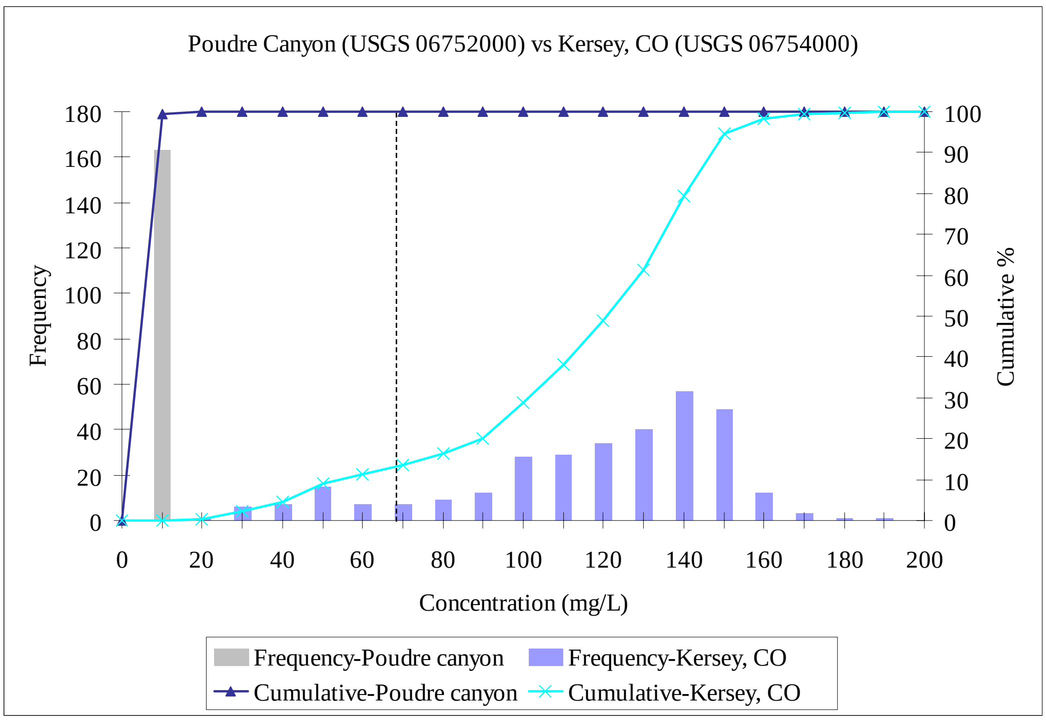
Table 8. Potassium (mg/L)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	1.04	6.64
Mode	1.00	7.50
Median	1.00	6.70
Standard Deviation	0.49	1.67
Minimum	0.30	2.00
Maximum	6.00	14.00
Number of Samples	161	260
Variance	0.24	2.78

Sodium

The FAO guideline for sodium is less than 69 mg/L (Table 2). All of the sodium concentrations at the Poudre canyon gage whereat or below 11 mg/L (Figure 10). All sodium concentrations exceed this value at the Kersey site. The maximum concentration at the Kersey location was 182 mg/L. Approximately 87 percent of the sodium concentrations were above the suggested FAO guideline at the Kersey site.

Figure 10. Sodium (mg/L)
Frequency and Cumulative Percent Frequency



Mean sodium concentrations were significantly higher at the Kersey gage than at the Poudre canyon gage 114 mg/L as compared to 5 mg/L (Table 9).

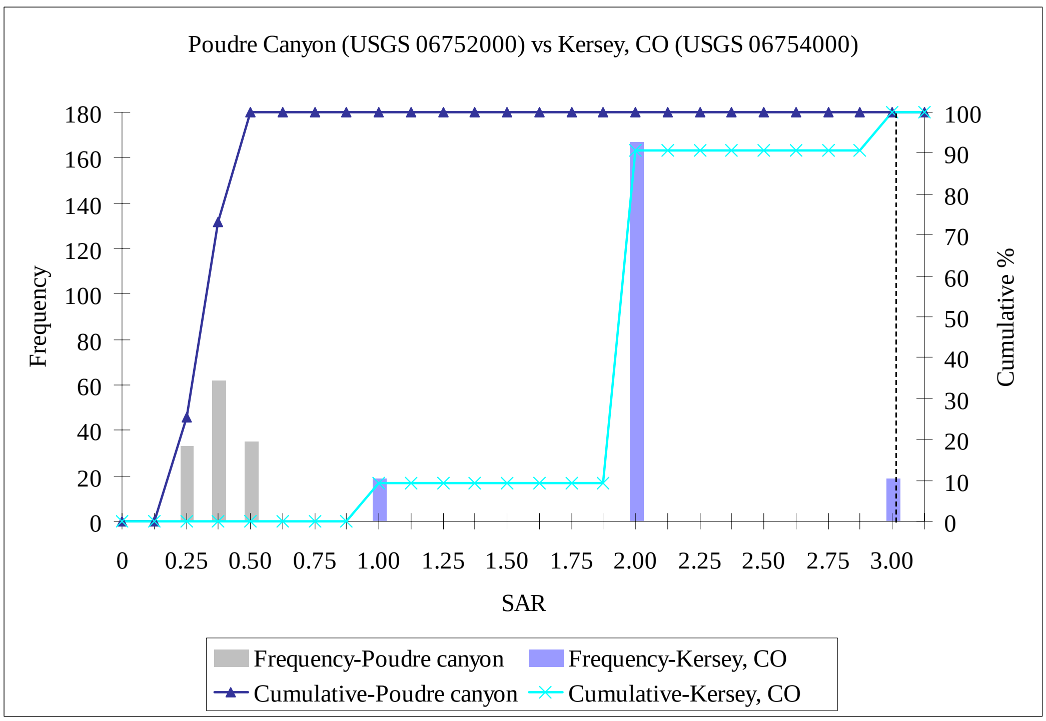
Table 9. Sodium (mg/L)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	4.51	113.86
Mode	4.00	140.00
Median	4.05	122.00
Standard Deviation	2.15	34.02
Minimum	1.30	18.50
Maximum	11.00	182.00
Number of Samples	164	318
Variance	4.62	1157.29

Sodium Adsorption Ratio

Sodium adsorption ratio (SAR) values for both the Poudre canyon and Kersey locations are within the recommended 0–3.0 (Figure 11), but there were differences of mean SAR values between locations. All of the SAR values at the Poudre canyon gage were less than or equal to 0.5 but increased to 3.0 at Kersey.

Figure 11. Sodium Adsorption Ratio
Frequency and Cumulative Percent Frequency



Summary statistics show mean, mode, and median SAR values at the Poudre canyon and Kersey gage were significantly different (Table 10).

Table 10. Sodium Adsorption Ratio
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	0.30	2.00
Mode	0.30	2.00
Median	0.30	2.00
Standard Deviation	0.08	0.43
Minimum	0.20	1.00
Maximum	0.50	3.00
Number of Samples	130	205
Variance	0.01	0.19

Boron

Boron concentrations were below the FAO guideline of 0.7 mg/L (Table 2) for both the Poudre canyon and Kersey locations (Figure 12). However, the boron concentration at the Kersey gage can exceed the guideline of 0.5 mg/L (Ayers, 1977). All of the boron data at the Poudre canyon were less than or equal to 0.18 mg/L while concentrations increased to 0.59 mg/L at the Kersey site. Boron concentrations below detection limits were treated as zero for calculation purposes.

Statistical summary data for boron concentrations show mean, mode, and median concentrations of 0.03 mg/L at the Poudre canyon site while the Kersey concentrations were approximately 0.25 mg/L (Table 11).

Figure 12. Boron (mg/L)
Frequency and Cumulative Percent Frequency

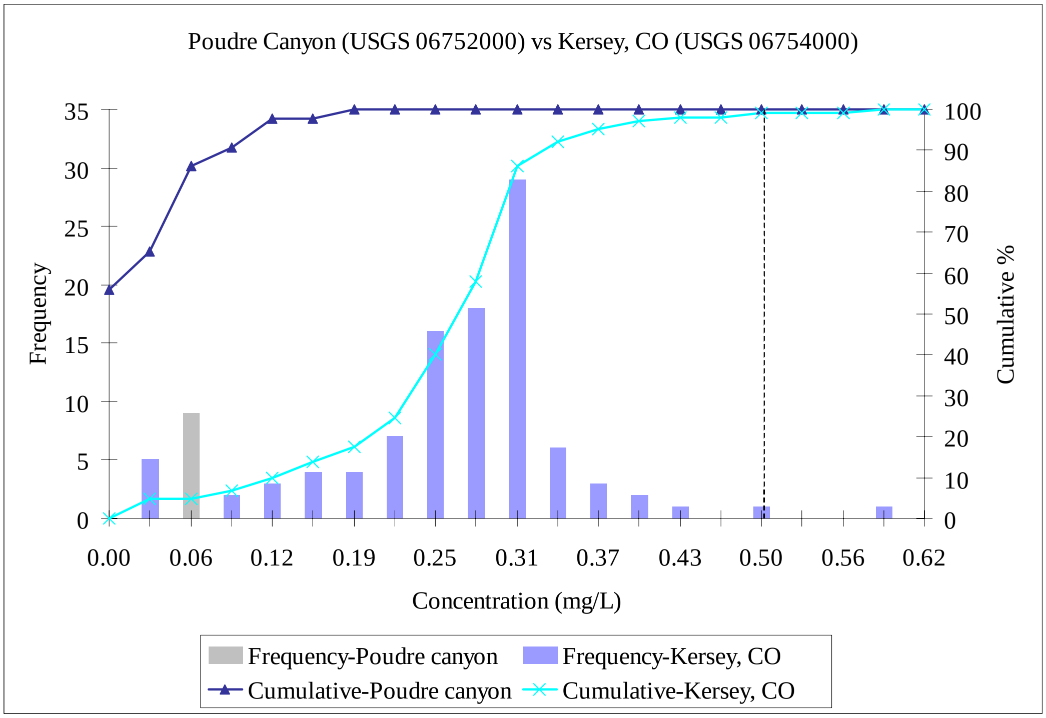


Table 11. Boron (mg/L)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	0.03	0.25
Mode	0.00	0.28
Median	0.00	0.27
Standard Deviation	0.04	0.09
Minimum	0.00	0.01
Maximum	0.18	0.56
Number of Samples	43	102
Variance	0.00	0.01

Phosphorous

Orthophosphate as phosphorous is within the usual range (0-2 mg/L) in irrigation water. There are no guidelines or recommendations for phosphorous (Table 2). Phosphorous concentrations at the Poudre canyon gage did not exceed 0.11 mg/L (Figure 20) with a mean of 0.01 mg/L. Kersey had a mean of 0.58 mg/L with a maximum of 1.50 mg/L (Table 12). Although the Kersey site phosphorous concentrations are low, they are significantly higher than concentrations found in the Cache la Poudre River.

Figure 13. Orthophosphate as Phosphorous (mg/L)
Frequency and Cumulative Percent Frequency

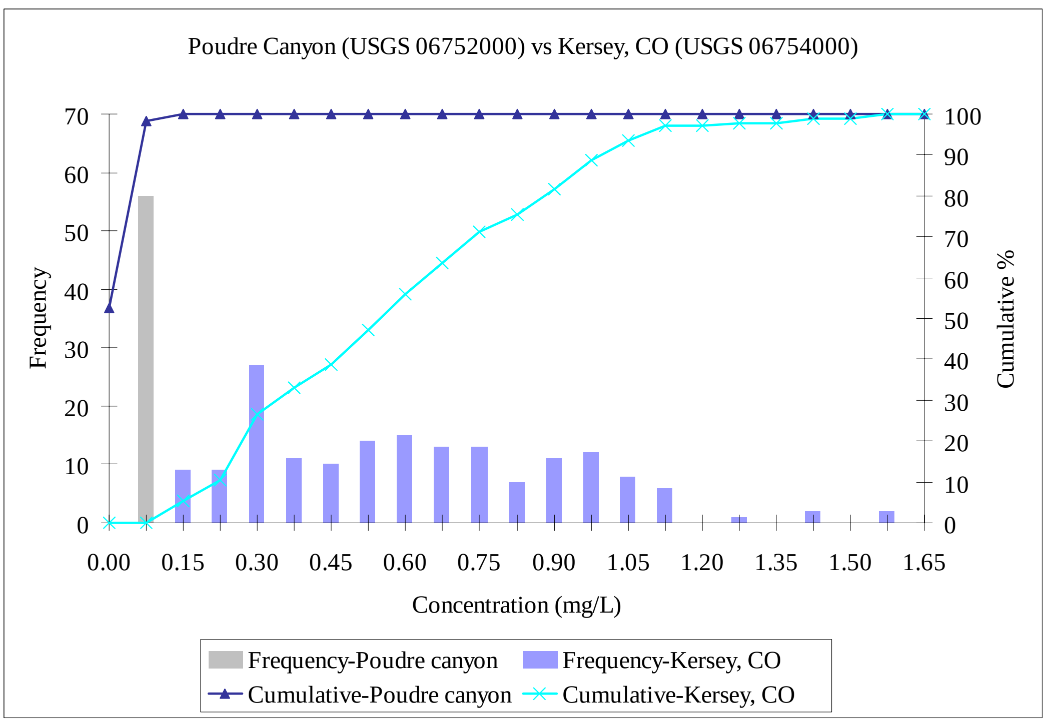


Table 12. Orthophosphate as Phosphorous (mg/L)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	0.01	0.58
Mode	0.00	0.28
Median	0.00	0.55
Standard Deviation	0.02	0.31
Minimum	0.00	0.09
Maximum	0.11	1.50
Number of Samples	122	170
Variance	0.00	0.10

Sulfate

Sulfate concentrations for both the Poudre canyon and Kersey sites were within the usual range of 0 to 780 mg/L found in irrigation water. There are no FAO guidelines for this constituent (Table 2). The sulfate concentrations at the Poudre canyon gage did not exceed values of 16 mg/L with a mean of 6.0 mg/L, whereas the concentrations were as high as 770 mg/L at the Kersey gage with a mean of 454 mg/L (Figure 14).

Figure 14. Sulfate (mg/L)
Frequency and Cumulative Percent Frequency

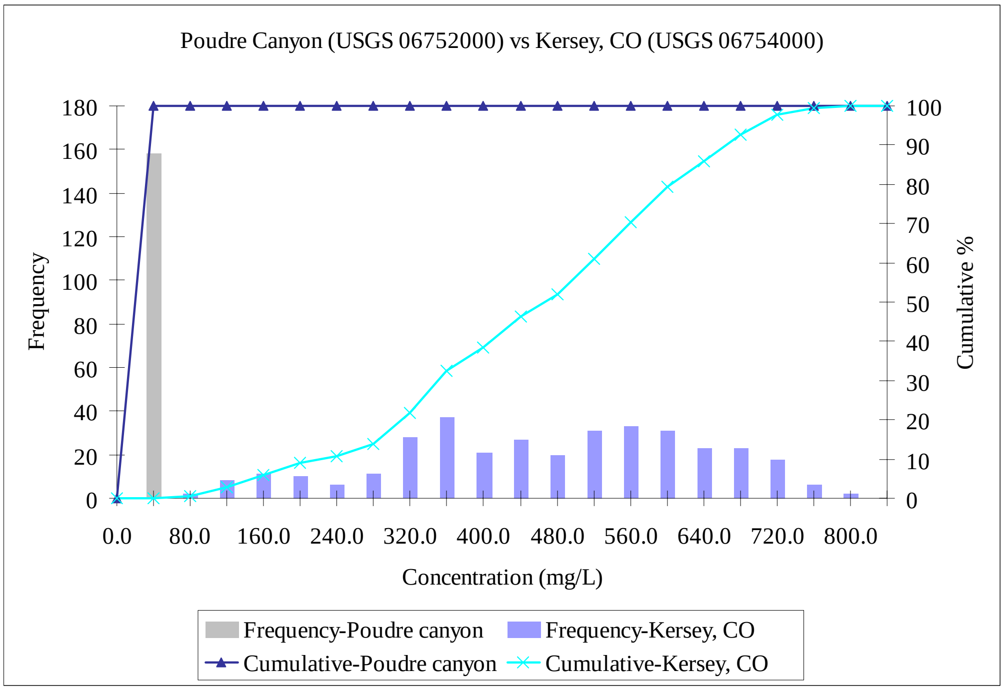


Table 13. Sulfate (mg/L)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	5.97	454.34
Mode	5.00	570.00
Median	5.40	476.50
Standard Deviation	2.80	162.96
Minimum	1.20	63.00
Maximum	16.00	770.00
Number of Samples	158	348
Variance	7.83	26600

Chloride

Chloride concentrations were within the FAO guidelines of 140 mg/L (Table 2) at both locations (Figure 15). All of the upstream concentrations were lower than 10 mg/L while the Kersey mean concentration is 51.8 mg/L (Table 14). The Kersey gage concentrations ranged from 8 to 189 mg/L.

Figure 15. Chloride (mg/L)
Frequency and Cumulative Percent Frequency

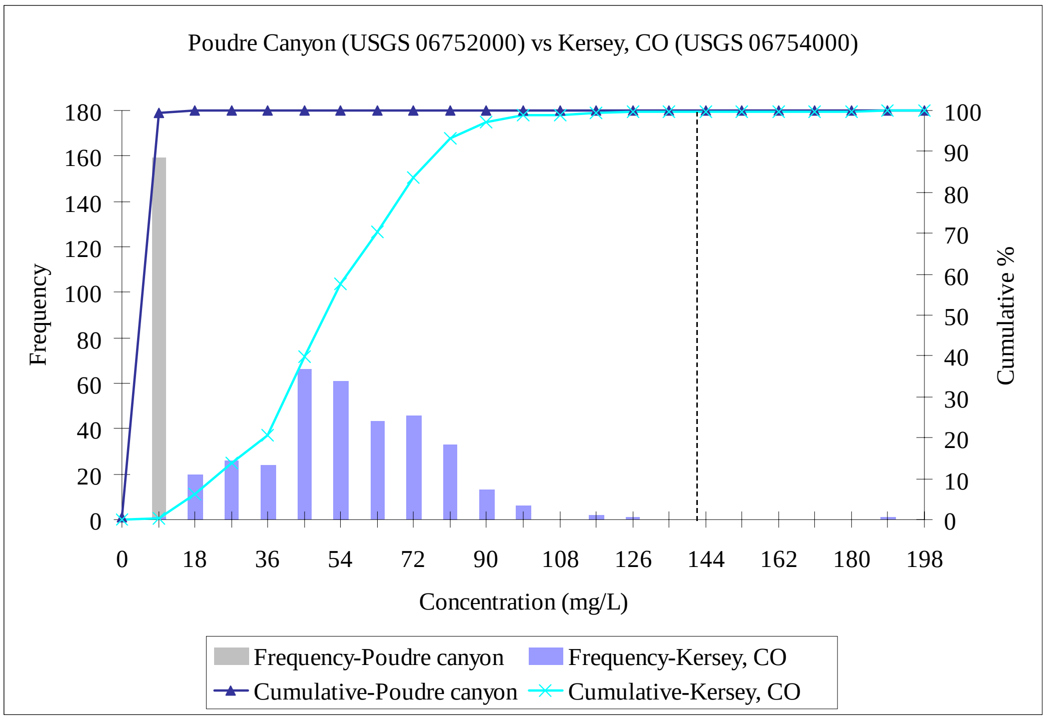


Table 14. Chloride (mg/L)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	2.18	51.83
Mode	1.40	39.00
Median	1.80	50.00
Standard Deviation	1.59	21.78
Minimum	0.00	8.00
Maximum	11.00	189.00
Number of Samples	161	343
Variance	2.52	474.34

Nitrate - Nitrogen

The nitrate - nitrogen recommendation is less than 5.0 mg/L. Maximum nitrate - nitrogen concentrations at the Poudre canyon gage were 0.5 mg/L, with a mean of 0.08 mg/L (Figure 16). The nitrogen concentrations at the Kersey gage had a maximum of 10.0 mg/L. Approximately 60 percent of the nitrogen concentrations at this location exceeded the FAO guideline (Table 2).

Figure 16. Nitrate - Nitrogen (mg/L)
Frequency and Cumulative Percent Frequency

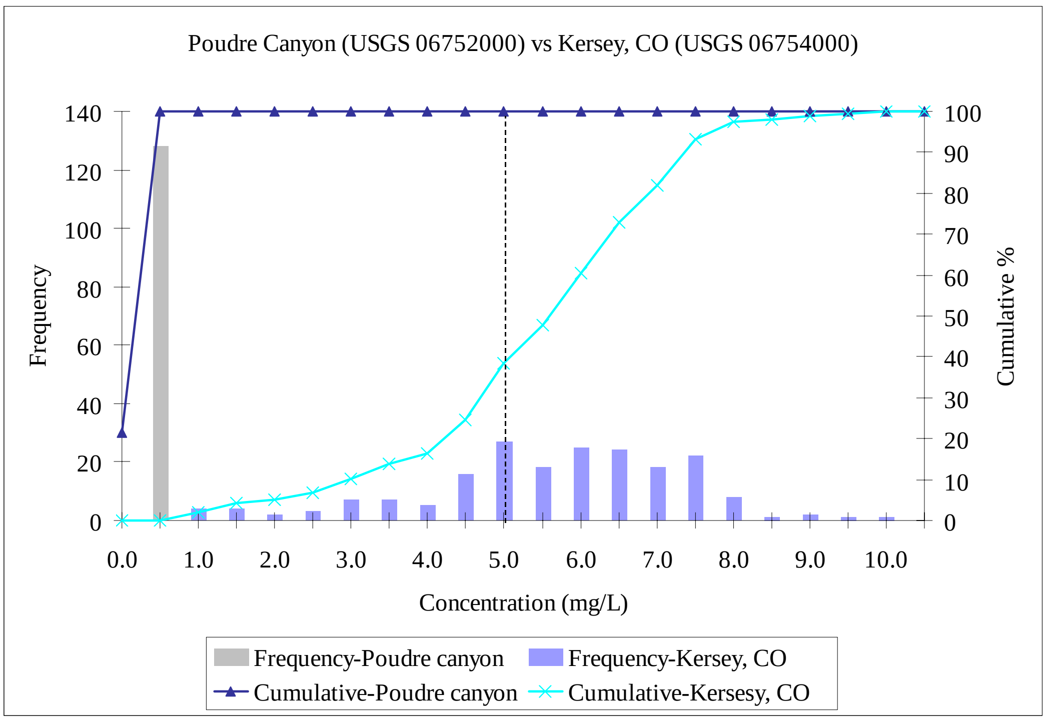


Table 15. Nitrite - Nitrogen (mg/L)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	0.08	5.43
Mode	0.00	4.90
Median	0.05	5.60
Standard Deviation	0.09	1.71
Minimum	0.00	0.75
Maximum	0.50	10.00
Number of Samples	163	195
Variance	0.01	2.92

Percent Crop Reduction

Although the constituents previously analyzed may effect crop production as determined by the FAO guidelines, estimates of crop reduction for this review were based on the regional crops abilities to withstand increased salinity concentrations in irrigation water (Table 16). Crop production is directly related with the amount of water transpired through a crop as well as plant tolerances to salt concentrations. Therefore, the usability of irrigation water will vary (Ayers, 1977).

Table 16. Potential yield reduction from saline irrigation water[1].
EC values are in dS/m, to convert to uS/cm multiply by 1000.

	% Yield reduction			
Crop	0%	10%	25%	50%
	Electrical conductivity[2]			
Barley	5.3	6.7	8.7	12.0
Sugarbeet[3]	4.7	5.8	7.5	10.0
Wheat	4.0	4.9	6.4	8.7
Alfalfa	1.3	2.2	3.6	5.9
Cabbage	1.3	2.2	2.9	4.2
Corn (silage)	1.2	2.1	3.5	5.7
Corn (grain)	1.1	1.7	2.5	3.9
Lettuce	0.9	1.4	2.1	3.4
Onion	0.8	1.2	1.8	2.9
Carrots	0.7	1.1	1.9	3.1
Beans	0.7	1.0	1.5	2.4

[1] Adapted from "Quality of Water for Irrigation." R.S. Ayers. Jour. Of the Irrig. And Drain. Div., ASCE. Vol 103, No. IR2, June 1977, pp.135-154 and "Irrigation Water Quality Criteria." T.A. Bauder, G.E. Cardon, R.M. Waskom, and J.G. Davis. CSU Cooperative Extension. No. 0.506, July 2003.

[2] EC of irrigation water (dS/m at 25°C).

[3] Sensitive during germination period. EC should not exceed 3 dS/m.

The FAO guideline for EC is 0.7 dS/m (Table 2). A statistical comparison of electrical conductivity (Table 17) shows a mean conductivity of 0.11 dS/m at the Poudre canyon gage and approximately 1.4 dS/m at the Kersey gage. Maximum electrical conductivity values at Kersey were as high as 2.5 dS/m.

Table 17. Electrical Conductivity (dS/m)
Statistical comparison

Summary Statistic	Poudre Canyon (USGS 06752000)	Kersey, CO (USGS 06754000)
Mean	0.11	1.39
Mode	0.05	1.60
Median	0.10	1.49
Standard Deviation	0.06	0.36
Minimum	0.03	0.32
Maximum	0.29	2.52
Number of Samples	166	390
Variance	3.27	132.79

The recommendation for EC for irrigation water quality is less than 700uS/cm or less than 0.7 dS/m (to convert to dS/m to uS/cm multiply the first by 1000). Potential yield reductions may occur when EC is greater than 700uS/cm (0.7dS/m). No potential yield reduction would be expected from using water from the Cache la Poudre River. Crop yield reductions of up to 10 percent may be expected if using water from Kersey for beans, carrots, corn, onion, and lettuce (Table 16).

Discussion

Water quality is significantly different between the Cache la Poudre River at the canyon mouth and the South Platte River at the Kersey gage. Mean water quality constituent values for the Poudre canyon and Kersey sites were generally within the FAO guidelines (Table 18). However, water quality measurements taken at Kersey occasionally exceeded the recommended values.

Table 18. Comparison of mean values to recommended values.

Constituent	Units	FAO Guideline	Poudre Canyon	SPR at Kersey
pH	standard	6.5-8.4	7.48	7.87
Dissolved oxygen	mg/L		9.52	9.24
Electrical conductivity	uS/cm	<700	107.5	1386
Calcium	mg/L		12.1	119.2
Magnesium	mg/L		3.07	55.6
Potassium	mg/L		1.04	6.64
Sodium	mg/L	<69	4.5	113.8
SAR		<3.0	0.3	2.0
Boron	mg/L	<0.7	0.03	0.25
Phosphate	mg/L		0.01	0.58
Sulfate	mg/L		5.97	454
Chloride	mg/L	<140	2.18	51.8
Nitrate-nitrogen	mg/L	<5	0.08	5.43

Mean electrical conductivities were 110 and approximately 1400 uS/cm for the Poudre canyon gage and the Kersey gage respectively. According to the FAO guidelines, salinity problems begin to occur when conductivity concentrations exceed 700 uS/cm (0.7 dS/m). All conductivity data for the canyon site were below the guideline. Approximately 92 percent of all the South Platte River conductivity measurements exceeded the recommended FAO guideline.

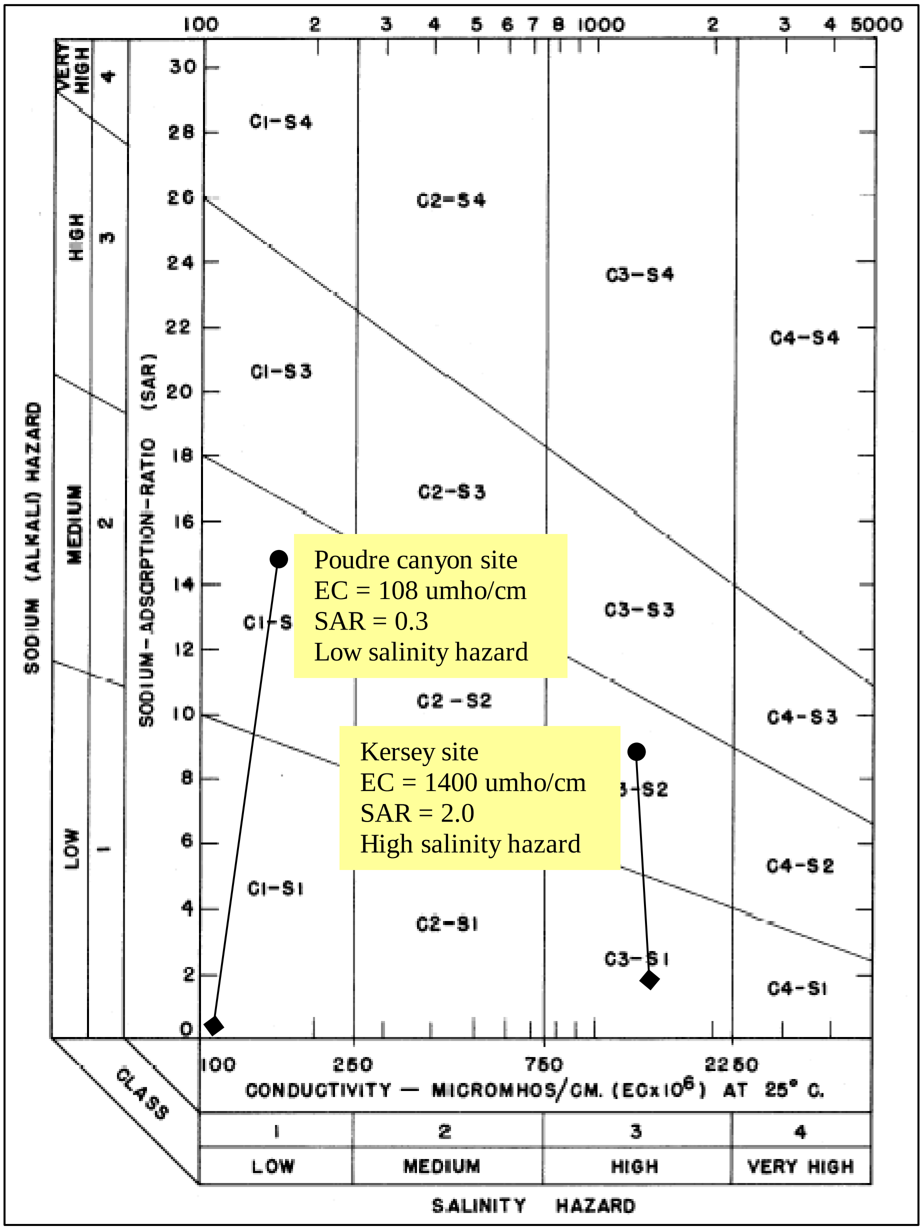
Potential crop yield reductions are expected from irrigating with water taken from the South Platte River near Kersey with the exception of barley, sugarbeets, and wheat

(Table 16). These crops have relatively high tolerances to salt concentration in soil and water. Alfalfa and cabbage yields could be reduced when irrigated with waters of higher electrical conductivity from water supplied from the South Platte River. Corn and lettuce yield reductions of up to 10 percent would be expected using the same water. Onion, carrot, and bean yields would be reduced more than 10 percent given their sensitivity to salt loading.

To determine water infiltration problems, EC and SAR need to be compared together. Electrical conductivity data from the Poudre canyon gage were all less than 700 uS/cm with approximately 55 percent less than 200 uS/cm. Electrical conductivity at Kersey was often higher than 700 uS/cm. Therefore, a low salinity hazard exists from water supplied from the Poudre canyon site (C1-S1) while a high salinity hazard exists with water supplied from the Kersey location (C3-S1) (Figure 28) (USSSL, 1954). Both sites have low sodium hazards for irrigation water.

Low salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop (USSSL, 1954). High salinity water (C3) cannot be used on soils with restricted drainage, and salinity control should be used and salt tolerant crops selected. Low sodium water (S1) can be used on most soils with little danger of sodium harm (USSSL, 1954).

Figure 17. Diagram for the classification of irrigation water



The recommendation for sodium is less than 69 mg/L (Ayers, 1977). The mean and maximum values at the Poudre canyon site were well below this recommendation. The mean sodium concentration at Kersey is 114 mg/L and exceeds the recommended guideline.

Chloride and boron concentrations were below the FAO guidelines. Mean concentrations at the Kersey site were significantly higher for both chloride and boron. Chloride concentrations at the Poudre canyon site were 2.18 mg/L and 51.83 mg/L at the Kersey site. Mean boron concentrations were 0.03 mg/L at the Poudre canyon gage as compared with 0.25 mg/L at Kersey.

Poudre canyon nitrate - nitrogen concentrations had a maximum value of 0.5 mg/L and a mean of 0.08 mg/L. These were well below the conservative guideline of 5.0 mg/L. The Kersey site mean was 5.43 mg/L and a maximum of 10.0 mg/L. The nitrogen addition in irrigation water may affect crop yields if nitrogen fertilization is not adjusted accordingly.

No guidelines are recommended for phosphorous, but the mean concentration at the Poudre canyon gage was 0.01 mg/L while the mean concentration was 0.6 mg/L at Kersey. Irrigation with waters high in phosphorus may affect crop yields if fertilization rates are not adjusted properly. The higher nitrogen and phosphorous concentrations are due to effluent discharge from the Denver metro area wastewater treatment plants into the South Platte River, and would be expected to increase with continued human population growth.

Calcium, magnesium, potassium, and sulfate all follow similar trends in which the concentrations at the Kersey site were greater than concentrations at the Poudre canyon location. Calcium means were 12 mg/L and 119 mg/L for the Poudre canyon and Kersey sites, respectively. Magnesium mean concentrations were 3 mg/L at the Poudre canyon and 56 mg/L at Kersey. Potassium concentrations were 1.0 mg/L and 6.6 mg/L for the Poudre canyon and Kersey sites. The mean concentration for sulfate differed the most between locations. The mean at the Poudre canyon was 6 mg/L while the Kersey mean was 450 mg/L.

Exchanges to the Glade Reservoir will occur primarily during the months of May and June. Diversions to the Galeton Reservoir will occur during low flow months, primarily late winter and early spring. Water pumped from the South Platte River will be stored in Galeton Reservoir, mixed in the ditches with existing water, or pumped directly into the ditch system without mixing. The total estimated supply from Galeton Reservoir would be approximately 22,000 acre-feet. The water from the South Platte River is of lower quality than water from the Cache la Poudre River as measured by national and international irrigation guidelines, Crop yields for salt sensitive crops would be expected to decrease.

Salt sensitive crops are particularly susceptible in the early grow stages and efforts should be made to minimize their exposure to salts via other water sources. Hoffman, 2004, made similar observations in the report “Impact of utilizing water supplies from the South Platte water conservation project on crop production”. That report used a maximum conductivity of 1.3 dS/m for the South Platte River at Kersey (Hoffman, 2004). The long term record has a mean conductivity of 1.4 dS/m, and approximately 60% of the data are greater than 1.4 dS/m and the maximum value is 2.5dS/m (Figure 6). Salt concentrations are expected to increase in the South Platte River as the human population increases, especially when reverse osmosis treatment facilities for drinking water become operational. The Hoffman modeling effort underestimates the potential crop yield reductions.

If the project does proceed, recommendations for monitoring have been proposed (Hoffman, 2004). The current investigation also supports the following:

- Proportion of irrigation water from the ditch company's supply should be increased and exchange water reduced when growing salt sensitive crops.
- Crops are more sensitive to salinity in the early growth stages. Ditch water should be supplied early in preference to exchange water.
- Monitor water quality through the system over time, and sample soils when salt measurements are high.

It cannot be said that implementation of these recommendations would prevent decreased crop production or soil salinization. Monitoring is not mitigation.

Conclusion

The proposed NISP water transfers include diverting water from the Poudre canyon mouth and replacing it with water supplied from the South Platte River near Kersey. Mean values of various water quality constituents were used in this review. Water quality constituent concentrations may decrease with increased streamflow, but given the relatively low flows on the river the last few years; annual means were used for comparative purposes, rather than seasonal values. The differences between the concentrations with streamflow were small compared to the concentrations differences seen between sites. Water quality in the South Platte River is less desirable than Cache la Poudre River water quality for irrigation. Nitrogen and salt concentrations in the South Platte River water may very well affect crop yields.

Potential problems with water infiltration as assessed by the sodium adsorption ratio (SAR) and electrical conductivity showed that irrigation water supplied from Kersey has a high salinity hazard (EC of 1400 uS/cm and an SAR of 2.0). The water at the Poudre canyon site has a low salinity hazard. Mean electrical conductivity was 108 uS/cm and SAR was 0.3. Waters at both locations have a low sodium hazard. The FAO recommendation for electrical conductivity is less than 700 uS/cm.

Also of special interest for irrigation water are sodium, chloride, and boron concentrations. Sodium concentrations at the Kersey site were higher (114 mg/L) than the FAO standard of less than 69 mg/L. The sodium concentration at the Poudre canyon gage was approximately 5 mg/L. Chloride and boron concentrations at both sites were lower than the FAO standards of 140 mg/L and 0.7 mg/L, respectively.

The mean nitrate-nitrogen concentration was 0.08 mg/L at the Poudre canyon location and 5.43 mg/L at the Kersey site, with a maximum of 10.0 mg/L. The recommended concentration is 5.0 mg/L. This represents a significant nitrogen input through irrigation with South Platte River water. Above ground vegetation (leaves) responds most to nitrogen fertilization, roots and root crops do not. Nitrogen addition by water should be accounted for in the recommended nitrogen fertilizer rates. Unless a nitrogen credit program is initiated with the farmer, with the cooperation of the water user, root crop yields may decrease.

Crop yields depend on climate, soil, irrigation methods, irrigation water, and management practices. Given these variables, estimates of crop reduction are difficult at best, and were based on the regional crops abilities to withstand increased salinity concentrations in irrigation water. Irrigation waters from the Poudre canyon site would have no effect on crop yield. However, there is a potential yield reduction of up to 10 percent for lettuce, onions, carrots, and beans using water from the South Platte River.

Under the proposed NISP, waters taken from the South Platte River could be stored in Galeton Reservoir and then pumped into the ditches, approximately halfway through the canals and this supply would be mixed with Cache la Poudre River water that enters at the head of each ditch, or pumped directly into the ditches. The higher constituent concentraions in the South Platte River could be diluted to avoid any potential crop yield reduction.

The salt load to the field (salts in the irrigation water) will be increased under the exchange scenario. One acre-foot of irrigation water with Cache la Poudre water from the canyon mouth will result in a salt load of approximately 190 pounds of salt per acre-foot of water applied, with a maximum of 506 pounds when the conductivity is at the maximum. Conversely, water from the South Platte River at Kersey would result in n average salt load of 2,410 pounds per acre-foot of salt, and a maximum load of 4,383 pounds per acre-foot. Water quality constituent concentrations tend to increase in the Cache la Poudre River moving from the mouth of the canyon to the confluence with the South Platte River. Water quality changes are due to land use activities and water uses. Field measurements of electrical conductivity in the summer of 2004 in the Larimer & Weld Ditch were approximately 500 uS/cm and the New Cache Ditch was 650 uS/cm, resulting in a salt load of 870 and 1,130 pounds per acre-foot respectively. Increased salt loads have decreased crop quality and yield, but the prediction of such changes is difficult.

Generally speaking, the potential decrease in crop production under irrigation will increase with increased exchange water in the ditch systems. The impacts range from no decrease with no exchange, to up to 10 percent yield reduction with full exchange water. Lettuce, carrots, beans, and onions are salt sensitive and produced under both ditch systems.

Literature Cited

Ayers, R.S., 1977. Quality of water for irrigation. Jour. of the Irrigation and Drainage Division, ASCE. Vol 103, No. IR2, pp.135-154

Ayers, R.S. and Wescot, D.W., 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper. 29 Rev. 1

Bauder, T.A., Cardon, G.E., Waskom, R.M., and Davis, J.G., 2003. Irrigation water quality criteria. Colorado State University Cooperative Extension. No. 0.506

Environmental Protection Branch, 2004. Treated municipal wastewater irrigation guidelines, EPB 235. Saskatchewan Environment.

Gates, T.K., Sanders, T.G., and Podmore,T.H., 1993. Recommended water quality criteria for agricultural diversions in Colorado. Project Tech. Report No. 1.

Hoffman, G. J. 2004. Impact of water supplies from the South Platte conservation project on crop production, Report to Northern Colorado Water Conservancy District. 16 pp.

National Water Information System, 2004. Accessed 8 August. http://waterdata.usgs.gov/nwis

National Water-Quality Assessment Program website, 2004. Accessed 11 October. http://co.water.usgs.gov/nawqa/splt/html/spbasininfops.html

Northern Integrated Supply Project, 2004. Phase II Alternative Evaluation. Final Report. Prepared for Northern Colorado Water Conservancy District.

Magnuson, D., 2004. Personal communication.

Stednick, J.D., 1991. Wildland water quality sampling and analysis. San Diego: Academic Press, Inc.

US Soil Salinity Laboratory, 1954. Saline and Alkaline Soils Handbook. Pub. No. 60.

Appendix

Electrical Conductivity

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	107.49	1386.10
Variance	3272.13	132792.89
Observations	166	390
Pooled Variance	94217.21	
Hypothesized Mean Difference	0	
df	554	
t Stat	-44.95	
P(T<=t) one-tail	2.9861E-187	
t Critical one-tail	1.65	
P(T<=t) two-tail	5.9722E-187	
t Critical two-tail	1.96	

Sodium Adsorption Ratio

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	0.30	2.00
Variance	0.01	0.19
Observations	130	205
Pooled Variance	0.12	
Hypothesized Mean Difference	0	
df	333	
t Stat	-44.34	
P(T<=t) one-tail	4.6581E-142	
t Critical one-tail	1.65	
P(T<=t) two-tail	9.3163E-142	
t Critical two-tail	1.97	

Sodium

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	4.51	113.86
Variance	4.62	1157.29
Observations	164	318
Pooled Variance	765.86	
Hypothesized Mean Difference	0	
df	480	
t Stat	-41.10	
P(T<=t) one-tail	1.2572E-159	
t Critical one-tail	1.65	
P(T<=t) two-tail	2.5144E-159	
t Critical two-tail	1.96	

Chloride

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	2.18	51.83
Variance	2.52	474.34
Observations	161	343
Pooled Variance	323.96	
Hypothesized Mean Difference	0	
df	502	
t Stat	-28.88	
P(T<=t) one-tail	4.623E-109	
t Critical one-tail	1.65	
P(T<=t) two-tail	9.246E-109	
t Critical two-tail	1.96	

Boron

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	0.03	0.25
Variance	0.00	0.01
Observations	43	102
Pooled Variance	0.01	
Hypothesized Mean Difference	0	
df	143	
t Stat	-15.59	
P(T<=t) one-tail	6.00208E-33	
t Critical one-tail	1.66	
P(T<=t) two-tail	1.20042E-32	
t Critical two-tail	1.98	

Nitrogen

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	0.08	5.43
Variance	0.01	2.92
Observations	163	195
Pooled Variance	1.59	
Hypothesized Mean Difference	0	
df	356	
t Stat	-39.89	
P(T<=t) one-tail	1.0627E-133	
t Critical one-tail	1.65	
P(T<=t) two-tail	2.1254E-133	
t Critical two-tail	1.97	

pH

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	7.48	7.87
Variance	0.30	0.10
Observations	164	363
Pooled Variance	0.16	
Hypothesized Mean Difference	0	
df	525	
t Stat	-10.26	
P(T<=t) one-tail	6.40904E-23	
t Critical one-tail	1.65	
P(T<=t) two-tail	1.28181E-22	
t Critical two-tail	1.96	

Dissolved Oxygen

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	9.52	9.24
Variance	3.41	3.26
Observations	292	189
Pooled Variance	3.35	
Hypothesized Mean Difference	0	
df	479	
t Stat	1.65	
P(T<=t) one-tail	0.049809748	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.099619496	
t Critical two-tail	1.96	

Phosphorous

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	0.01	0.58
Variance	0.00	0.10
Observations	122	170
Pooled Variance	0.06	
Hypothesized Mean Difference	0	
df	290	
t Stat	-20.23	
P(T<=t) one-tail	1.17363E-57	
t Critical one-tail	1.65	
P(T<=t) two-tail	2.34726E-57	
t Critical two-tail	1.97	

Calcium

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	12.09	119.20
Variance	43.76	1403.11
Observations	163	277
Pooled Variance	900.33	
Hypothesized Mean Difference	0	
df	438	
t Stat	-36.16	
P(T<=t) one-tail	6.9161E-134	
t Critical one-tail	1.65	
P(T<=t) two-tail	1.3832E-133	
t Critical two-tail	1.97	

Magnesium

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	3.07	55.62
Variance	3.45	347.51
Observations	162	276
Pooled Variance	220.46	
Hypothesized Mean Difference	0	
df	436	
t Stat	-35.76	
P(T<=t) one-tail	4.9208E-132	
t Critical one-tail	1.65	
P(T<=t) two-tail	9.8416E-132	
t Critical two-tail	1.97	

Potassium

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	1.04	6.64
Variance	0.24	2.78
Observations	161	260
Pooled Variance	1.81	
Hypothesized Mean Difference	0	
df	419	
t Stat	-41.49	
P(T<=t) one-tail	8.664E-151	
t Critical one-tail	1.65	
P(T<=t) two-tail	1.7328E-150	
t Critical two-tail	1.97	

Sulfate

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	5.97	454.34
Variance	7.83	26555.38
Observations	158	348
Pooled Variance	18285.61	
Hypothesized Mean Difference	0	
df	504	
t Stat	-34.56	
P(T<=t) one-tail	2.2495E-135	
t Critical one-tail	1.65	
P(T<=t) two-tail	4.4989E-135	
t Critical two-tail	1.96	