Final Report

For

Irrigation Water Quality Monitoring of the Jordan River, 2008

Prepared for

Salt Lake City Corporation

By

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EXECUTIVE SUMMARY

The goal of the Jordan River Water Quality Project is to assess the quality of irrigation water removed from the Jordan River at three diversion locations: Jordan Narrows (JN), Cahoon and Maxfield (CM), and Jordan & Salt Lake Canal (JSLC). During 2008, Salt Lake City Corporation personnel took water samples on 12 dates from April 18 to September 25, 2008. Utah State University Analytical Laboratories (USUAL), an EPA-certified laboratory, performed water analyses on the samples. USUAL is located at Utah State University (USU) in Logan, Utah.

From the 2008 samples, average salinities measured as electrical conductivity (EC) were:

- JN, 1.51 dS/m (TDS = 964 mg/l)
- CM, 1.41 dS/m (TDS = 905 mg/l)
- JSLC, 1.46 dS/m (TDS = 934 mg/l)

The average salinity of all samples was 1.46 dS/m (TDS = 935 mg/l), versus 1.45 dS/m (TDS = 926 mg/l) in 2007 and 1.27 dS/m (TDS =814 mg/l) in 2006. The one percent increase in salinity did not put salinity outside the 1.0–2.7 dS/m range that represents only a ‘slight to moderate’ restriction on plant use, (Ayers and Westcot, 1985).

Even with prolonged use of such water, all fiber, seed and sugar crops except bean will have no decrease in their production potential. The potential yield of bean will be 75–90% of optimum. Of the grasses and forage crops, alfalfa, clover, forage corn, foxtail and orchard grass yield potential will be 90–100% of optimum. The yield potential of other grasses and forage crops will not be reduced. Yield potential of red beet, broccoli, cucumber, squash and tomato that are categorized as vegetables will not be reduced. Other vegetable crops such as cabbage, celery, sweet corn, pepper, potato, spinach and sweet potato will have a maximum yield reduction of 10%. Other vegetable crops will have a yield reduction range of 10–25%. All fruit crops will have a reduction in their yield potential. Almond, apricot, blackberry, boysenberry and plum will have 10–25% reduction in their optimal yield potential. Grape and peach will have a maximum of 10% reduction in their optimal yield potential. Strawberry yield potential is 50–75% of optimum.

Average chloride (Cl) concentration of all samples from the three sites was 6.91 meq/l, versus 6.57 meq/l in 2007, and 5.38 meq/l in 2006. This water does not present a chloride hazard.

The salinity and adjusted R_{Na} together indicate that the water does not pose a potential soil infiltration problem (sodic hazard). Overall average adjusted R_{Na} was 3.03 $(meq/l)^{1/2}$, versus 3.18 $(meq/l)^{1/2}$ for 2007 and 2.36 $(meq/l)^{1/2}$ for 2006.

Overall average boron (B) concentration was 0.31 mg/l, versus 0.27 mg/l in 2007 and 0.23 mg/l in 2006. Because the sensitive plant threshold hazard value is 0.50 mg/l, Jordan River water does not currently pose a boron hazard.

INTRODUCTION

The quality of water from a particular source refers to characteristics that affect its use for a specific purpose. Such characteristics or properties determine the extent to which the water satisfies water-user needs. Water quality is defined using biological, chemical, and physical parameters. Irrigation water quality is most significantly defined via the potential impacts of its chemical parameters on the receiving soil, plants, and biomass consumers.

Because water quality is based upon potential impacts, irrigation water quality assessment considers:

- crop salt tolerance
- soil physical and chemical properties
- climatic conditions
- irrigation technology and management (method, frequency, and other factors).

Irrigation management is critically important in determining how marginal water can best be used. Hence, water quality suitability and potential impact assessment relies upon irrigation practice.

Growing plants remove only small amounts of salt from a root zone. To avoid harmful salt build-up in a root zone, leaching is practiced. Leaching involves intentionally applying more water than is needed by the plant—the excess water flushes salt from the root zone into a drainage network. The availability of a drainage path (and outlet), by which excess water can depart, is essential.

IRRIGATION WATER QUALITY

Water suitability for irrigation is based on the potential severity of problems that might result from long-term use of the water. Potential harmful impacts can primarily result from trace elements and salinity in the water. Trace elements are important because they can potentially cause phytotoxic effects. Boron (B) and other trace elements are not included in quantified salinity.

Jordan River water suitability for irrigation is assessed using three criteria: toxicity, sodicity, and salinity.

- Toxicity. Specific ions can alter plant metabolic processes and potentially can be toxic. Effects are independent of soil water osmotic potential, and are selective for the involved plants and elements.
- Sodicity. Excess sodium (NaX) adsorbed on the soil's physical structure can reduce the soil's ability to transmit water and air. Excess NaX is measured by the sodium adsorption ratio (SAR).
- Salinity. Salinity reduces the availability of soil water to the plants by lowering the osmotic (solute) potential of the soil water. The osmotic potential is not related to the type of soluble salts, but rather is a function of total salt concentration.

Here, water salinity is defined as the total sum of dissolved electrolytes. Major electrolyte components are:

- cations
    - calcium (Ca)
    - magnesium (Mg)
    - sodium (Na)
    - potassium (K)
- anions
    - chloride (Cl)
    - sulfate (SO_4)
    - bicarbonate (HCO_3).

Total salinity is measured and reported using electrical conductivity (EC in dS/m) and/or total dissolved solids (TDS in mg/l).

SOIL SALINITY MANAGEMENT

A salinity problem exists when crop yields decrease due to salt accumulation in the root zone. Salt accumulation results because plants remove nearly pure water from the root zone, leaving behind the salt that entered with the irrigation water.

Leaching is a procedure for controlling soil salinity. Leaching involves adding more water to the root zone than the plant needs. Leaching removes accumulated soluble salt, transmitting it into the drainage network. The leaching fraction (LF) is the amount of water departing from the root zone, divided by the amount entering the root zone. Amount is often defined as a depth (per unit area).

$$\text{Leaching Fraction }(\text{LF}) = \frac{\text{Depth of water leaving root zone}}{\text{Depth of water entering root zone}} \tag{1}$$

The larger the LF, the lower the resulting average root zone salinity is. Commonly employed LFs of 15-20% mean that plants are using 85-80% of the applied water, respectively. The drainage system must be able to remove the excess water. Otherwise, a rising water table will worsen the salinity problem.

The timing of the leaching is not critically important, provided the crop salt tolerance is not exceeded for an extended time period. Leaching is usually not necessary during each irrigation (Ayers and Westcot, 1985). Generally, once-a-season leaching is adequate. Within the study area, the total of snow-melt plus spring and fall precipitation often provides sufficient leaching. If not, leaching via irrigation before planting is necessary.

Another salinity-addressing practice is to grow salt-tolerant crops. Salinity tolerance of common agricultural crops can range 8 to 10 fold. Water undesirable for some crops is suitable for others. Salt tolerance guidelines, that include ‘restriction on use’ with respect to applied water, are available for many crops. Such guidelines constrain the crops that might be irrigated with a particular water, and suggest management methods to optimize biomass production.

SODIC HAZARD

Irrigation water sodium (Na) concentration determines how much Na is adsorbed by the soil. Excessive adsorbed Na reduces how well water can infiltrate. The resulting hazard is inadequate soil moisture for plant growth.

Sodic problems tend to occur in the top few centimeters of soil. Adsorbed Na causes low soil structural stability, by dispersing soil aggregates. Dispersed particles clog pores that would otherwise transmit water. Upon drying, the result is a hard surface crust on the soil.

Irrigation water sodic hazard is assessed using the sodium adsorption ratio (SAR). This is also termed R_{Na} (Suarez, 1981), the ratio of the total concentration of sodium to that of calcium plus magnesium (U.S. Salinity Laboratory Staff, 1954).

$$SAR = R_{Na} = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \tag{2}$$

where SAR is in $(mmol/l)^{1/2}$, and Na, Ca, and Mg are the total concentrations (meq/l) in the water of each ion, respectively. To compute SAR in $(meq/l)^{1/2}$, use the same meq/l concentrations for Na, Ca, and Mg, and an equation that differs from Equation 2 in that it does not divide by 2 in the denominator.

The larger the SAR value, the greater is the sodic hazard potential--although the SAR at which one might anticipate potential sodic problems is also affected by the water EC. The greater the water salinity, the greater the SAR that can be tolerated before water infiltration into the soil is affected (Ayers and Westcot, 1985).

Another parameter, the adjusted R_{Na} (adj R_{Na}), includes the effect of potential calcium carbonate ($CaCO_3$) formation. The $CaCO_3$ acts as a sink for Ca. The $CaCO_3$ correction considers the HCO_3 /Ca ratio, the soil water EC, and the partial pressure of soil CO_2. It is commonly assumed that the resulting adj R_{Na} value is about 10 percent greater than SAR (Suarez, 1981; Ayers and Westcot, 1985). However, here we use an adj R_{Na} equation presented by Ayers and Westcot (1985):

$$\text{adj } R_{Na} = \frac{Na}{\sqrt{\left(\frac{Ca_x + Mg}{2}\right)}} \tag{3}$$

where adj R_{Na} is in $(mmol/l)^{1/2}$, and Na and Mg are the total concentrations (meq/l) in the water of each ion, respectively. Ca_x is a modified calcium value obtained from Table 11 (Ayers and Westcot, 1985), reported in meq/l. To compute adj RNa in $(meq/l)^{1/2}$, use the same meq/l concentrations for Na, Ca, and Mg, and an equation that differs from Equation 3 in that it does not divide by 2 in the denominator.

Ca_x represents a Ca concentration in the irrigation water modified due to: (1) salinity of the applied water (EC_w); (2) HCO_3/Ca ratio (HCO_3 and Ca in meq/l); and (3) the estimated partial pressure of CO_2 in the surface few millimeters of soil (P_{CO2} = 0.0007 atmospheres). A simple application was created to systematically calculate the average for a given EC_w and HCO_3/Ca ratio.

TOXICITY HAZARD

Toxicity occurs when plants absorb particular constituents sufficiently that crop yield is reduced or crop damage occurs. Toxicity hazard is independent of salinity, and is plant-specific. Most susceptible to toxicity are perennial woody plants such as fruit trees, grapes, and berries.

Here, the ions evaluated for toxicity are chloride (Cl) and boron (B). These ions usually accumulate in leaf edges and tips, where water loss is greatest. Ions do not rapidly accumulate in plant tissues, so visual symptoms of toxicity usually develop slowly.

PROJECT OBJECTIVE

This project was initiated in 1987. The project objective is to monitor the quality of the irrigation water in the Jordan River, Salt Lake County, Utah. Actions include:

1. Monitoring the irrigation water quality at three Jordan River sites at which water is diverted, from 18 April 2008 through 25 September 2008.
2. Monitoring selected trace element (heavy metal) concentrations at the three diversion locations, at the beginning and end of the diversion season.
3. Determining the water chemical composition, and assessing the potential impact of diverted water quality on crop production after long usage.
4. Preparing and submitting a report.

GENERAL HYDROLOGY

The Jordan River flows 55 miles, originating at Utah Lake, flowing through the Salt Lake City environs, and emptying into the Great Salt Lake. The river supplies water for industries, wildlife management areas, and agricultural irrigation. It provides storm water and wastewater drainage.

At Jordan Narrows, ten miles downstream from Utah Lake, the Jordan River enters Salt Lake County. The US Geological Survey has had a continuous stream flow recording station at Jordan Narrows since 1937. Almost all water diverted from the Jordan River for agricultural irrigation within Salt Lake County is diverted at Jordan Narrows.

Seven major canals convey the diverted water northward. Within Salt Lake County, the Jordan River receives groundwater inflow, urban drainage, and irrigation return flow.

From 9000 South Bridge northward, Jordan River water quality is significantly affected by these inflows, except during high flow periods (Harr et al, 1971).

PREVIOUS STUDIES

Other than from previous sampling at the same locations as addressed here, relatively little irrigation water quality data is available for the Jordan River. Thorne and Thorne (1951) reported that Jordan Narrows sampling on 04/08/49 yielded EC of 1.43 dS/m and no sodic hazard. They also sampled other sites.

After sampling many of the same sites as Thorne and Thorne (1951), James and Jurinak (1986) concluded that irrigation water quality had not changed significantly during the intervening 25 years. During four 1949 sampling dates, Jordan River water at Riverton, Utah, ranged from 1.8 to 2.3 dS/m (Thorne and Thorne, 1951). At the same site, during two 1981 sampling dates, EC ranged from 1.7 to 1.9 dS/m (James and Jurinak, 1986). In July 1982, the EC was 1.2 dS/m (James and Jurinak, 1986). These data show normal variability in salinity. They are insufficient to establish baseline salinity values.

The current project is part of a sampling program that began in 1987. Since then, the Salt Lake City Corporation has performed irrigation season sampling at about two-week intervals at three sites—Jordan Narrows, Cahoon and Maxfield, and Jordan & Salt Lake Canal. Data from the three sites is sufficiently similar to discuss them as a single database. During 1987-2005, at the Jordan Narrows diversion, salinity has ranged from 0.36 to 2.6 dS/m. Per Ayers and Westcot (1985), this places a 'slight to moderate' restriction on use by plants. The SAR has ranged from 1.17 to 6.4 meq/l. Boron concentrations have ranged between 0.11 and 0.58 mg/l. Data for the three sites are reported by Jurinak (1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, and 2005), and Peralta and Timani (2006, 2007).

METHOD

Sampling sites and method have been the same since initiation in May 1987. The three sampling sites are located at diversions of Jordan River water, in Salt Lake County, Utah. The three sites are Jordan Narrows (JN), Cahoon and Maxfield (CM), and Jordan & Salt Lake Canal (JSLC).

During 2008, sampling began on 18 April and terminated on 25 September. There were 12 sampling dates. Salt Lake City Corporation (SLCC) performed the sampling. They refrigerated the samples and transmitted them to the USU Analytical Laboratory (USUAL), Utah State University, Logan, Utah. USUAL, an EPA certified laboratory, performed the analyses. We believe that SLCC and USUAL followed EPA guidelines for all analyses, record keeping, sample handling, storage, and quality control.

RESULTS AND DISCUSSION

Table 1 summarizes ranges and averages of selected water quality parameters for the three sites during the 2008 irrigation season. Tables 2–4 contain 2008 data for Jordan Narrows, Cahoon and Maxfield, and Jordan & Salt Lake Canal, respectively. The dates listed in these tables are the sampling dates reported to USUAL with the sample. All are treated as one data base. Figures 1–4 compare the 2008 analyte averages with those of 2007 and 2006. Figures 5–16 show the 2006–2008 times series of analyte seasonal averages.

SALINITY. Tables 2–4 summarize water salinity results. At JN, salinity, measured as electrical conductivity (EC), averaged 1.51 dS/m (TDS = 964). At CM, salinity averaged 1.41 dS/m (TDS = 905). At JSLC, salinity averaged 1.46 dS/m (TDS = 935). The relatively low average salinity (EC = 1.48 dS/m; TDS = 948 mg/l) is in the low end of a ‘slight to moderate’ restriction on prolonged periods of plant water use (Ayers and Westcot, 1985). Prolonged irrigation with such water must occur before root zone salt accumulation harms plant growth.

To predict deleterious salinity effect, standard practice is to report expected crop yield as a percentage of the yield expected if irrigating using non-saline water. The yield expected without salinity effect is considered the optimal potential yield. Similarly, optimum production is a relative term. It is defined as the production without deleterious salinity effect on yield, with all other factors being equal. Here, all optimal and degraded potential yields assume conventional surface irrigation and 15–20% leaching fraction.

One can estimate potential yields using either irrigation water salinity (EC_w) or soil salinity (EC_e). We use EC_w to predict the potential yields of crops because that does not require soil analyses.

Table 5 shows the potential yield percentage of selected crops (categorized into fiber, seed and sugar, grasses and forage, vegetable, and fruit crops) irrigated with the sampled saline water. This list includes only species or varieties among those considered by Ayers and Westcot (1985). Inclusion in Table 5 does not assure that listed crops grow successfully in Salt Lake County. Climatic conditions might prevent full yield potential even without considering salinity. We include some plants for which comparables might be grown in Salt Lake County, even though the precise species might not. Figures 17–19 show the expected productivity of selected sensitive vegetables, moderately sensitive vegetables and fruit crops as a function of irrigation water salinity. The horizontal line in each figure represents the 2008 EC seasonal average of all samples from all locations. The intersection of this line with the potential productivity curve of a certain crop predicts potential crop productivity if irrigated with average water quality. If the two lines do not intersect, the crop productivity will not be affected by average irrigation water quality.

Ayers and Westcot (1985) reported production potential percentages for crop varieties based on irrigation water salinity. We used their percentages with our sampled water quality to present a range of potential crop yields. To provide as much detail as practicable, we did this four times—once using the 2008 average irrigation water salinity from each of the three sampling locations, and once using the overall blended average 2008 salinity (1.46 dS/m). In Table 5, if a crop is not expected to have any reduction in its production potential due to salinity, the lower production percentage contains a “-“.

Table 6 shows the expected production potential of some vegetable and fruit crops grouped based on their tolerance to irrigation water salinity. As with Table 5, climatic conditions might reduce potential crop yield from what is reported in Table 6. As a public service, the lists of crops reported in Tables 5 and 6 are long.

Fiber, Seed and Sugar Crops. Bean will have 75–90% of yield potential. The other crops of this category (Table 5) will have their maximum yield potential (100% of optimum production).

Grasses and Forage Crops. Alfalfa, clover, forage corn, foxtail and orchard grass will have 90–100% of yield potential. The other grasses and field crops (Table 5) will have their maximum yield potential (100% of optimum production).

Vegetable Crops. The yield potential of salt-sensitive crops, such as bean, carrot and onion, and of moderately sensitive crops such as lettuce, radish, and turnip is about 75–90% of optimum. The yield potential of other moderately sensitive crops, such as cabbage, celery, pepper, potato, spinach and sweet corn is about 90-100% of optimum. The yield potential of other moderately sensitive crops such as squash and tomato is unaffected by irrigation water salinity.

Fruit Crops. Ayers and Westcot (1985) consider grape to be moderately salt sensitive. Often, apricot, peach, plum, and strawberry are considered to be salt sensitive. With prolonged use of the water, strawberry yield potential is 50–75% of optimum. Apricot and plum yield potential is 75–90% of optimum. Grape and peach yield potential is 90–100% of optimum. The above comments indicate relative salt tolerances. Absolute tolerances depend on soil conditions, climate, and management practices. Increasing the leaching factor can reduce the salinity effect on crop yield. Sprinkler irrigation can increase the salinity hazard. Proper drip irrigation can reduce the salinity hazard.

SODICITY. Sodic hazard is affected by both irrigation water SAR and EC. Salinity tends to improve soil structure by enhancing aggregation. Thus it counteracts the harmful effect of Na adsorption on clay minerals. Increasing water salinity permits tolerating a larger SAR before soil structure and infiltration are harmed. Considering both the EC and SAR or the adj R_{Na} values, Tables 2–4 indicate no sodic hazard. The absence of sodicity hazard implies no potential for soil filtration problem development from irrigation water quality.

BORON. During 2008, the average Boron concentration of all samples was 0.31 mg/l. The maximum concentration was 0.52 mg/l. On average, no boron hazard is considered present because these values are below the 0.5 mg/l threshold value for boron sensitive plants. It should be noted that the Boron concentration of sampling date 08/08/11 was at the threshold level at each of the three location. No other samples showed such high Boron concentrations.

CHLORIDE. Chloride concentration averages were: 7.15 meq/l at JN, 6.61 meq/l at CM, and 6.93 meq/l at J&SL. The overall 2008 average is 6.91 meq/l, versus the 6.57 meq/l 2007 average and 5.38 meq/l 2006 average. This indicates a slight hazard, because the ‘slight to moderate’ range for surface irrigation is 4-10 meq/l.

TRACE ELEMENTS. Trace elements are those whose concentration in water is <100 mg/l, and usually results from geochemical weathering of the earth’s crust. All natural waters contain trace elements. Usually, high trace element concentrations indicate anthropogenic impacts. USUAL reported trace element concentrations for all samples they analyzed this year at no extra charge. They only charged for the ICP analysis when it was specifically requested from people delivering the samples to be analyzed. Table 7 shows the results that do not suggest a hazard. However, the analysis is not sufficiently accurate to determine whether a selenium hazard exists (the recommended maximum selenium concentration is 0.02 mg/l, but the available USUAL equipment detection limit for selenium is 0.1 mg/l). More expensive and accurate instruments are needed to get an accurate reading of Selenium concentration.

SUMMARY AND CONCLUSIONS

The average 2008 salinity is 1.46 dS/m (TDS = 935 mg/l), versus 1.45 dS/m (TDS = 926 mg/l) in 2007 and 1.27 dS/m (TDS =814 mg/l) in 2006. Plant use restrictions are in the slight region of ‘slight to moderate’. Restrictions assume a 15-20% leaching factor and conventional surface irrigation.

At Jordan Narrows, salinity averaged 1.51 dS/m (TDS = 964 mg/l). At Cahoon and Maxfield, the average was 1.41 dS/m (TDS = 905 mg/l). At Jordon & Salt Lake Canal, the average was 1.46 dS/m (TDS = 934 mg/l).

Due to salinity, prolonged use of the irrigation water can cause crop yield to decrease. Most yield potentials of fiber, seed and sugar, grasses and forage, vegetable, and fruit crops are at least 90% of potential optimum. However, potential yield of bean, carrot, lettuce, onion, radish and turnip are 75–90% of optimum. Strawberry yield potential is 50–75% of optimum. If pepper and peach are irrigated using Jordan Narrows water, they will have 75–90% potential yield. However, they will have 90–100% potential yield if irrigated using water from the other two locations or blended from all three locations in equal proportions. If bean is irrigated using Jordan Narrows water, it will have 50–75% potential yield. However, it will have 75–90% potential yield if irrigated using water from the other two locations or blended from all three locations in equal proportions. If sphaerophysa is irrigated using Jordan Narrows water, it will have 90–100% potential yield. However, it will have no reduction in its production potential yield if irrigated by water from the other two locations or blended from all three locations in equal proportions.

The average adjusted R_{Na} of all samples was 3.03 $(meq/l)^{1/2}$. This and the average salinity value indicate no potential soil infiltration (sodic) hazard.

The average chloride concentration of all samples was 6.91 meq/l, versus 6.57 meq/l in 2006, and 5.38 meq/l in 2006. The data do not indicate existence of a chloride hazard.

The average boron concentration of all samples was 0.31 mg/l–below the 0.5 mg/l threshold value for boron sensitive plants. The data do not indicate existence of a boron hazard.

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TABLES

Table 1. 2008 Season Range and Average Values of Selected Water Quality Parameters

Jordan Narrows			Range		Average	Count
			Lower	Upper		
EC	electrical conductivity	dS/m	1.16	1.75	1.51	12
TDS	total dissolved solids	mg/l	744.32	1,116.80	964.16	12
SAR	sodium adsorption ratio	$(meq/l)^{1/2}$	2.23	3.62	2.94	12
adj R_{Na}	adjusted R_{Na}	$(meq/l)^{1/2}$	2.21	3.66	3.11	12
Cl	Chloride	meq/l	4.88	8.38	7.15	12
B	Boron	mg/l	0.21	0.52	0.32	12
Cahoon and Maxfield			Range		Average	Count
			Lower	Upper		
EC	electrical conductivity	dS/m	1.04	1.72	1.41	11
TDS	total dissolved solids	mg/l	663.68	1,101.44	905.02	11
SAR	sodium adsorption ratio	$(meq/l)^{1/2}$	2.15	3.42	2.81	11
adj R_{Na}	adjusted R_{Na}	$(meq/l)^{1/2}$	2.25	3.63	2.97	11
Cl	Chloride	meq/l	4.77	8.24	6.61	11
B	Boron	mg/l	0.19	0.49	0.30	11
Jordan and Salt Lake Canal			Range		Average	Count
			Lower	Upper		
EC	electrical conductivity	dS/m	1.20	1.73	1.46	12
TDS	total dissolved solids	mg/l	764.80	1,107.84	934.24	12
SAR	sodium adsorption ratio	$(meq/l)^{1/2}$	2.30	3.39	2.85	12
adj R_{Na}	adjusted R_{Na}	$(meq/l)^{1/2}$	2.35	3.58	3.02	12
Cl	Chloride	meq/l	5.11	8.29	6.93	12
B	Boron	mg/l	0.21	0.51	0.31	12
Summary of Three Locations			Range		Average	Count
			Lower	Upper		
EC	electrical conductivity	dS/m	1.04	1.75	1.46	35
TDS	total dissolved solids	mg/l	663.68	1,116.80	935.31	35
SAR	sodium adsorption ratio	$(meq/l)^{1/2}$	2.15	3.62	2.87	35
adj R_{Na}	adjusted R_{Na}	$(meq/l)^{1/2}$	2.21	3.66	3.03	35
Cl	Chloride	meq/l	4.77	8.38	6.91	35
B	Boron	mg/l	0.19	0.52	0.31	35

Table 2. Jordan Narrows Analytes

Year 2008	EC	TDS	Ca	Mg	Na	K	Cl	HCO_3	SO_4	B	SAR		adj RNa		pH
	dS/m	mg/l	meq/l							mg/l	$(mmol/l)^{1/2}$	$(meq/l)^{1/2}$	$(mmol/l)^{1/2}$	$(meq/l)^{1/2}$	
08/04/18	1.30	829.44	3.11	4.25	7.53	0.37	7.02	3.38	4.73	0.25	3.92	2.77	4.25	3.01	7.67
08/05/09	1.46	934.40	2.97	4.51	6.92	0.41	6.57	2.46	4.75	0.26	3.58	2.53	3.70	2.62	7.63
08/05/22	1.16	744.32	2.43	3.41	5.39	0.32	4.88	1.84	3.58	0.21	3.16	2.23	3.13	2.21	7.77
08/06/13	1.32	845.44	2.89	4.19	6.65	0.37	6.12	3.99	4.27	0.31	3.53	2.50	3.87	2.73	8.14
08/06/27	1.39	887.04	2.87	4.33	6.72	0.42	6.63	3.68	4.58	0.28	3.54	2.50	3.83	2.71	7.79
08/07/11	1.62	1,035.52	2.87	4.80	7.99	0.45	7.33	5.83	4.80	0.30	4.08	2.88	4.55	3.22	7.99
08/07/23	1.62	1,038.72	2.74	4.84	8.24	0.44	7.53	2.76	5.14	0.31	4.23	2.99	4.40	3.11	7.48
08/08/08	1.50	960.64	2.20	4.71	8.14	0.46	7.67	4.80	5.04	0.52	4.38	3.10	4.70	3.32	7.30
08/08/29	1.75	1,116.80	2.14	5.02	9.04	0.50	7.64	3.60	5.46	0.36	4.78	3.38	4.98	3.52	7.46
08/09/05	1.72	1,101.44	1.91	4.68	8.79	0.48	7.73	4.00	4.96	0.34	4.84	3.42	5.07	3.58	8.23
08/09/18	1.66	1,063.68	2.37	5.11	9.27	0.51	8.38	4.00	5.62	0.34	4.80	3.39	5.08	3.60	7.77
08/09/25	1.58	1,012.48	2.29	5.14	9.86	1.60	8.29	2.40	5.47	0.33	5.11	3.62	5.18	3.66	8.03
Average	1.51	964.16	2.56	4.58	7.88	0.53	7.15	3.56	4.87	0.32	4.16	2.94	4.40	3.11	7.77

Table 3. Cahoon and Maxfield Analytes

Year 2008	EC	TDS	Ca	Mg	Na	K	Cl	HCO_3	SO_4	B	SAR		adj RNa		pH
	dS/m	mg/l	meq/l							mg/l	$(mmol/l)^{1/2}$	$(meq/l)^{1/2}$	$(mmol/l)^{1/2}$	$(meq/l)^{1/2}$	
08/04/18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08/05/09	1.41	903.68	2.93	4.32	6.47	0.39	6.35	2.46	4.54	0.25	3.40	2.40	3.52	2.49	8.03
08/05/22	1.12	718.08	2.35	3.21	5.26	0.30	4.77	2.15	3.27	0.19	3.16	2.23	3.18	2.25	7.52
08/06/13	1.12	719.36	2.62	3.49	5.50	0.30	5.11	3.38	3.53	0.28	3.15	2.22	3.39	2.40	7.99
08/06/27	1.04	663.68	2.22	3.20	5.02	0.31	4.80	3.07	3.25	0.19	3.05	2.15	3.21	2.27	7.88
08/07/11	1.40	893.44	2.53	4.00	6.73	0.37	6.21	3.38	3.94	0.25	3.72	2.63	3.96	2.80	8.10
08/07/23	1.47	942.08	2.63	4.33	7.36	0.40	6.74	3.38	4.57	0.27	3.95	2.79	4.20	2.97	7.83
08/08/08	1.45	927.36	2.17	4.58	7.99	0.44	7.36	4.40	4.82	0.49	4.35	3.08	4.65	3.28	7.58
08/08/29	1.67	1,066.24	2.16	4.80	8.60	0.47	7.39	3.60	5.20	0.34	4.61	3.26	4.82	3.41	7.21
08/09/05	1.72	1,101.44	1.91	4.68	8.79	0.48	7.73	4.00	4.96	0.34	4.84	3.42	5.07	3.58	8.23
08/09/18	1.61	1,029.12	2.27	5.05	9.12	0.50	8.07	5.20	5.34	0.33	4.77	3.37	5.14	3.63	7.73
08/09/25	1.55	990.72	2.37	5.05	9.15	1.57	8.24	4.00	5.39	0.33	4.75	3.36	5.04	3.57	7.73
Average	1.41	905.02	2.38	4.25	7.27	0.50	6.61	3.55	4.44	0.30	3.98	2.81	4.20	2.97	7.80

Table 4. Jordan and SL Canal Analytes

Year 2008	EC	TDS	Ca	Mg	Na	K	Cl	HCO_3	SO_4	B	SAR		adj RNa		pH
	dS/m	mg/l	meq/l							mg/l	$(mmol/l)^{1/2}$	$(meq/l)^{1/2}$	$(mmol/l)^{1/2}$	$(meq/l)^{1/2}$	
08/04/18	1.29	828.16	3.04	4.21	7.53	0.38	7.19	2.46	4.69	0.26	3.95	2.79	4.12	2.91	8.04
08/05/09	1.43	917.76	2.97	4.41	6.71	0.40	6.49	2.76	4.56	0.26	3.49	2.47	3.67	2.59	8.04
08/05/22	1.23	785.92	2.56	3.58	5.74	0.34	5.11	2.15	3.65	0.21	3.28	2.32	3.32	2.35	7.69
08/06/13	1.20	764.80	2.74	3.67	5.82	0.32	5.42	3.38	3.77	0.29	3.25	2.30	3.51	2.48	7.89
08/06/27	1.21	775.04	2.56	3.79	5.88	0.36	5.73	3.38	3.90	0.24	3.30	2.33	3.53	2.50	7.99
08/07/11	1.57	1,003.52	2.86	4.65	7.84	0.44	7.11	3.39	4.60	0.29	4.05	2.86	4.31	3.05	8.11
08/07/23	1.59	1,014.40	2.84	4.69	7.93	0.44	7.33	3.68	4.95	0.30	4.08	2.89	4.39	3.10	7.98
08/08/08	1.47	938.88	2.28	4.65	7.66	0.45	7.47	4.00	4.88	0.51	4.12	2.91	4.38	3.09	7.70
08/08/29	1.73	1,107.84	2.24	4.94	9.07	0.49	7.73	4.00	5.41	0.36	4.79	3.39	5.06	3.58	7.08
08/09/05	1.62	1,034.88	2.00	4.42	8.37	0.45	7.19	4.00	4.68	0.32	4.67	3.30	4.92	3.48	7.70
08/09/18	1.62	1,034.88	2.41	5.10	9.13	0.51	8.15	4.40	5.44	0.33	4.71	3.33	5.04	3.57	7.69
08/09/25	1.57	1,004.80	2.48	5.10	9.16	1.59	8.29	4.40	5.48	0.33	4.71	3.33	5.05	3.57	7.75
Average	1.46	934.24	2.58	4.43	7.57	0.51	6.93	3.50	4.67	0.31	4.03	2.85	4.27	3.02	7.81

Table 5. Yield Potential of Selected Crop Species

Common name	Scientific name	Expected Production % in							
		Jordan Narrows		Cahoon and Maxfield		Jordan and Salt Lake Canal		Average	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Fiber, Seed and Sugar Crops									
Bean	*Phaseolus vulgaris*	50	75	75	90	75	90	75	90
Barley	*Hordeum vulgare*	-	100	-	100	-	100	-	100
Sorghum	*Sorghum bicolor*	-	100	-	100	-	100	-	100
Sugarbeet	*Beta vulgaris*	-	100	-	100	-	100	-	100
Wheat	*Triticum aestivum*	-	100	-	100	-	100	-	100
Grasses and Forage Crops									
Alfalfa	*Medicago sativa*	90	100	90	100	90	100	90	100
Clover, alsike	*Trifolium hybridum*	90	100	90	100	90	100	90	100
Clover, ladino	*Trifolium repens*	90	100	90	100	90	100	90	100
Clover, red	*Trifolium pretense*	90	100	90	100	90	100	90	100
Clover, strawberry	*Trifolium fragiferum*	90	100	90	100	90	100	90	100
Corn, forage (maize)	*Zea mays*	90	100	90	100	90	100	90	100
Foxtail, meadow	*Alopecurus pratensis*	90	100	90	100	90	100	90	100
Orchard grass	*Dactylis glomerata*	90	100	90	100	90	100	90	100
Barley, forage	*Hordeum vulgare*	-	100	-	100	-	100	-	100
Bermuda grass	*Cynodon dactylon*	-	100	-	100	-	100	-	100
Fescue, tall	*Festuca elatior*	-	100	-	100	-	100	-	100
Ryegrass, perennial	*Lolium perenne*	-	100	-	100	-	100	-	100
Sphaerophysa	*Sphaerophysa salsula*	90	100	-	100	-	100	-	100
Trefoil, narrowleaf birdsfoot	*Lotus corniculatus tenuifolium*	-	100	-	100	-	100	-	100
Vetch, common	*Vicia angustifolia*	-	100	-	100	-	100	-	100
Wheatgrass, tall	*Agropyron elongatum*	-	100	-	100	-	100	-	100
Wheatgrass, fairway crested	*Agropyron cristatum*	-	100	-	100	-	100	-	100
Wheatgrass, standard crested	*Agropyron sibiricum*	-	100	-	100	-	100	-	100
Wildrye, beardless	*Elymus triticoides*	-	100	-	100	-	100	-	100
Vegetable Crops									
Bean	*Phaseolus vulgaris*	50	75	75	90	75	90	75	90

Carrot	*Daucus carota*	75	90	75	90	75	90	75	90
Lettuce	*Lactuca sativa*	75	90	75	90	75	90	75	90
Onion	*Allium cepa*	75	90	75	90	75	90	75	90
Radish	*Raphanus sativus*	75	90	75	90	75	90	75	90
Turnip	*Brassica rapa*	75	90	75	90	75	90	75	90
Cabbage	*Brassica oleracea capitata*	90	100	90	100	90	100	90	100
Celery	*Apium graveolens*	90	100	90	100	90	100	90	100
Corn, sweet (maize)	*Zea mays*	90	100	90	100	90	100	90	100
Pepper	*Capsicum annuum*	75	90	90	100	90	100	90	100
Potato	*Solanum tuberosum*	90	100	90	100	90	100	90	100
Spinach	*Spinacia oleracea*	90	100	90	100	90	100	90	100
Sweet potato	*Ipomoea batatas*	90	100	90	100	90	100	90	100
Beet, red	*Beta vulgaris*	-	100	-	100	-	100	-	100
Broccoli	*Brassica oleracea botrytis*	-	100	-	100	-	100	-	100
Cucumber	*Cucumis sativus*	-	100	-	100	-	100	-	100
Squash, scallop	*Cucurbita pepo melopepo*	-	100	-	100	-	100	-	100
Squash, zucchini (courgette)	*Cucurbita pepo melopepo*	-	100	-	100	-	100	-	100
Tomato	*Lycopersicon esculentum*	-	100	-	100	-	100	-	100
Fruit Crops									
Strawberry	*Fragaria sp.*	50	75	50	75	50	75	50	75
Almond	*Prunus dulcis*	75	90	75	90	75	90	75	90
Apricot	*Prunus armeniaca*	75	90	75	90	75	90	75	90
Blackberry	*Rubus sp.*	75	90	75	90	75	90	75	90
Boysenberry	*Rubus ursinus*	75	90	75	90	75	90	75	90
Plum, prune	*Prunus domestica*	75	90	75	90	75	90	75	90
Grape	*Vitus sp.*	90	100	90	100	90	100	90	100
Peach	*Prunus persica*	75	90	90	100	90	100	90	100

Note: Not all listed species are necessarily grown in Salt Lake Valley. Reported yield reductions do not consider climatic impacts.

Table 6. Yield Potential of Selected Crops Grouped Based on Relative Sensitivity to Irrigation Water Salinity

		Expected Production % in							
		Jordan Narrows		Cahoon and Maxfield		Jordan & Salt Lake Canal		Average	
Common Name	*Scientific Name*	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Sensitive Vegetable Crops									
Bean	*Phaseolus vulgaris*	50	75	75	90	75	90	75	90
Carrot	*Daucus carota*	75	90	75	90	75	90	75	90
Onion	*Allium cepa*	75	90	75	90	75	90	75	90
Moderately Sensitive Vegetable Crops									
Lettuce	*Latuca sativa*	75	90	75	90	75	90	75	90
Radish	*Raphanus sativus*	75	90	75	90	75	90	75	90
Turnip	*Brassica rapa*	75	90	75	90	75	90	75	90
Cabbage	*B. oleracea capitata*	90	100	90	100	90	100	90	100
Celery	*Apium graveolens*	90	100	90	100	90	100	90	100
Pepper	*Capsicum annuum*	75	90	90	100	90	100	90	100
Potato	*Solanum tuberosum*	90	100	90	100	90	100	90	100
Spinach	*Spinacia oleracea*	90	100	90	100	90	100	90	100
Sweet Corn	*Zea mays*	90	100	90	100	90	100	90	100
Squash	*Cucurbita pepo melopepo*	-	100	-	100	-	100	-	100
Tomato	*Lycopersicon lycopersicum*	-	100	-	100	-	100	-	100
Sensitive Fruit Crops									
Strawberry	*Fragaria sp.*	50	75	50	75	50	75	50	75
Apricot	*Prunus armeniaca*	75	90	75	90	75	90	75	90
Plum	*Prunus domestica*	75	90	75	90	75	90	75	90
Peach	*Prunus persica*	75	90	90	100	90	100	90	100
Moderately Sensitive Fruit Crops									
Grape	*Vitis sp.*	90	100	90	100	90	100	90	100

Note: Not all listed species are necessarily grown in Salt Lake Valley. Reported yield reductions do not consider climatic impacts.

Table 7. Trace Element Concentrations (mg/l)[1, 2]

Date		Al	As	Ba	Fe	Mn	P	S	Si	Sr
08/04/18	Jordan Narrows	<	0.01	0.06	0.01	0.00	<	75.80	16.90	1.23
08/05/09		0.55	0.01	0.07	0.30	0.01	0.14	76.00	23.36	1.18
08/05/09		0.58	0.02	0.07	0.30	0.00	<	75.05	23.25	1.16
08/05/22		0.57	0.02	0.06	0.28	0.00	<	57.28	18.59	0.92
08/06/13		<	<	0.07	0.03	0.00	0.08	68.38	17.08	1.10
08/06/27		<	0.02	0.07	0.01	<	<	73.38	19.39	1.18
08/07/11		0.19	<	0.09	0.09	<	0.24	76.82	23.74	1.23
08/07/23		0.16	0.02	0.08	0.10	0.00	0.17	82.31	24.28	1.19
08/08/08		<	0.04	0.12	0.02	0.01	0.12	80.76	37.69	1.81
08/08/29		0.15	0.03	0.08	0.06	0.01	0.28	87.42	30.06	1.20
08/09/05		0.32	0.02	0.07	0.16	0.01	<	79.42	28.22	1.12
08/09/18		<	0.01	0.08	0.03	<	<	89.92	23.06	1.16
08/09/25		0.20	0.02	0.07	0.12	0.00	<	87.62	24.23	1.13
08/09/25		0.47	0.01	0.07	0.22	0.00	<	88.15	25.96	1.13
Average		0.35	0.02	0.08	0.12	0.01	0.17	78.45	23.99	1.19
08/04/18	Cahoon & Maxfield	-	-	-	-	-	-	-	-	-
08/05/09		0.69	0.01	0.07	0.39	0.01	0.11	72.74	22.54	1.12
08/05/09		0.60	<	0.07	0.34	0.01	0.09	71.12	21.75	1.10
08/05/22		0.36	0.01	0.07	0.17	0.00	<	52.28	16.72	0.84
08/06/13		0.12	<	0.07	0.06	0.00	<	56.59	14.49	0.94
08/06/27		0.17	<	0.06	0.08	<	<	52.07	13.83	0.83
08/07/11		0.16	<	0.08	0.10	0.00	0.10	63.03	17.82	1.03
08/07/23		0.24	0.01	0.08	0.09	0.00	0.09	73.19	20.63	1.07
08/08/08		<	0.04	0.12	0.03	0.00	<	77.12	36.02	1.71
08/08/29		<	0.04	0.08	0.02	0.00	0.13	83.26	26.89	1.15
08/09/05		0.19	0.02	0.08	0.10	0.01	<	74.96	26.86	1.08
08/09/18		<	0.02	0.08	0.03	<	<	85.45	23.11	1.11
08/09/25		0.30	0.01	0.08	0.14	<	<	86.29	24.03	1.11
08/09/25		0.43	0.01	0.08	0.20	0.00	<	85.63	24.78	1.11
Average		0.33	0.02	0.08	0.14	0.00	0.11	71.83	22.27	1.09
08/04/18	Jordan S.L. Canal	<	0.02	0.06	0.07	0.00	<	75.10	14.80	1.21
08/05/09		0.36	<	0.07	0.17	0.01	<	72.98	20.22	1.16

[1] Cd, Co, Cu, Mo, Ni, Pb, Se and Zn concentrations were all below respective detection limits in all three locations

[2] All Cahoon and Maxfield Cr readings were below detection limit except that of 08/08/29.

08/05/09		0.33	0.01	0.07	0.19	0.00	<	71.78	19.24	1.15
08/05/22		0.48	0.01	0.07	0.24	0.00	<	58.47	18.59	0.95
08/06/13		<	0.01	0.07	0.05	0.01	<	60.41	15.35	0.99
08/06/27		0.12	0.02	0.07	0.05	<	<	62.46	16.31	0.99
08/07/11		<	0.01	0.09	0.06	0.00	<	73.60	20.61	1.20
08/07/23		0.27	0.01	0.09	0.12	0.00	<	79.17	22.92	1.16
08/08/08		<	0.03	0.12	<	0.01	<	78.16	35.67	1.75
08/08/29		<	0.03	0.08	0.03	0.00	0.11	86.69	26.58	1.20
08/09/05		0.18	0.02	0.08	0.09	0.01	<	78.71	26.68	1.16
08/09/18		<	0.02	0.08	0.05	0.00	<	87.09	23.17	1.13
08/09/25		0.56	0.01	0.08	0.32	0.00	<	87.79	25.49	1.13
08/09/25		0.53	0.01	0.08	0.29	0.01	<	87.18	25.56	1.12
Average		0.35	0.02	0.08	0.13	0.00	0.11	75.69	22.23	1.16
Detection Limits		0.12	0.01	0.001	0.003	0.001	0.08	0.07	0.15	0.03

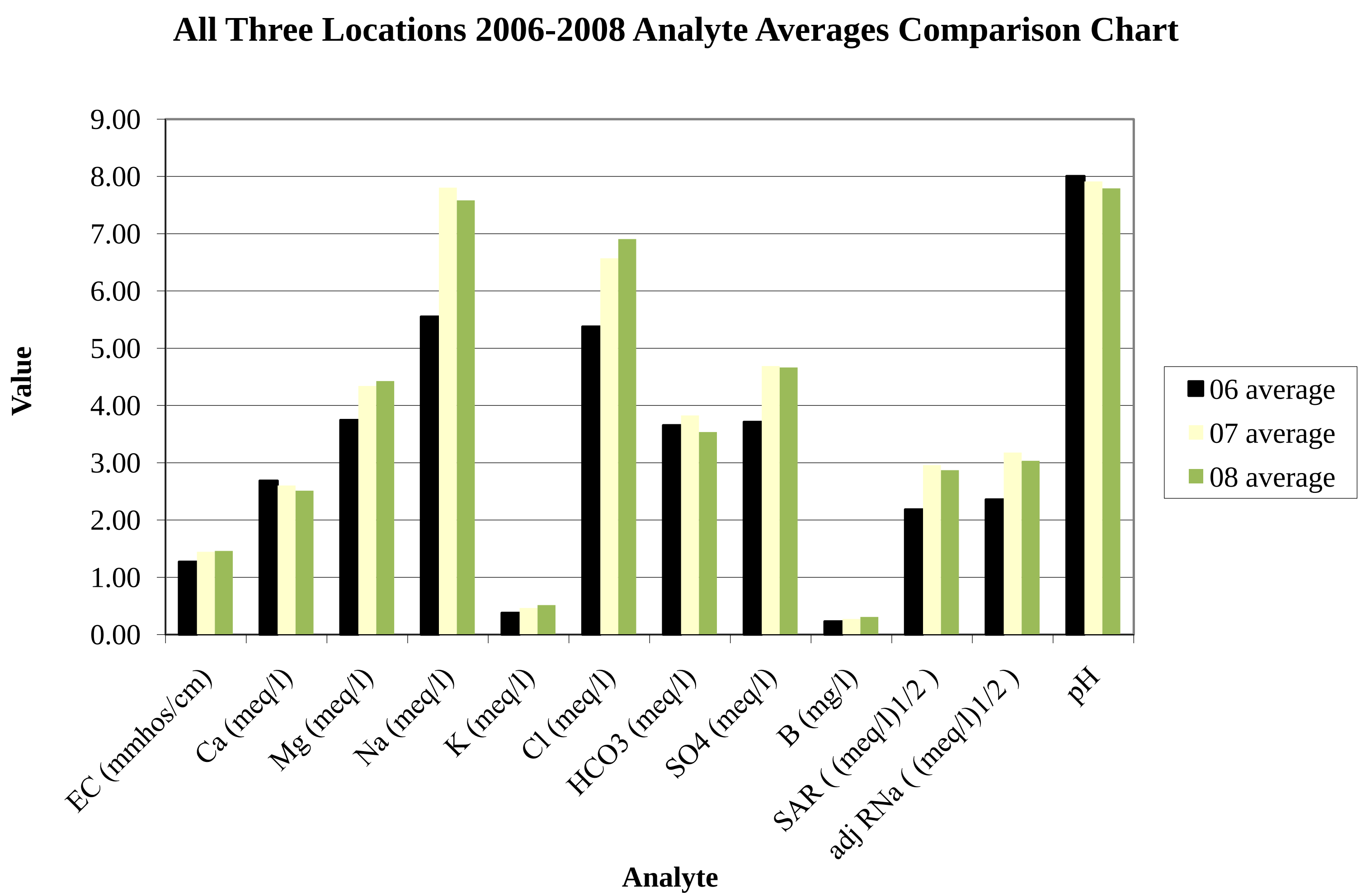

Figure 1: Analyte Three-Location Averages of Sampling Years 2006–2008.

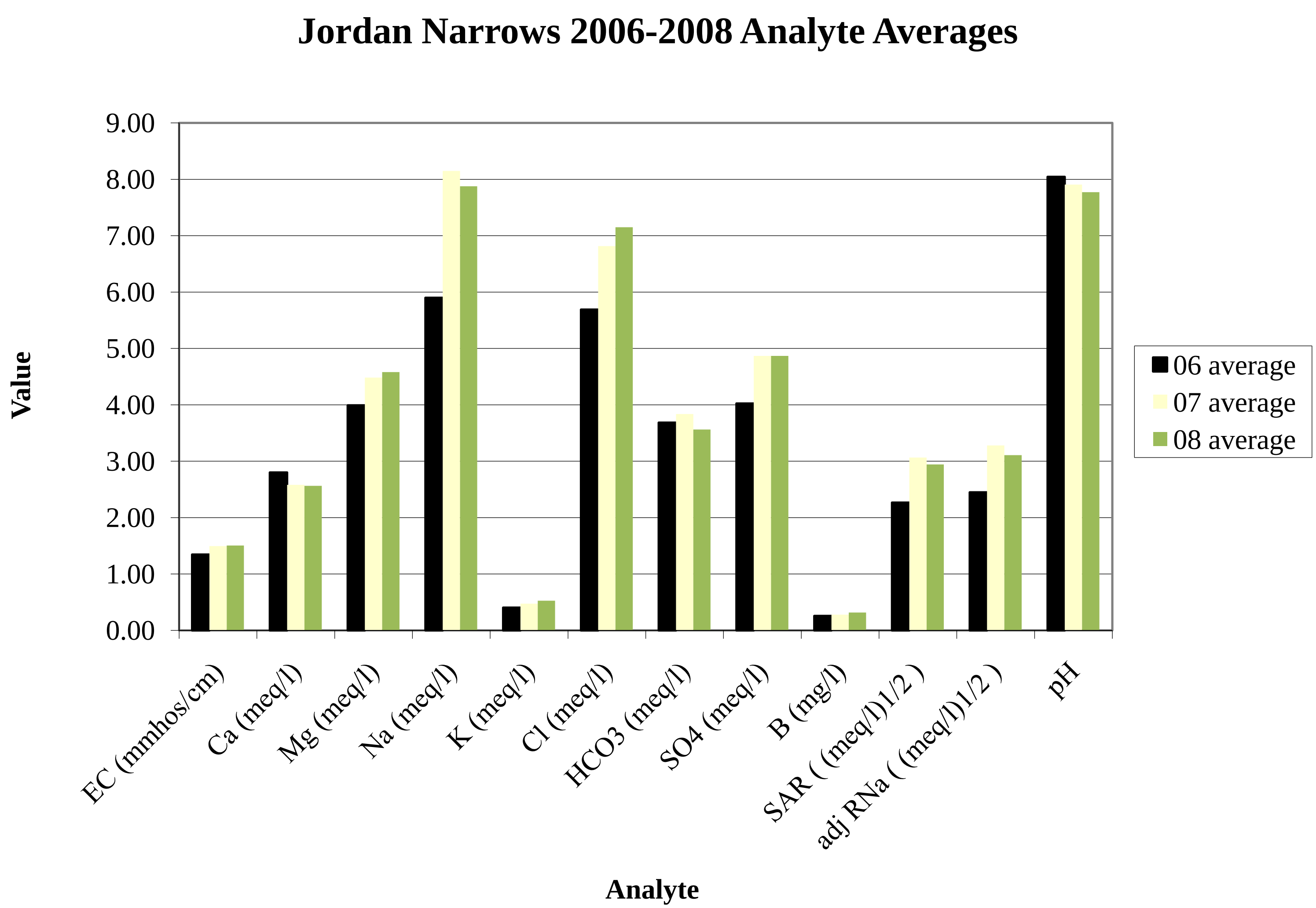

Figure 2: Analyte Averages of Sampling Years 2006–2008 for Jordan Narrows.

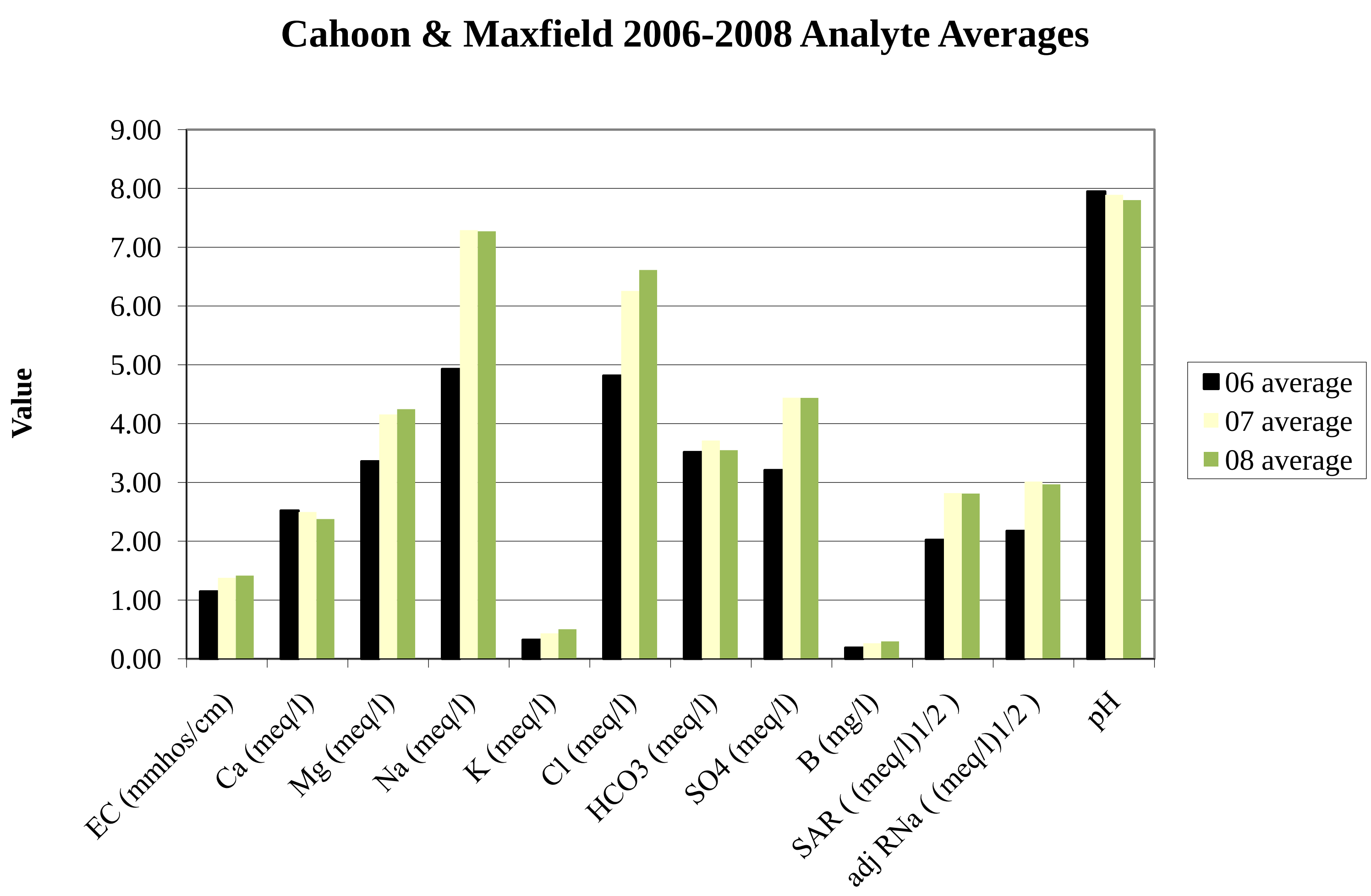

Figure 3: Analyte Averages of Sampling Years 2006–2008 for Cahoon and Maxfield.

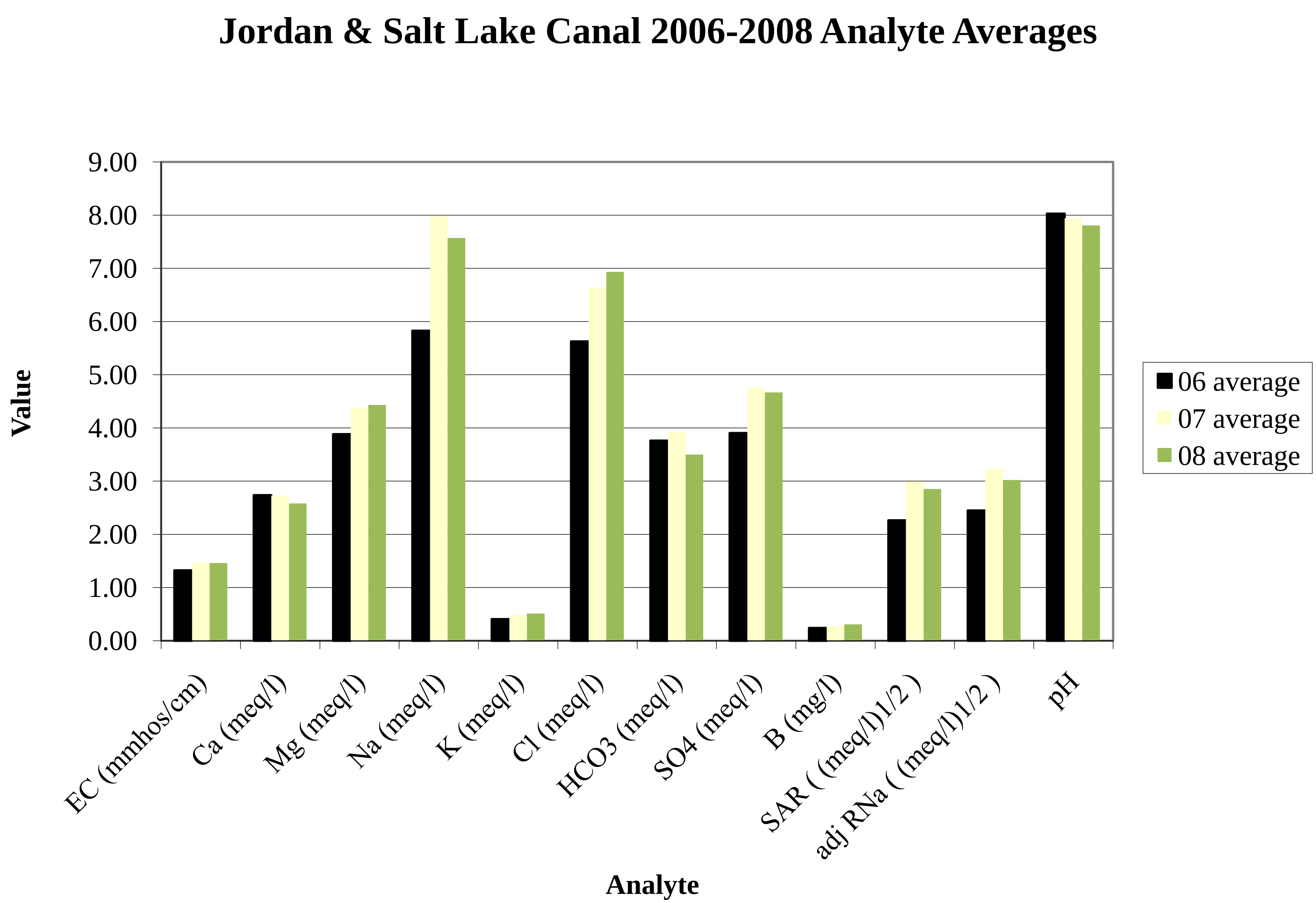

Figure 4: Analyte Averages of Sampling Years 2006–2008 for Jordan and Salt Lake Canal.

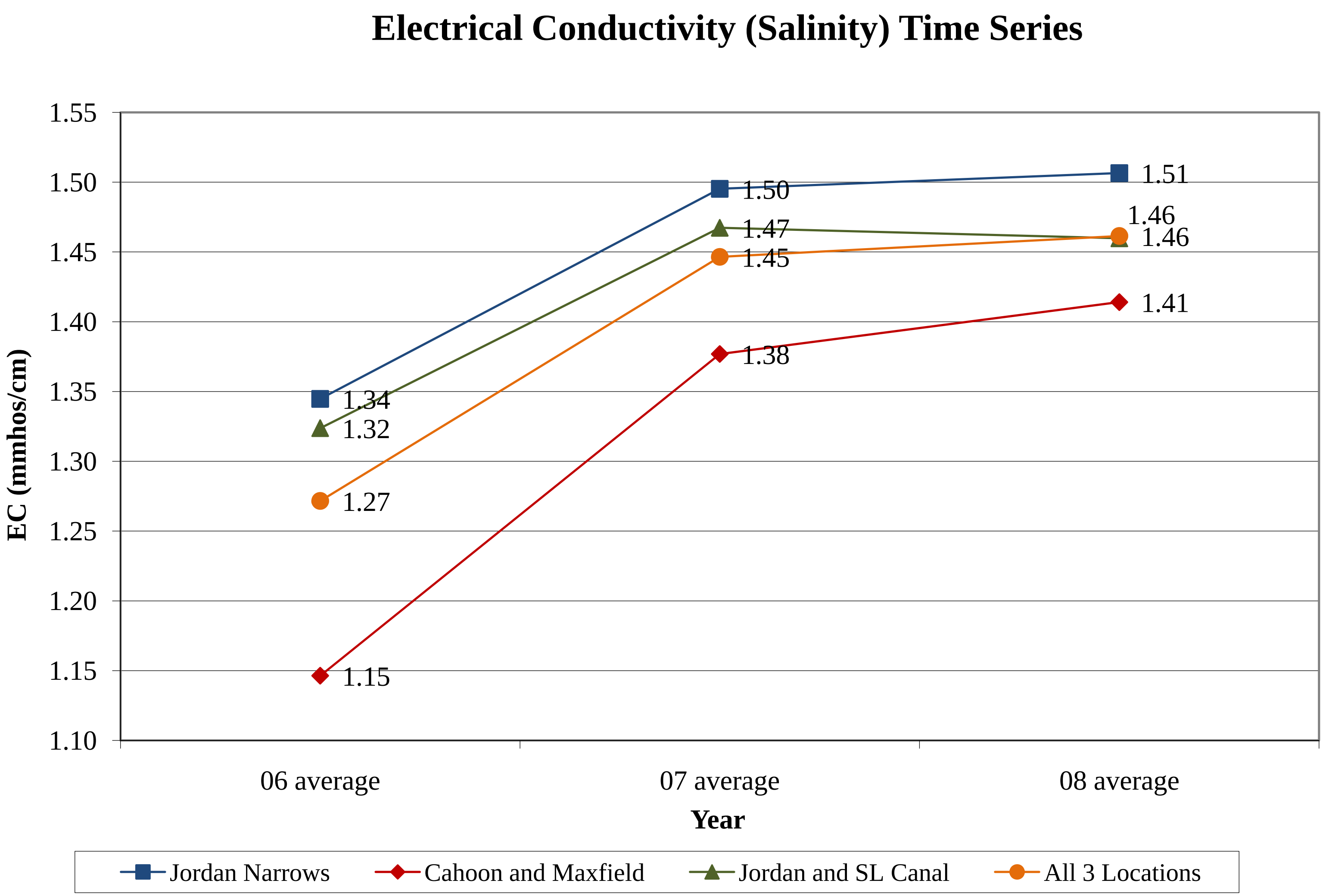

Figure 5: Electrical Conductivity 2006–2008 Seasonal Average Time Series

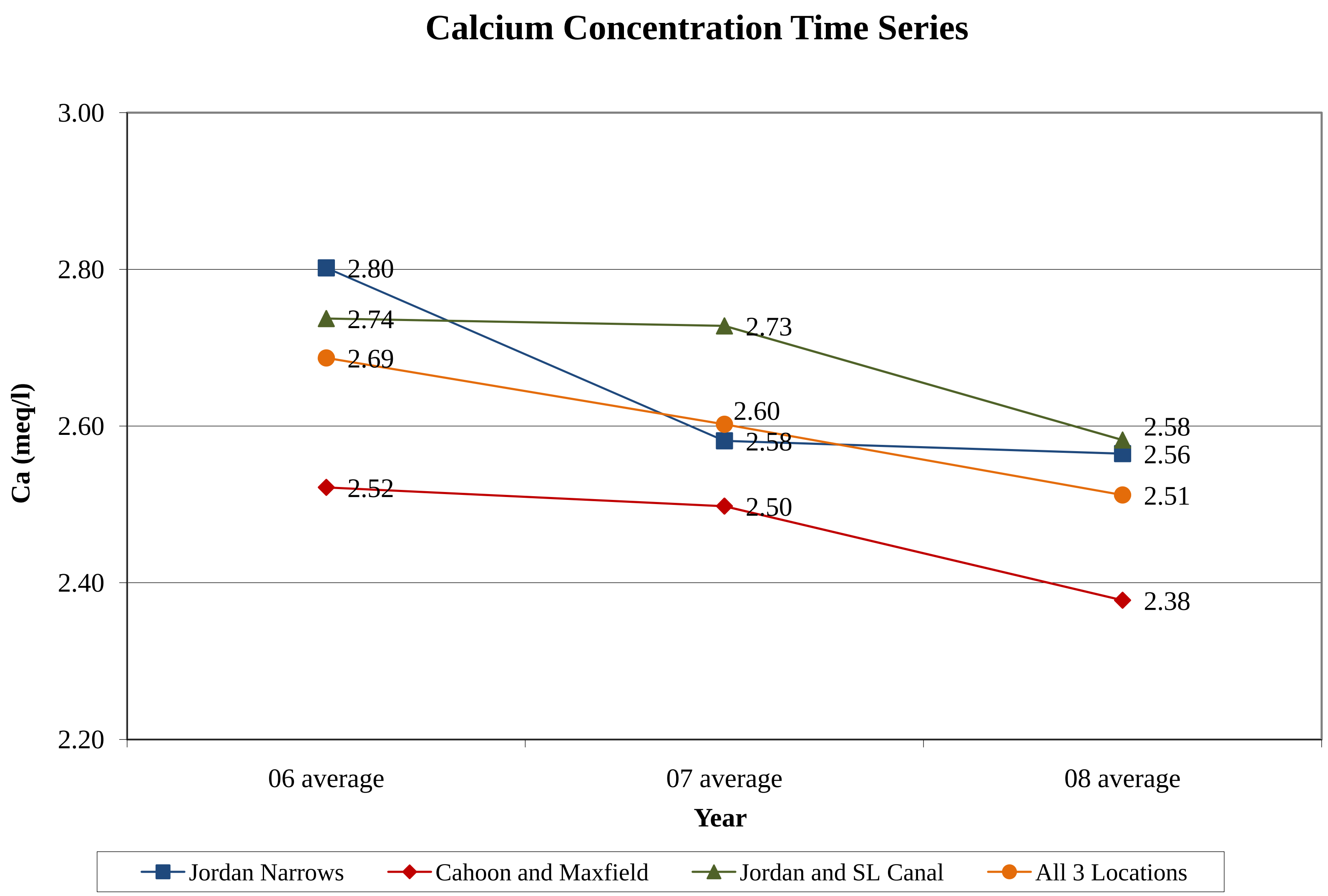

Figure 6: Calcium 2006–2008 Seasonal Average Time Series

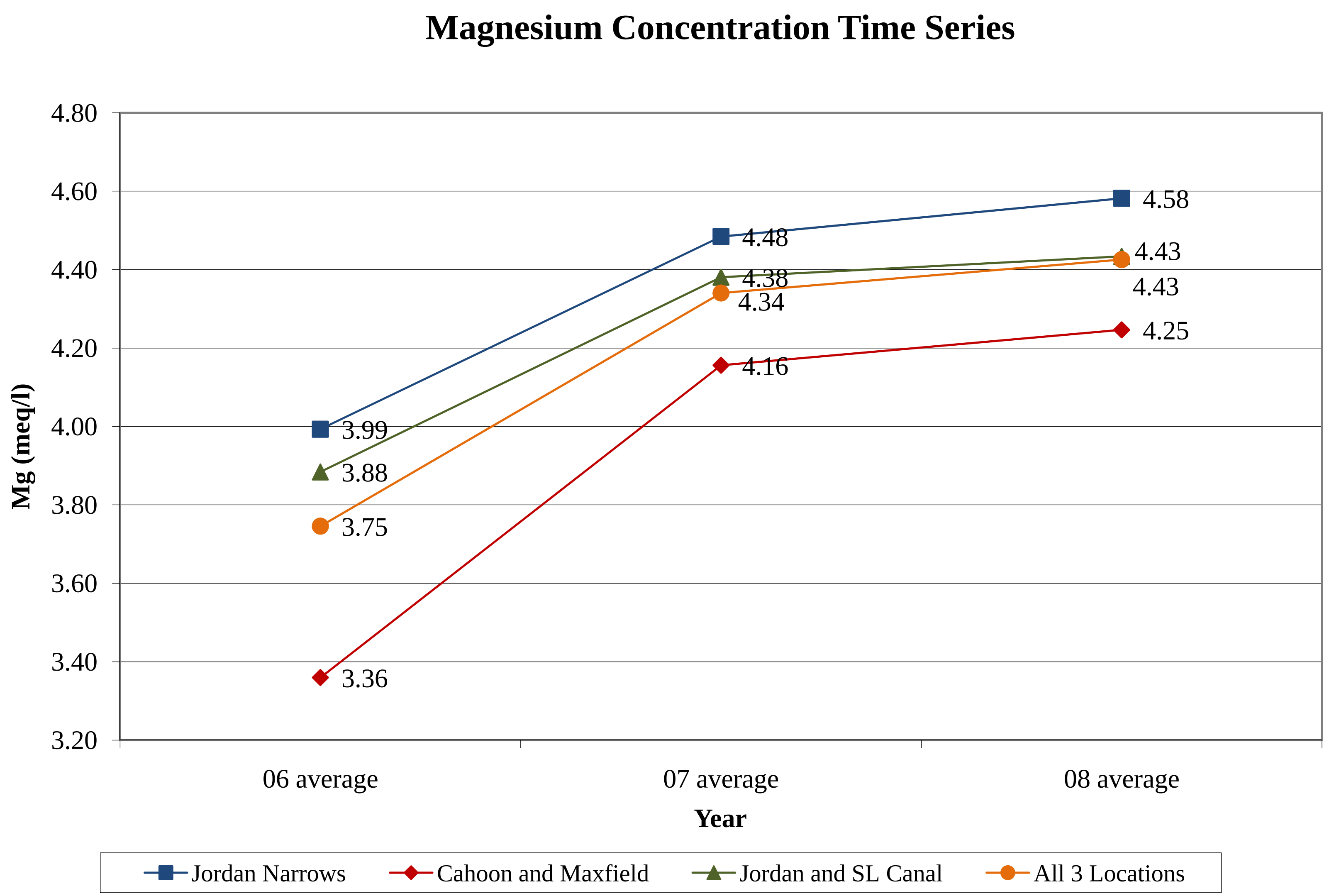

Figure 7: Magnesium 2006–2008 Seasonal Average Time Series

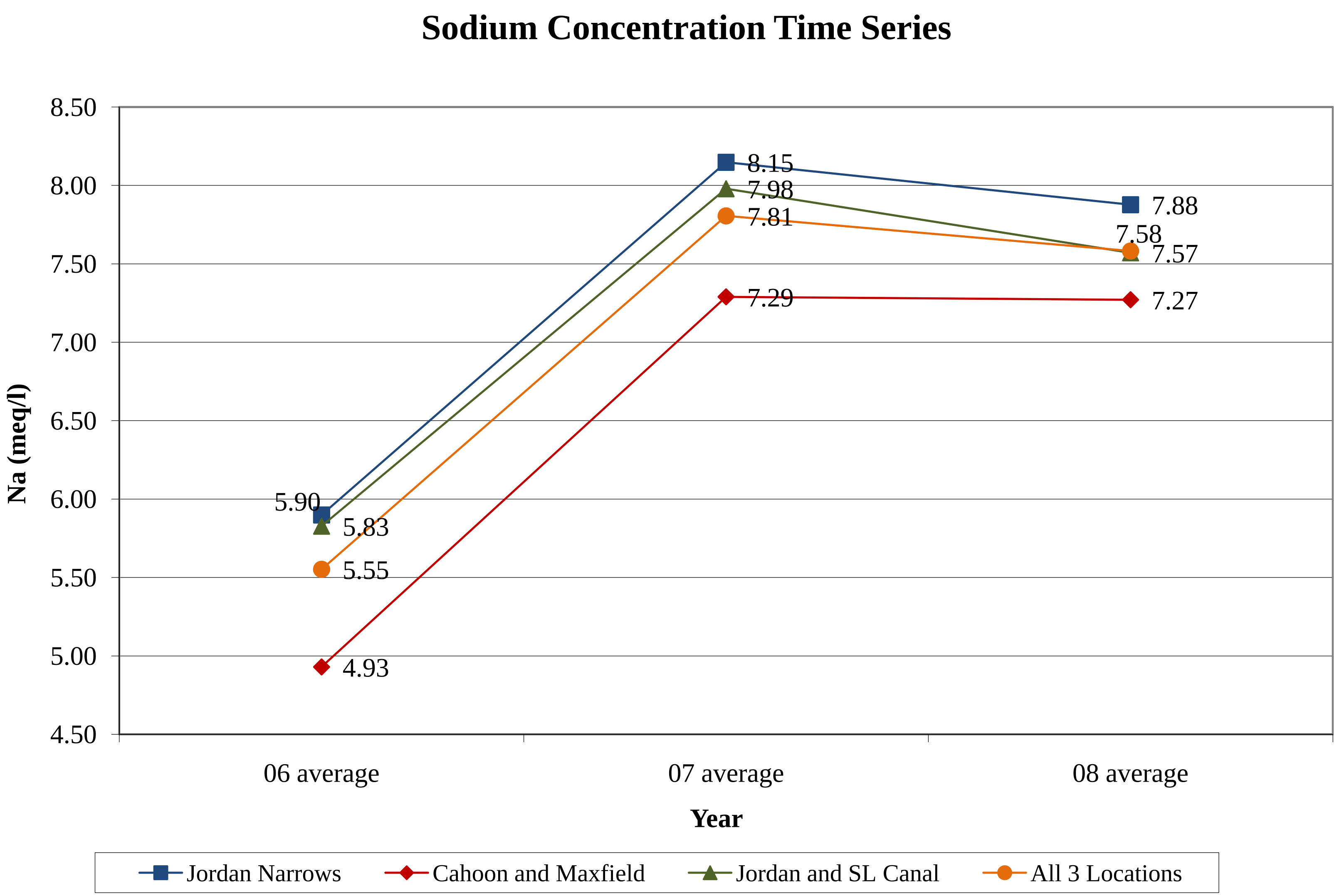

Figure 8: Sodium 2006–2008 Seasonal Average Time Series

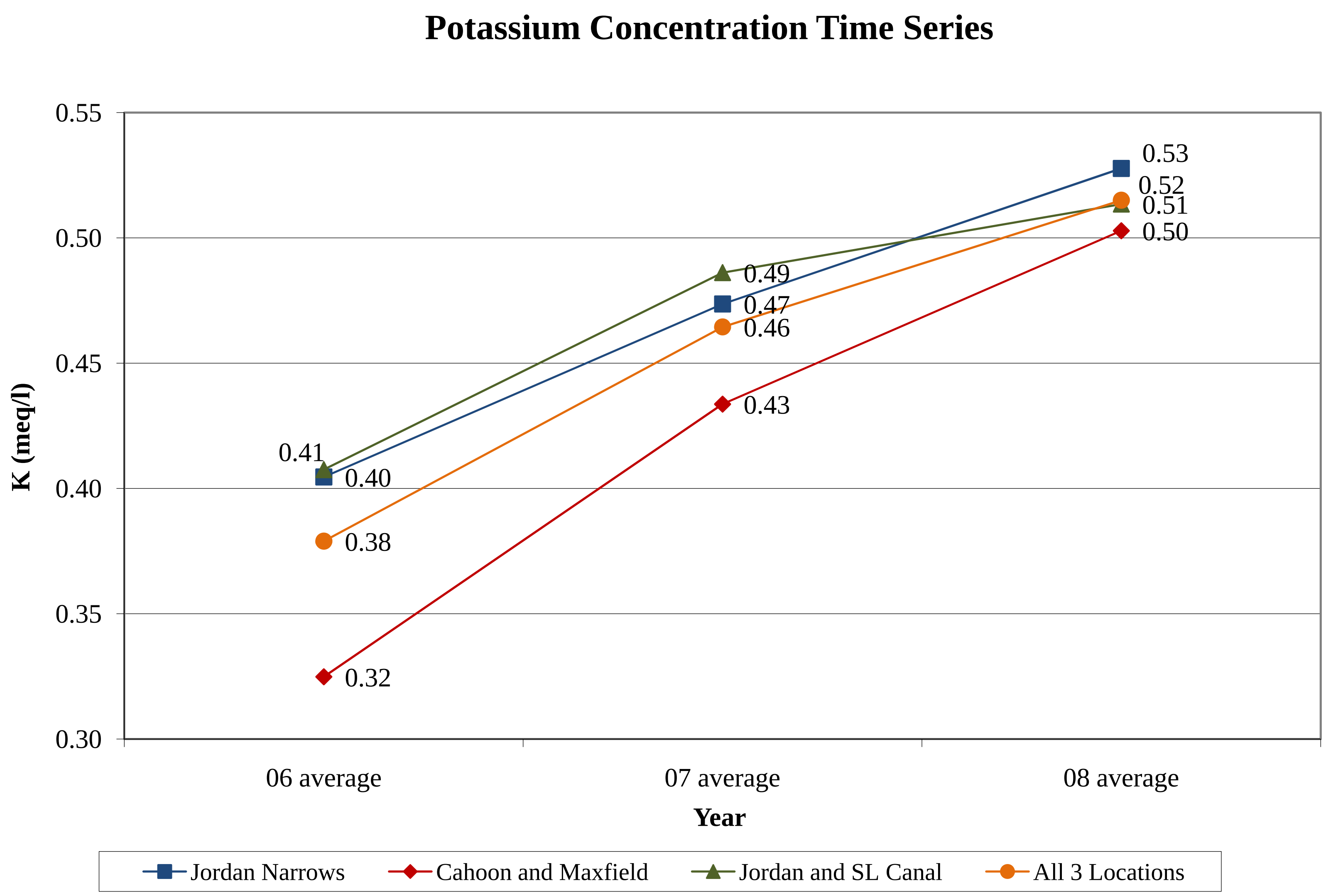

Figure 9: Potassium 2006–2008 Seasonal Average Time Series

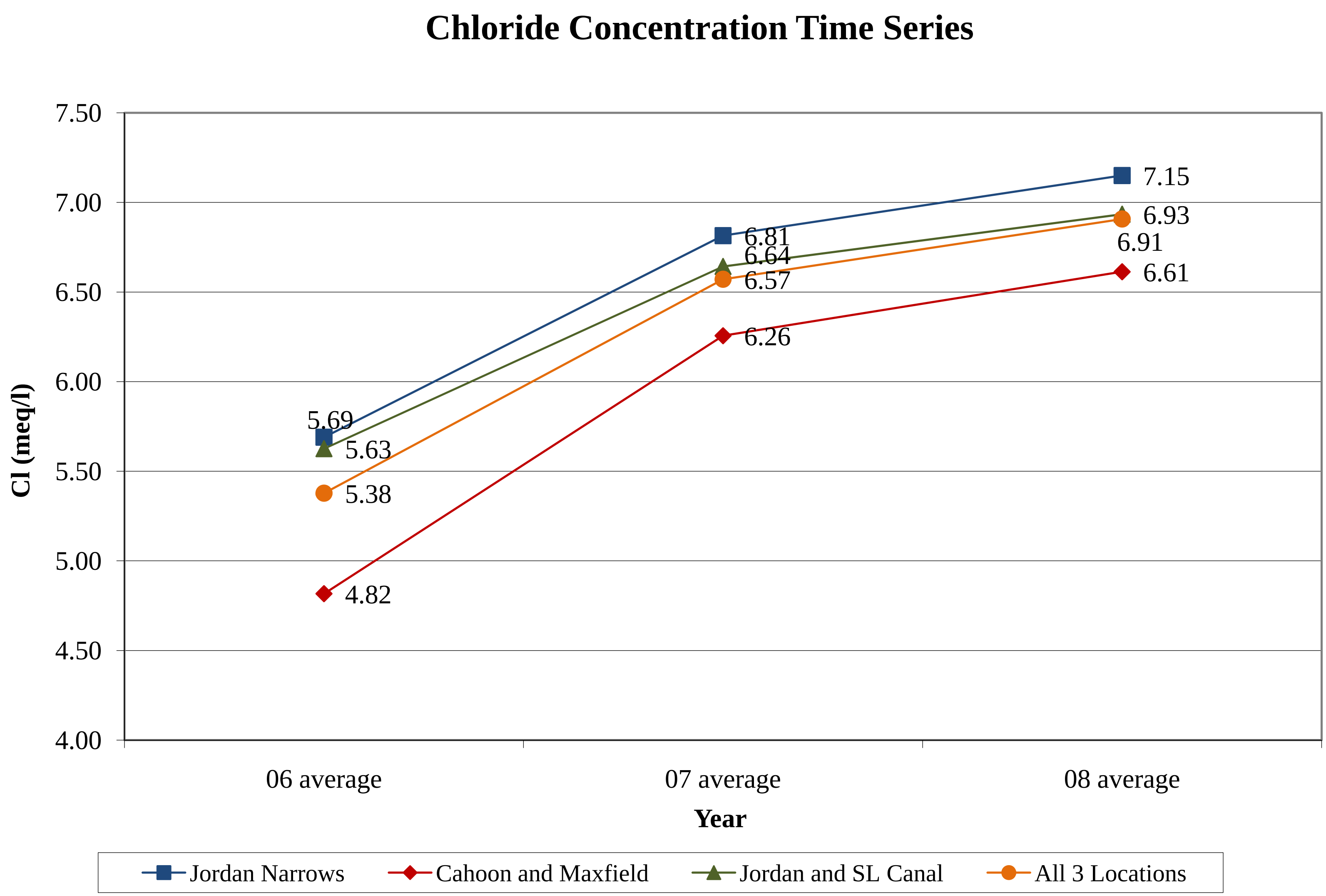

Figure 10: Chloride 2006–2008 Seasonal Average Time Series

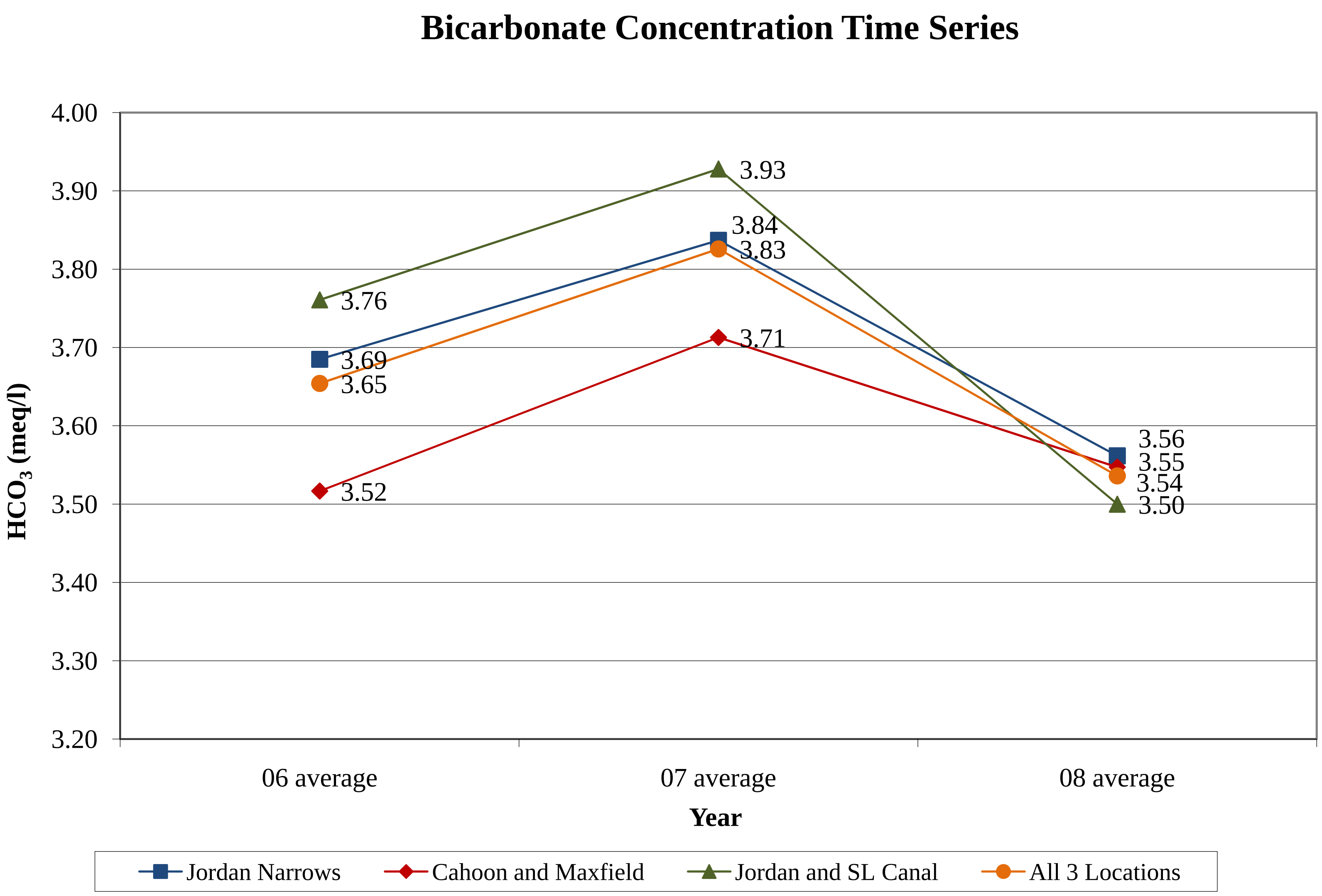

Figure 11: Bicarbonate 2006–2008 Seasonal Average Time Series

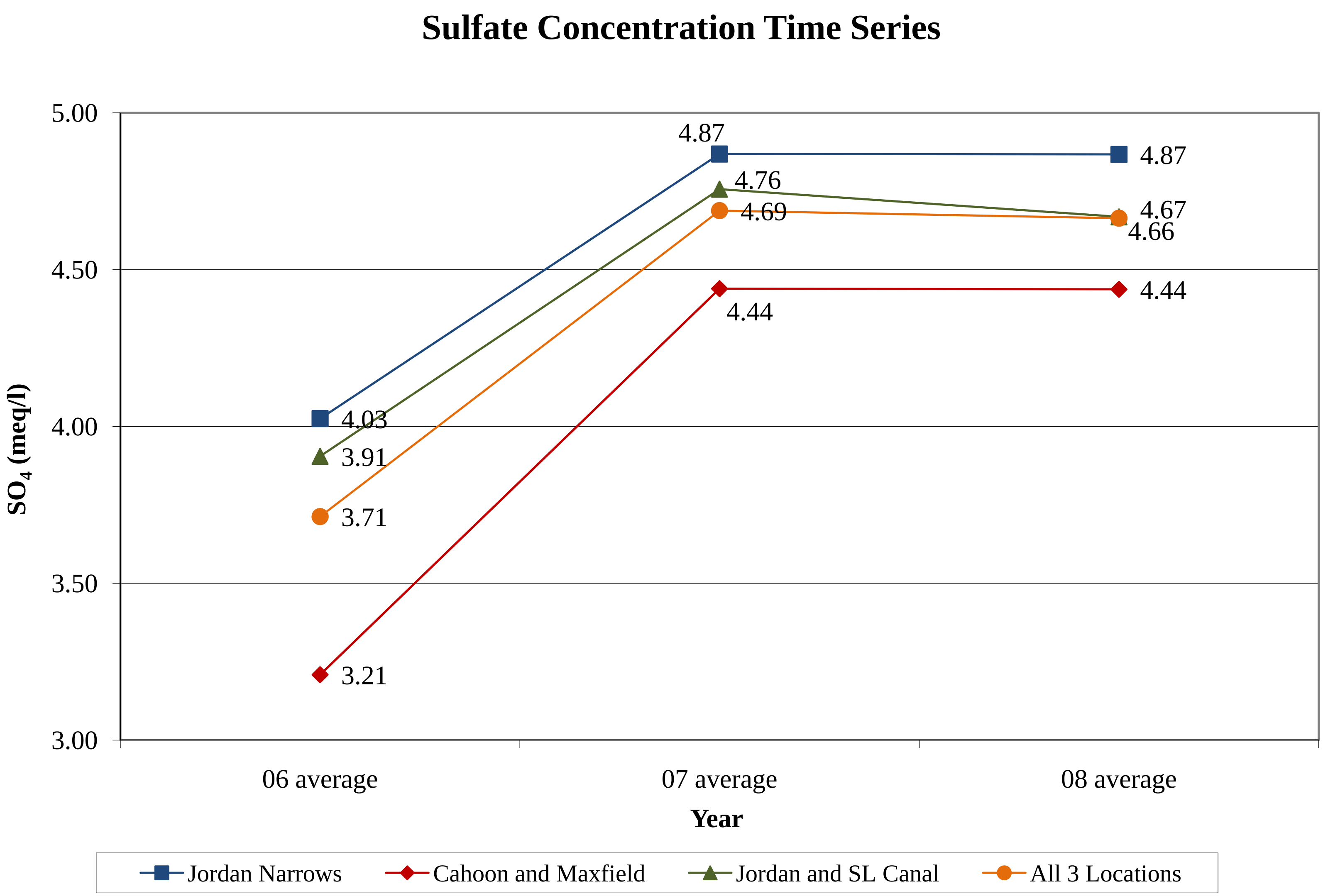

Figure 12: Sulfate 2006–2008 Seasonal Average Time Series

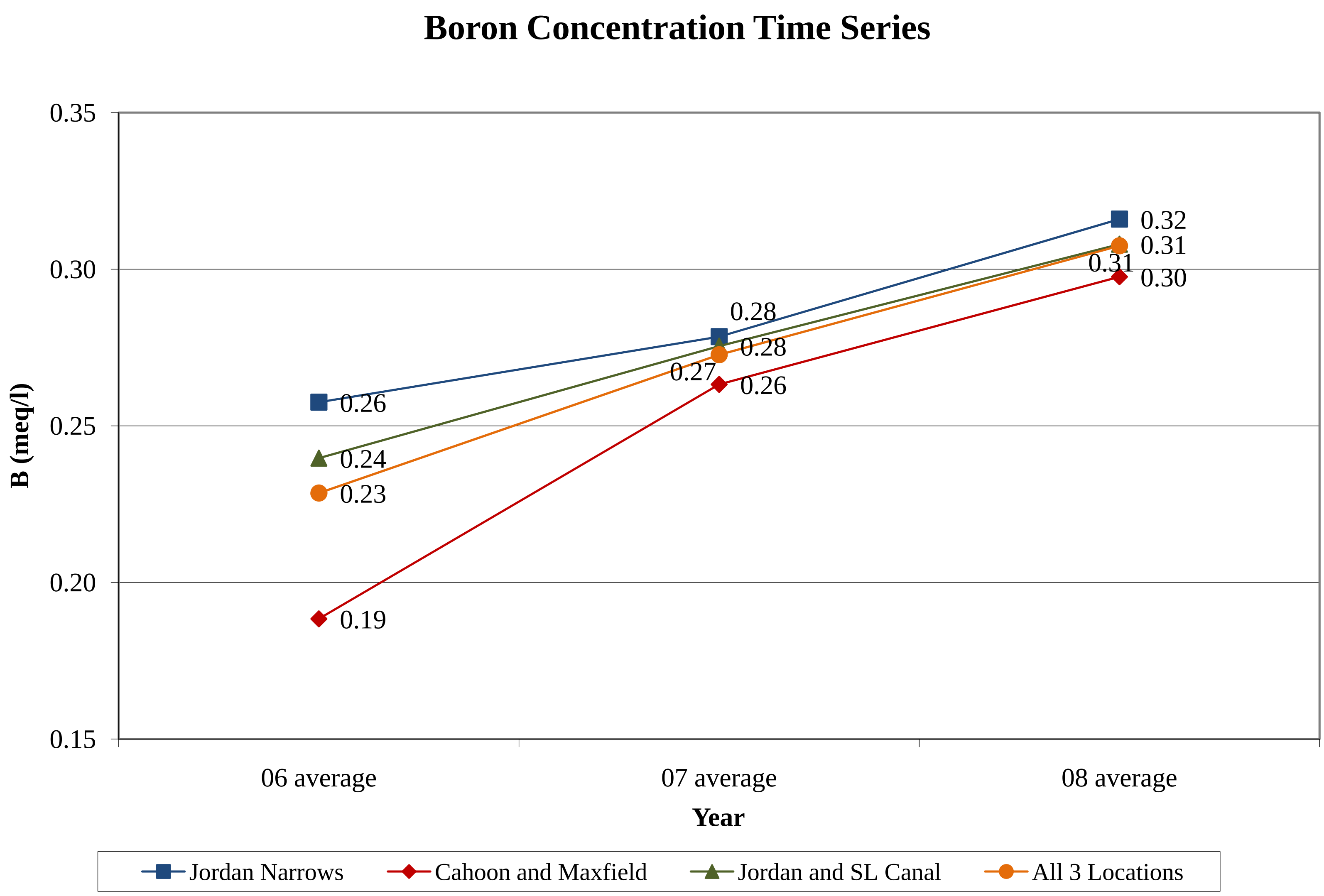

Figure 13: Boron 2006–2008 Seasonal Average Time Series

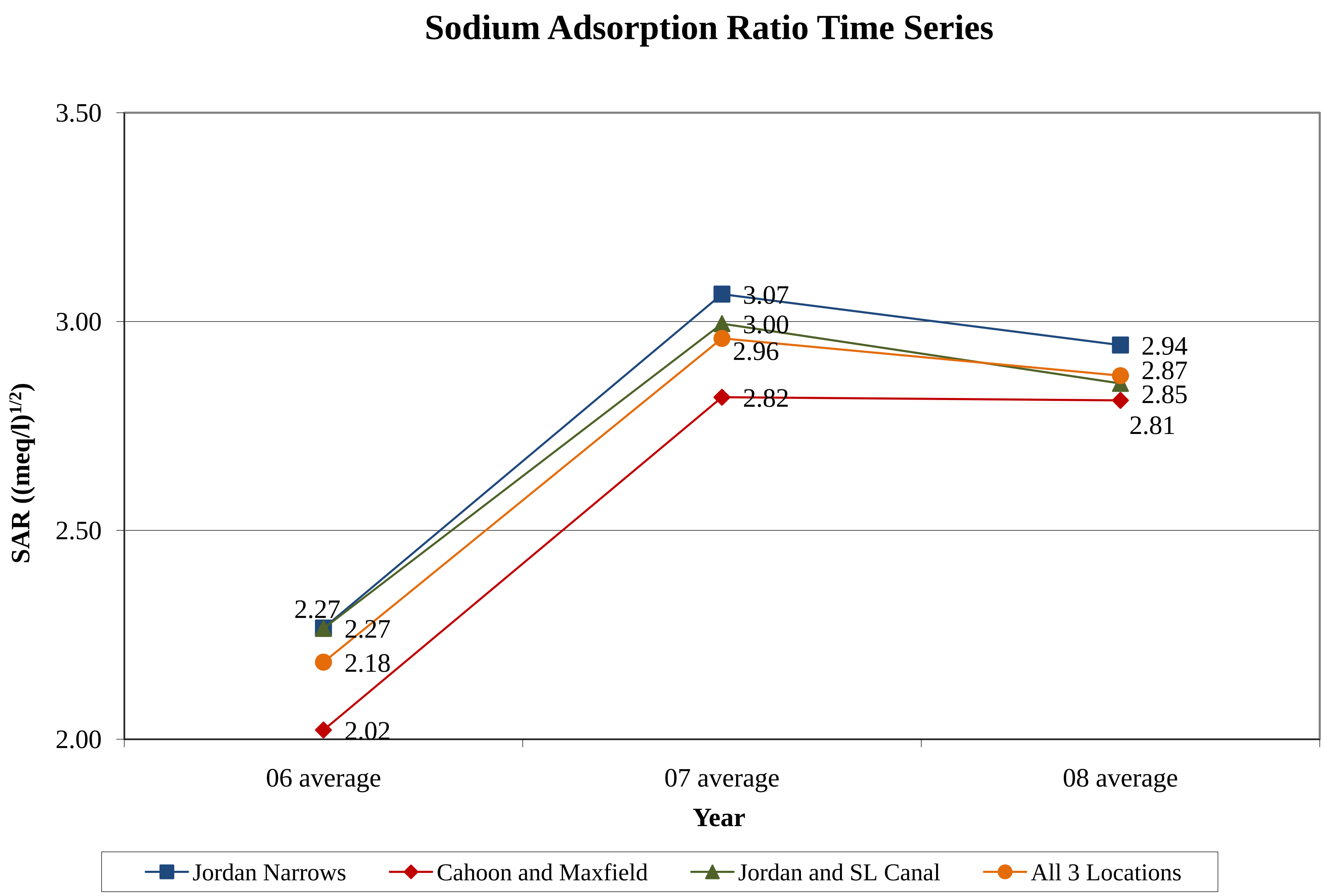

Figure 14: SAR 2006–2008 Seasonal Average Time Series

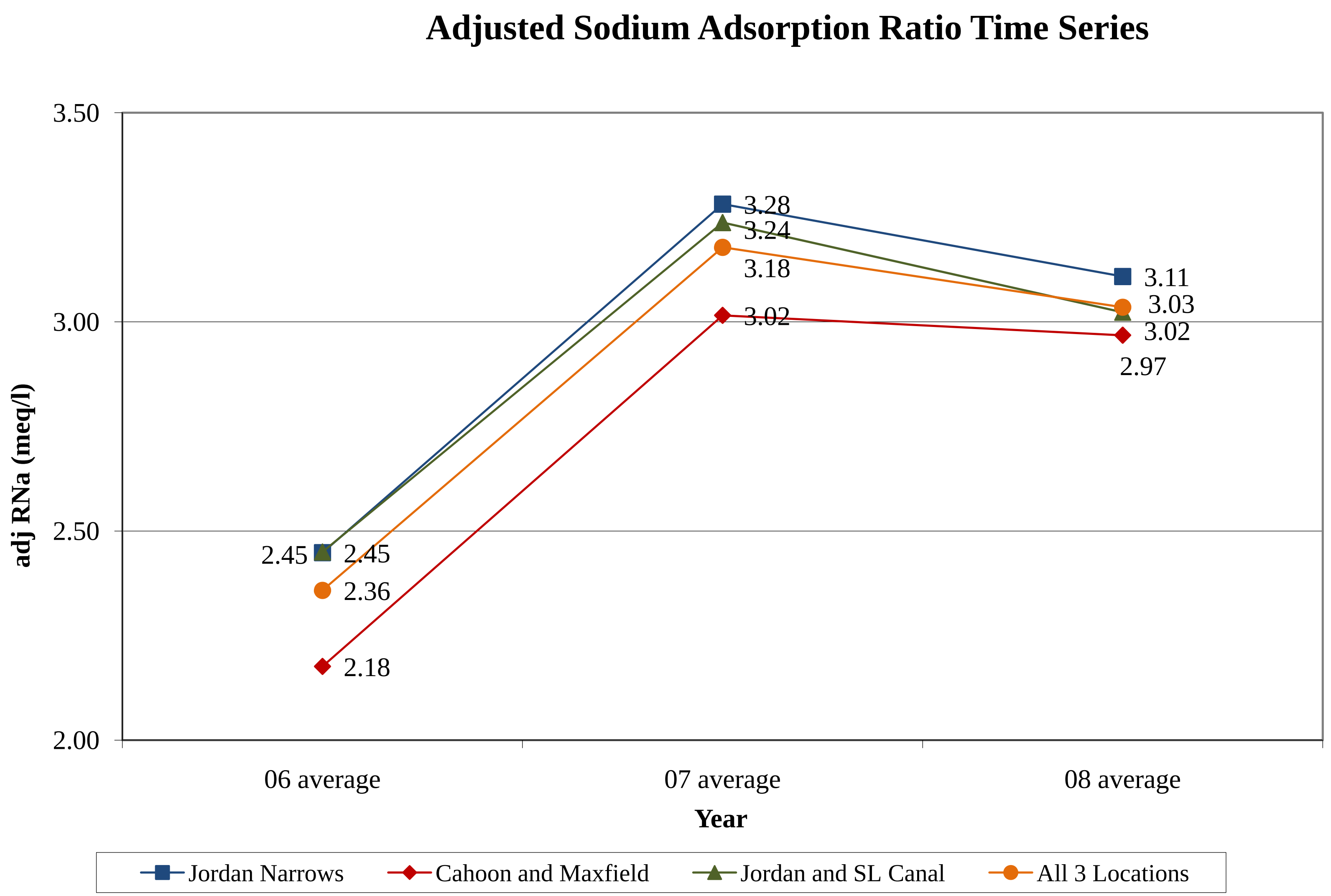

Figure 15: Adj RNa 2006–2008 Seasonal Average Time Series

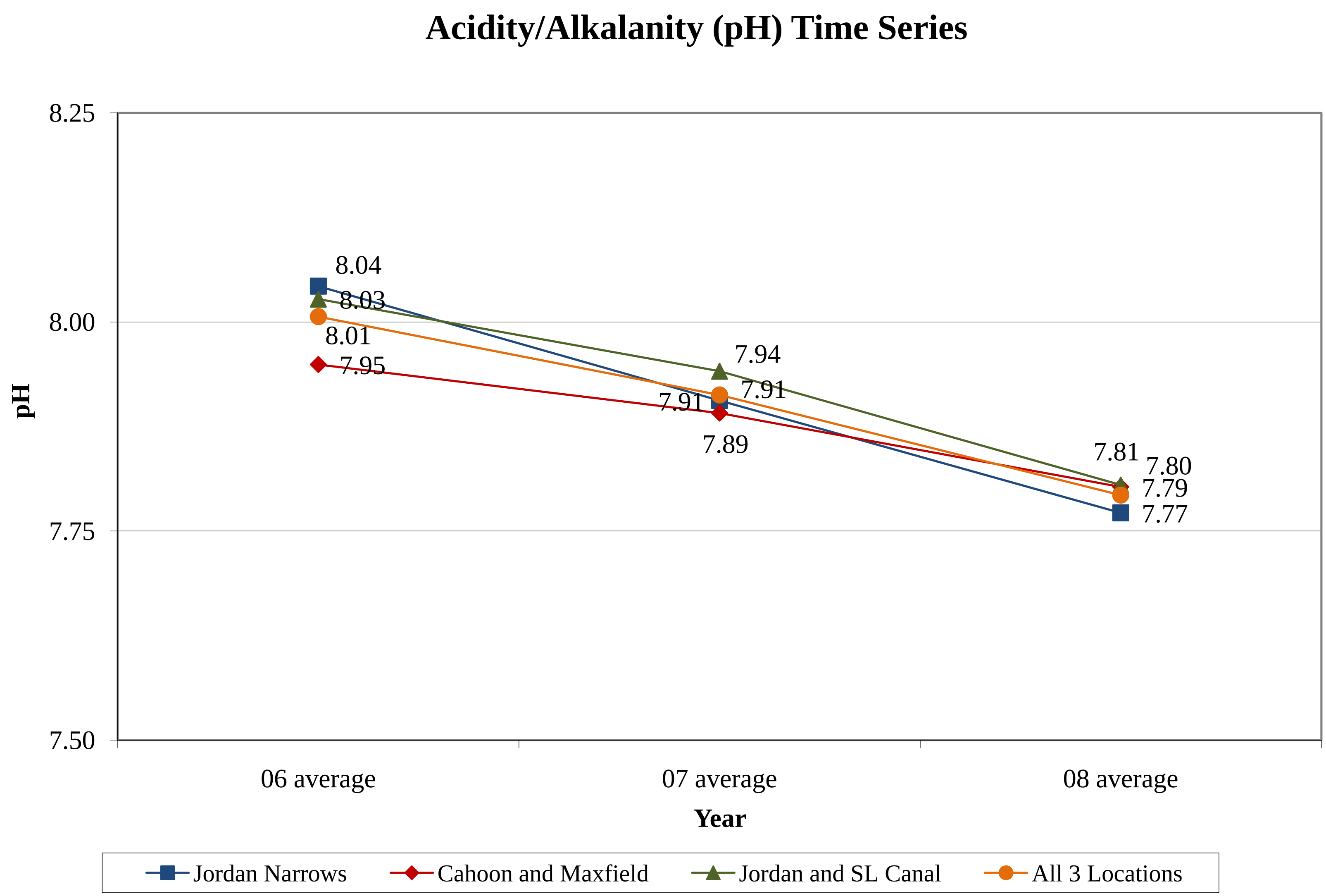

Figure 16: pH 2006–2008 Seasonal Average Time Series

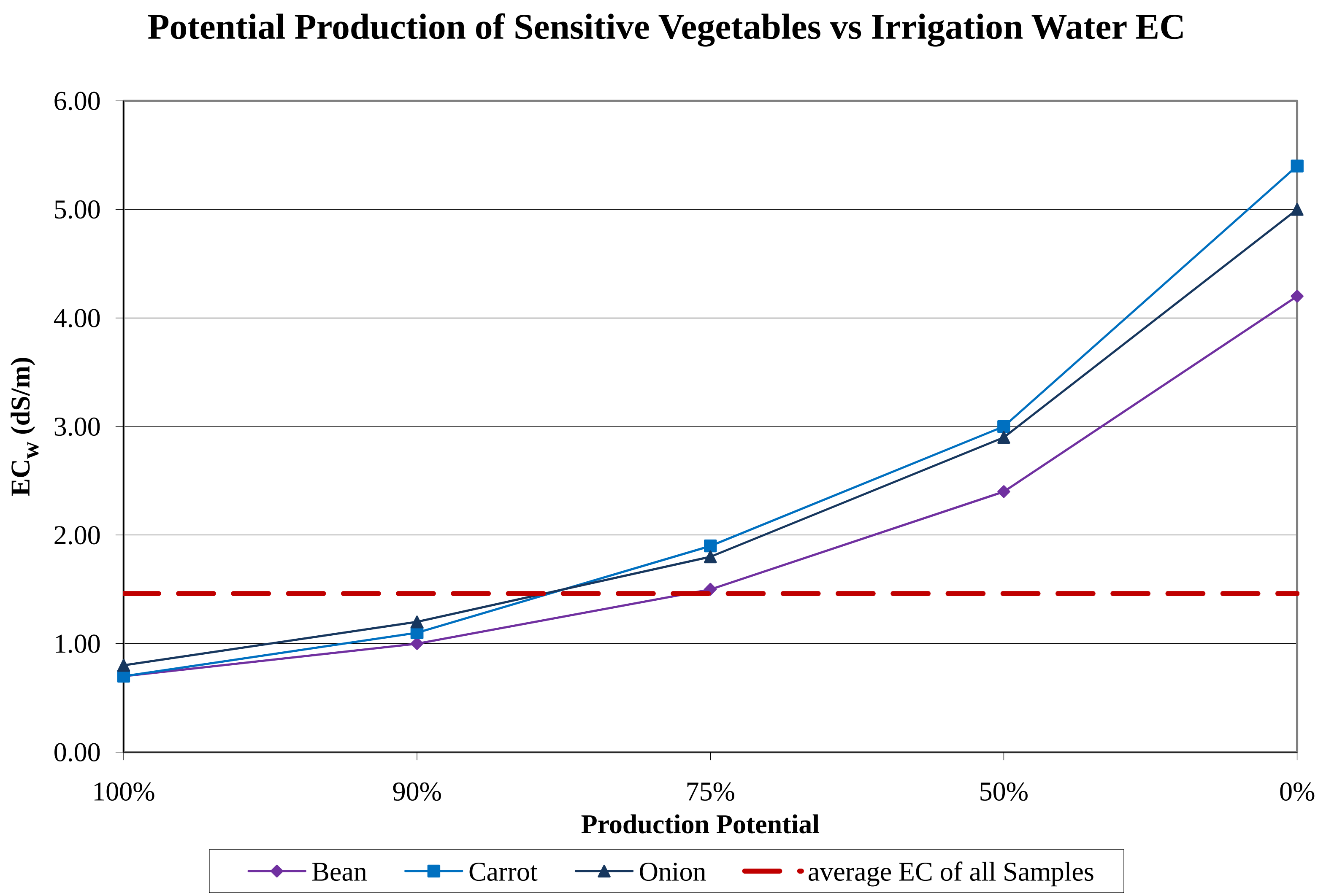

Figure 17: Productivity of Selected Sensitive Vegetables vs. Irrigation Water Salinity.

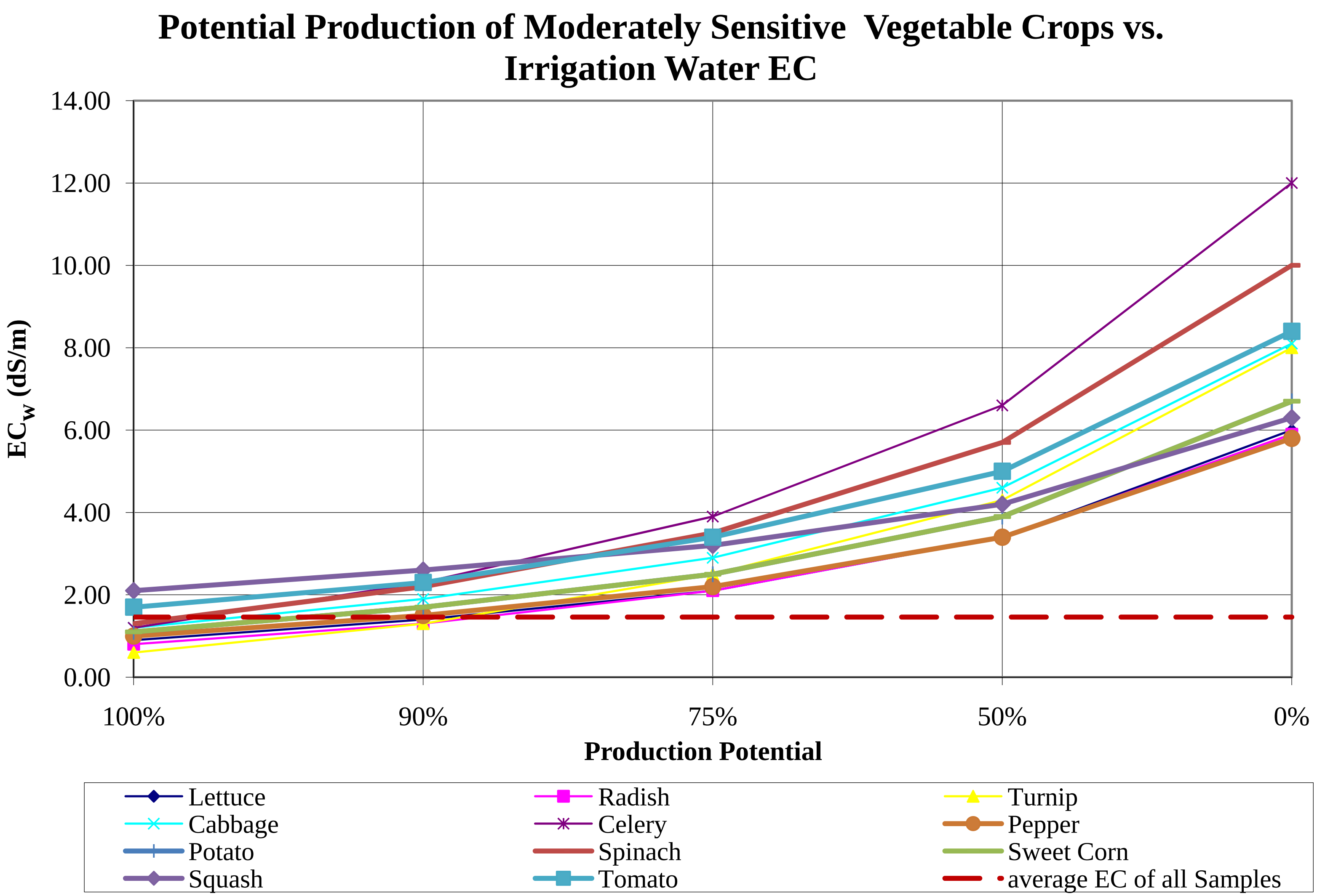

Figure 18: Productivity of Selected Moderately Sensitive Vegetables vs. Irrigation Water Salinity.

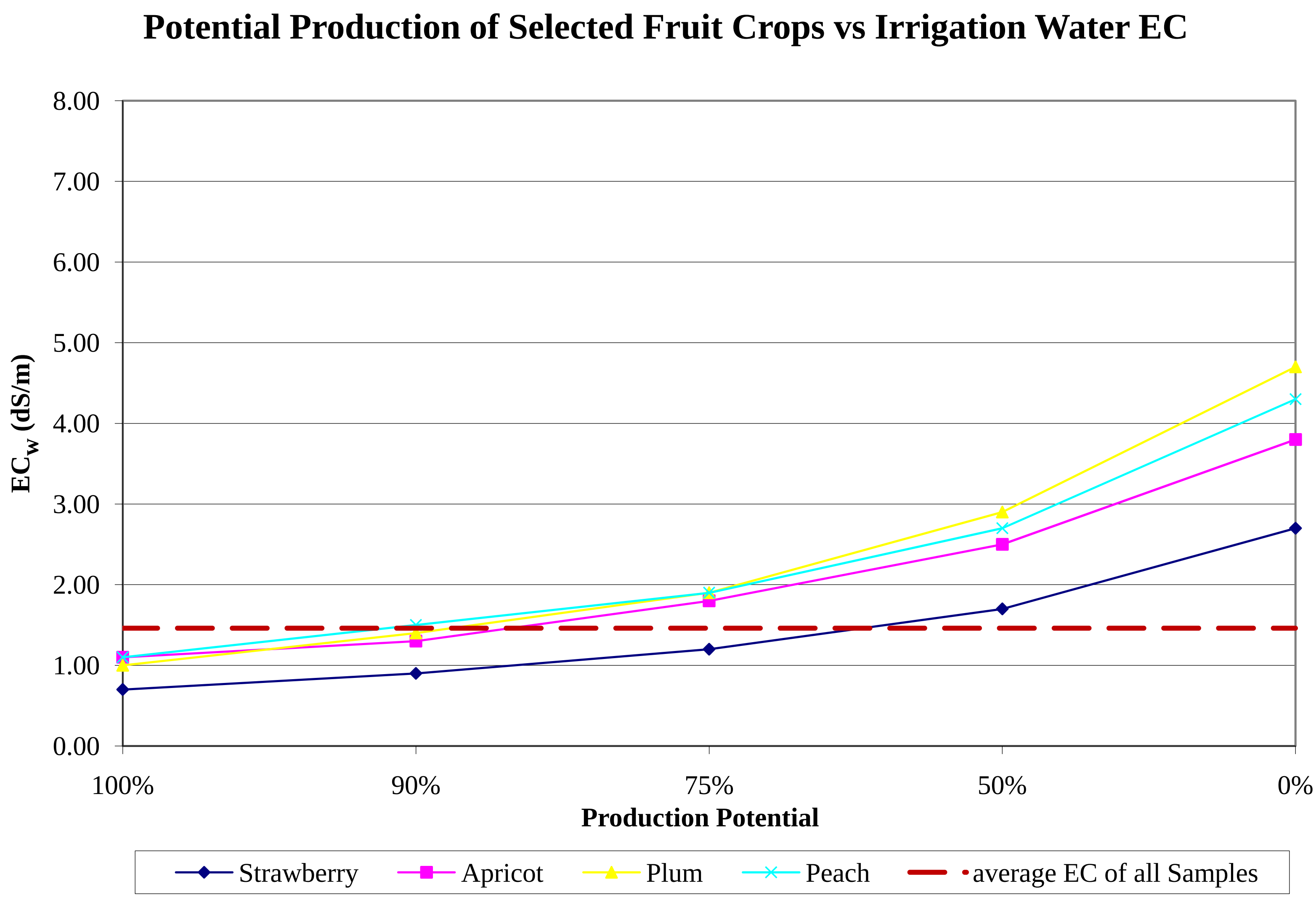

Figure 19: Productivity of Selected Fruit Crops vs. Irrigation Water Salinity.