Project Title: Soil Testing Five Years after Irrigation with Recycled Water

Project Final Report

Submitted to

Denver Water

By

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July, 2010

Table of Contents

List of Figures

List of Tables

List of Appendex

Definitions

Salinity refers the effect of total dissolved salts on soils or plants. Soil salinity is a measure of the quantity of dissolved salts in a soil, i.e. the saltiness of a soil. Salinity is most commonly gauged by electrical conductivity (EC) and is reported in units of dS/m or mmhos/cm.

Sodicity refers the high sodium effect on soils. High sodium content can cause deflocculation or breakdown of soil clay particles, making such a soil less permeable to both water and air. Sodicity is best gauged by soil exchangeable sodium percentage (ESP) or sodium adsorption ratio (SAR).

Executive Summary

In 2004, Colorado State University (CSU) collected soil baseline information from 10 landscape sites (parks and golf courses) in Denver that had just started to use recycled water for landscape irrigation. In 2009, 5 years after the initiation of recycled water irrigation, soil samples were collected near the original sampling areas and analyzed for soil characteristics. At each site, at least three locations were sampled. At each location, samples were taken at 0-20 and 20-40 cm depths at parks and schools. At golf courses, samples were taken at 0-20, 20-40, 40-60, 60-80, and 80-100 cm depths. Soil samples were tested for the following parameters: soil texture, soil pH, soil organic matter, soil salinity, exchangeable sodium percentage (ESP), chloride and boron content, and AB-DTPA extracted NO_3-N, P, K, Zn, Fe, Mn, and Cu content. Calcium, Mg, and Na content were determined from saturated paste extracts and sodium absorption ratio (SAR) was calculated. In addition, soil compaction and irrigation uniformity surrounding each sampling area were determined in 2009. Soil compaction and irrigation uniformity were not determined in 2004 sampling.

Data were subjected to analysis of variance and significant differences in soil properties prior to and 5 years after recycled water irrigation were determined by the general linear model (GLM) procedure using the statistical analysis software (SAS, 2010).

Major findings:

- ✓ Soil salinity (as gauged by soil electrical conductivity) and soil organic matter content did not increase at most of the sample sites over the five-year period;
- ✓ On average there was a slight increase in soil pH from 2004 to 2009.
- ✓ The average ESP and SAR values approximately doubled over the five-year period.
- ✓ Results suggested sodicity is of greater concern than salinity at most of the testing sites, since soil ESP and SAR are two parameters that exhibited the most significant changes

from 2004 to 2009. Soil and /or water amendment with calcium based products may help to displace Na and reduce ESP and SAR, especially at the surface (0-20 cm) depth. Continued increases of ESP and SAR could potentially cause reductions in soil hydraulic conductivity in soils with high clay content. Increased soil ESP and SAR may reduce soil aggregates stability and reduce overall soil health. More research is needed to 1) determine if soil ESP or SAR would continue to increase or would stabilize, 2) develop low cost, pre-irrigation water treatment strategies to decrease sodicity, and 3) develop specific landscape management techniques that will help to achieve urban water reuse sustainability.

- ✓ Although recycled water also contains P, no increase in soil P was observed over 5 years with recycled water irrigation. Nitrate–N content deceased significantly with soil depth. Nitrate-N level beyond the turfgrass rootzone in 2009 samples was < 3 mg kg^{-1}, well below the EPA standard for potable water quality (10 mg kg^{-1}). This indicates that nitrate contamination of groundwater should not be a great concern when using recycled water for the irrigation of turf systems. Dense, well-managed, and active-growing turfgrasses serve as bio-filtration systems for removal of excess nitrate.
- ✓ All except two sites had a good to excellent irrigation uniformity (> 70%. irrigation distribution uniformity). No clear relationship between irrigation distribution uniformity and measured soil parameters was observed. The 13.2% higher than average precipitation in 2009 growing season might have suppressed such relationships.
- ✓ Finally, management recommendations for landscape sites irrigated with recycled water are provided at the end of this report.

BACKGROUND

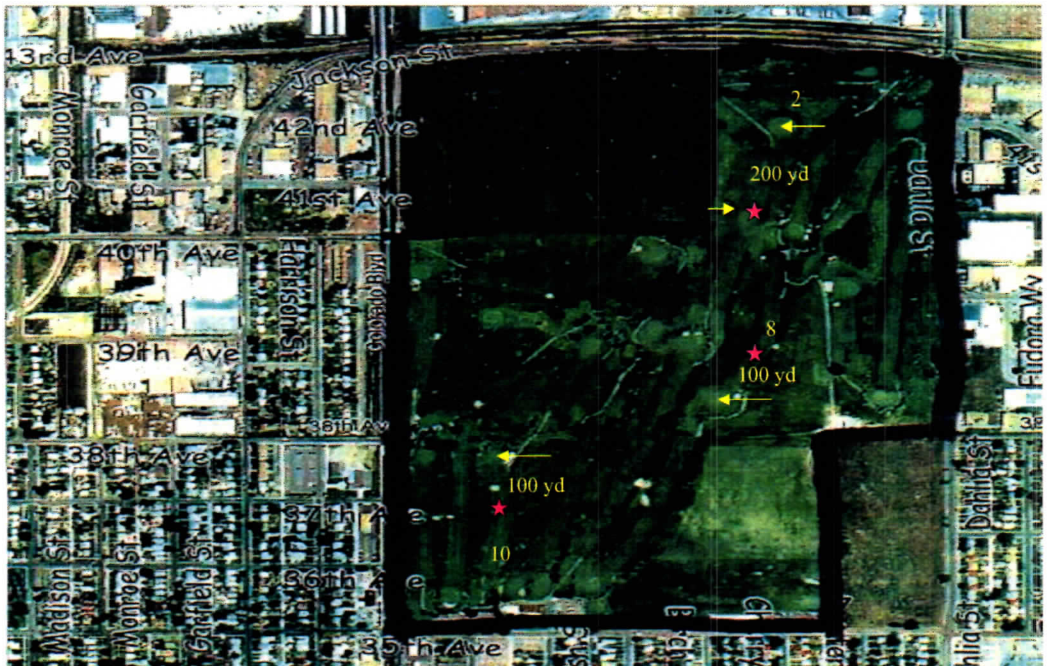
To ensure sustainable and affordable water supplies, Denver Water operates a recycled water system that treats and delivers recycled water for landscape irrigation and other non-potable purposes. Water reuse for irrigating landscapes is one of the approaches to maximize the existing water resources and stretch current urban water supplies. Phase one Denver Water's recycled water system provides recycled water to Swansea Park, Dunham Park, Bruce Randolph Middle School, Schaefer Park, Park Hill Golf Course, City Park Golf Course, and the Denver Zoo via 12 miles of pipeline. Recycled water is also delivered into the City Ditch, which supplies irrigation water to Washington Park, the Denver Country Club and City Park.

In 2004, CSU collected soil baseline information for the above mentioned parks, golf courses, and other facilities that just started to use recycled water for landscape irrigation. In September to October 2009, 5 years after the initiation of water reuse, soil samples were collected again from the original sites to determine if any changes have occurred.

SAMPLING PROCEDURES

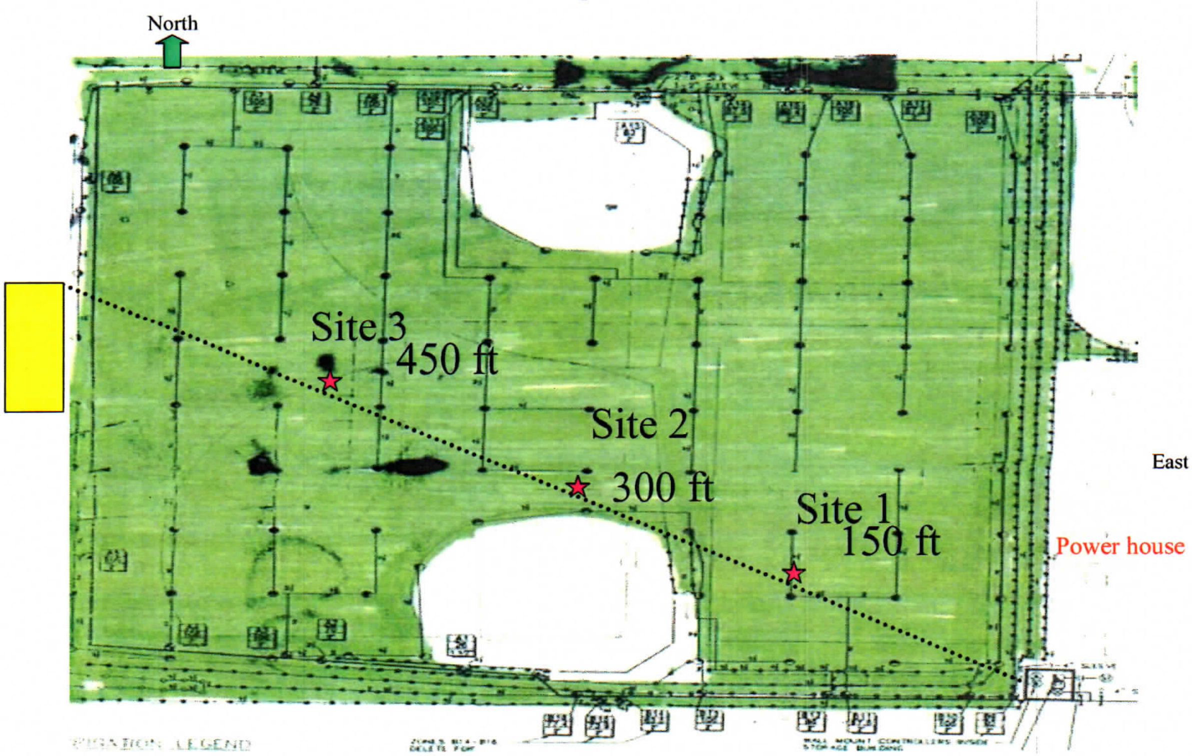
As in 2004, a total of about 100 soil samples were collected in September to October 2009 to test soil chemical properties. In 2009 sampling, samples were collected one foot away from the 2004 original sampling points. (The only exceptions were sample sites 5 and 6 at City Park where reconstruction were done to build cart path, so the 2009 samples were collected 20 feet northeast and 40 feet east of the original sample points). The soil sampling sites were marked and/or described on maps for individual facilities. At each facility, at least three locations were sampled. At each sample site, three cores were collected using a handheld boring tool. At parks and schools, samples were taken at 0-20 and 20-40 cm depths; at golf courses, samples were taken at 0-20, 20-40, 40-60, 60-80, and 80-100 cm depths. At Washington Park, samples were only taken to 0-20 cm depth, because of the Facility Manager's concerns about damage to wires buried underground. Three cores at each site and depth were combined. The following maps indicate the sampling sites at the 10 landscape facilities.

Park Hill Golf Course



Site 1: Fairway #2, Sampled at 20 ft east of the 200 yardage marker from the green.
Site 2: Fairway #8, Sampled at 20 ft east of the 100 yardage mark.
Site 3: Fairway #10, Sampled at 20 ft west of the 100 yardage mark.
★ Sampling location

Bruce Ranodolph Middle School



Form a line between the northwest corner of powerhouse and the northeast corner of the building west of the school.
Sampled at 150, 300, and 450 ft from the northwest corner of the powerhouse

Denver Country Club

Fairways #2: sampled at 20 ft south of the 175 yd irrigation head.
Fairway #14: sampled at 20 ft north of the 120 yd irrigation head.
Fairway #16: sampled at 20 ft north of the 121 yd irrigation head.
Fairway #18: sampled at 20 ft south of the 120 yd irrigation head.

128 acres

City Park

Sites 1 and 2. Started at the edge of the pavement looking at the statue of a man holding a sword. Measured due North toward a metal light post. Sampled at intervals of 150 and 300 ft.

Sites 3 and 4. Started at the Northwest of the Dr. Martin King Monument. Measured from the edge of pavement toward edge of tennis courts. Samples were taken at intervals of 150 and 300 ft.

Sites 5 and 6. Started from the light pole located next to a rock bridge. Measured from the light pole in line with the Southeast corner of the Natural History Museum. Samples were taken at 150 and 300 ft.

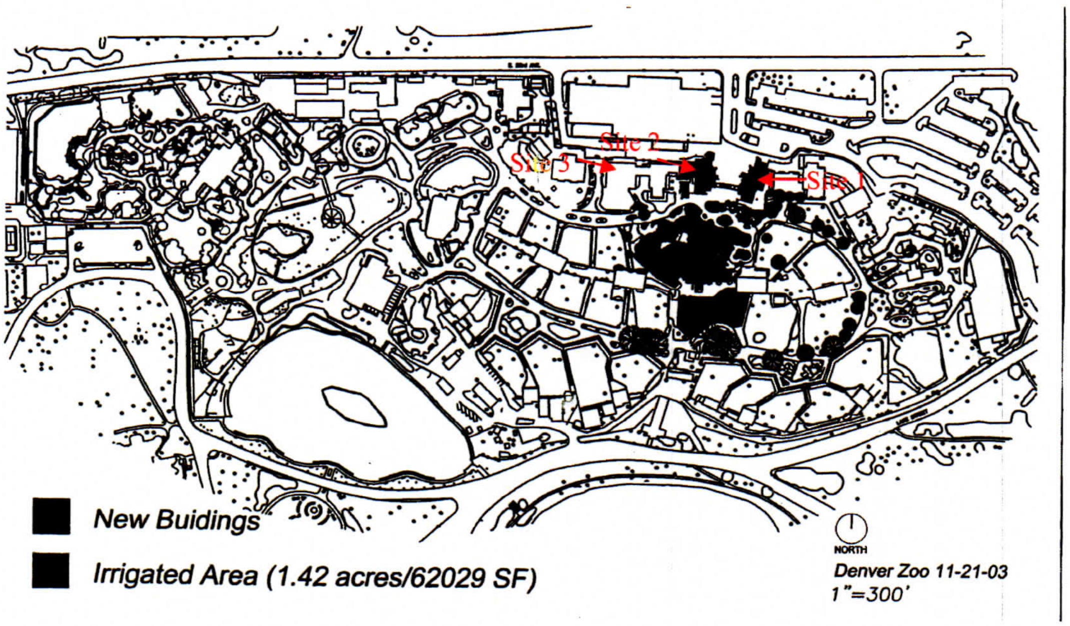
Washington Park

Site 1. Started at the Northwest corner of Dos Chappell Bath House, on the line in between the meeting of two sidewalk slabs. Measured northeast in line with green light pole, at 150 ft.

Sites 2, 3, 4, and 5. Started at light pole by crosswalk with intersection of Dowing and Kentucky to the west. Measured northeast, in line with the southeast corner of the white building. Sampled at intervals of 150, 250, 350, and 450 ft.

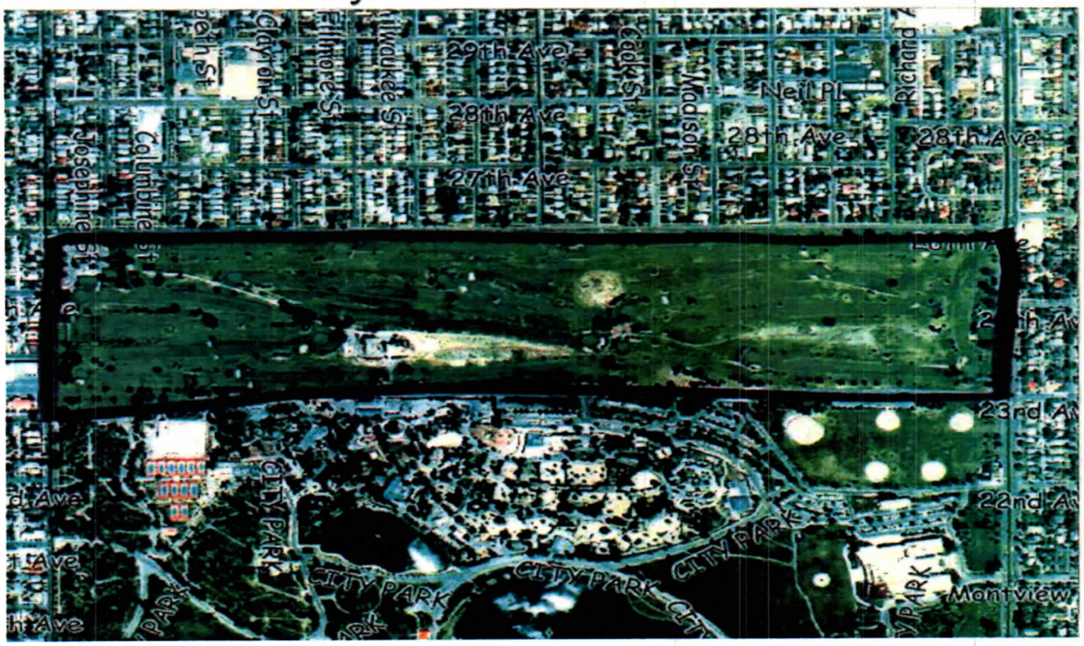
Site 6. Started at southwest base point of the white bridge on the east side of the road/bike path. Measured southeast, in line with the second white bridge's southwest base point, at 150 ft.

Denver Zoo



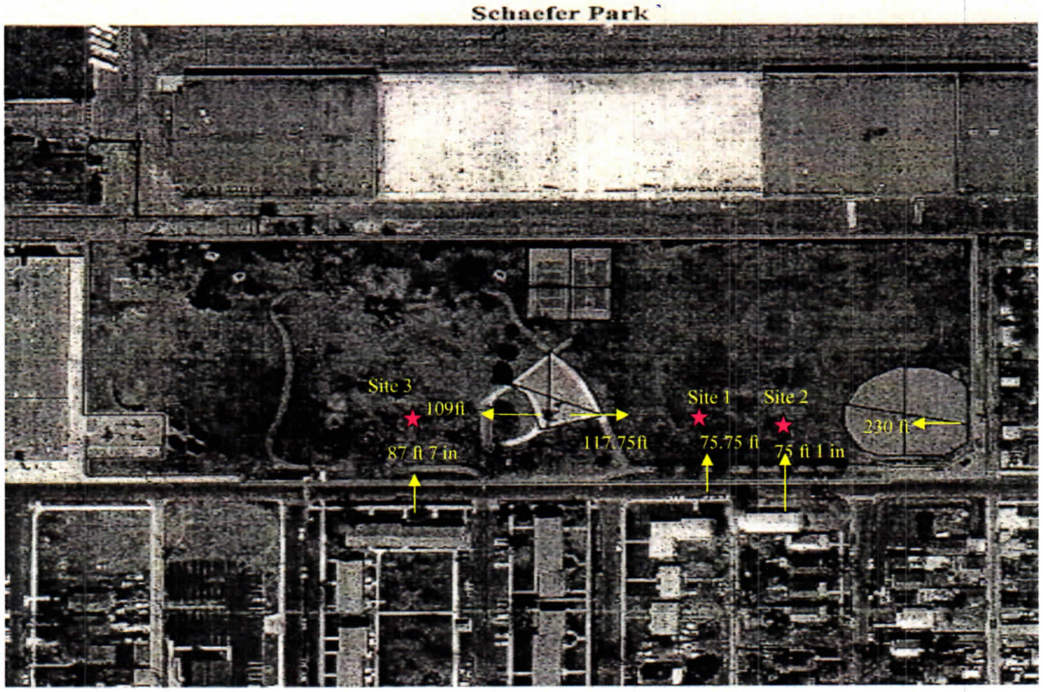
Site #1: sampled under an ash tree located northwest of the lion maternity gate.
Site #2: sampled under an ash tree located at northeast of the lion maternity gate.
Site #3: sampled right inside of the Denver Zoo main entrance, under a small ash tree.

City Park Golf Course



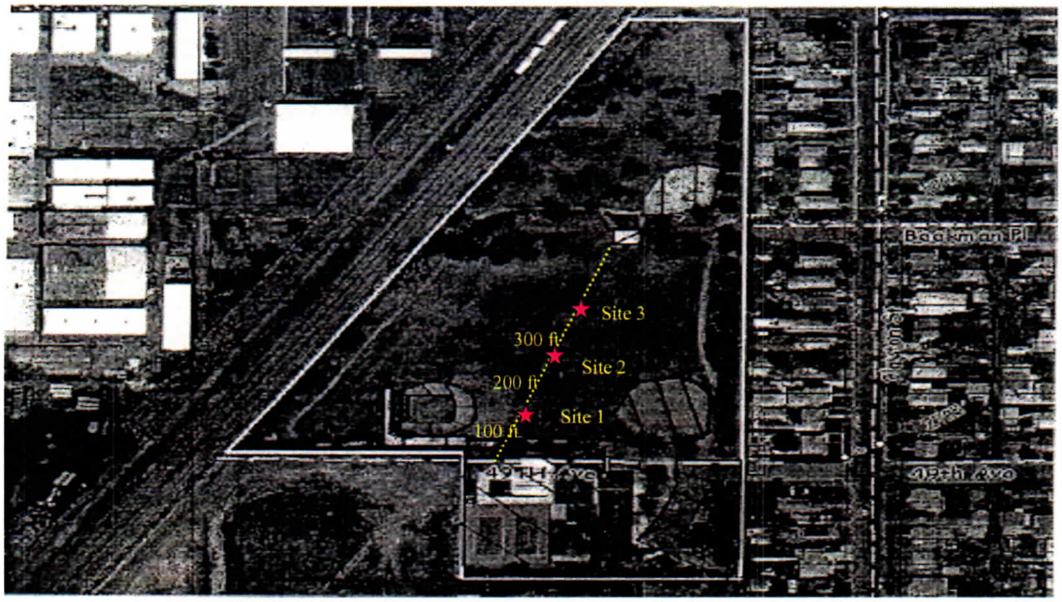
Site 1: Fairway #3, sampled at 10 ft south of the 216 yds (from green) irrigation head.
Site 2: Fairway #14, sampled at 10 ft north of the 265 yds irrigation head (from green).
Site 3: Fairway #17, sampled at 10 ft north of the 165 yds irrigation head.

Schaefer Park



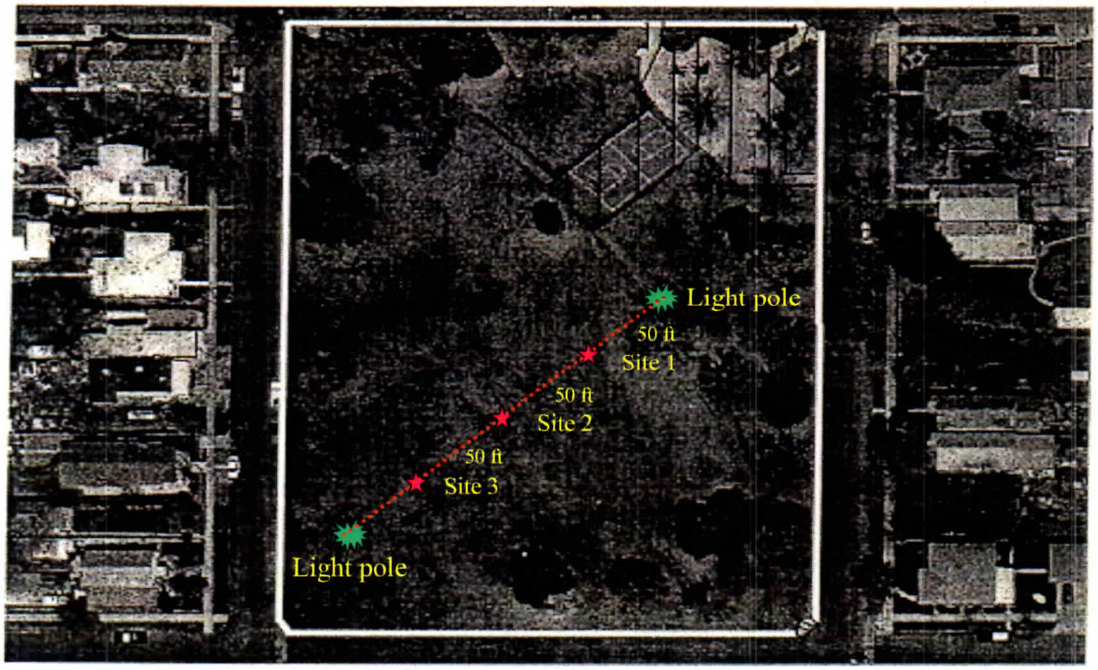
Site 1: the intersection of 117 ft 8 in east of concrete of the central playground and 75 ft 8 in north of 37 Ave .
Site 2: the intersection of 230 ft west from the fence metal pole (parallel to power pole) and 75ft 1 in. north of 37 Ave.
Site 3: the intersection of 109 ft 6 in west of power pole and 87ft 7 in north from 37 Ave.

Swansea Park



Sites 1, 2, and 3. Start at the northwest corner of the building located south of the park. Then line up with southwest corner of the storage building in the center of the park. Sampled at 100, 200, and 300 feet from the northwest corner of the south building.

Dunham Park



Sites 1, 2, and 3. Form a line between the light pole on the side walk close to Clayton Ave. and the light pole on Thompson Ave. Starting from the light pole on the side walk close to Clayton, sampled at 50, 100, and 150 ft from the light pole.

SOIL ANALYSIS

All soil samples were allowed to air dry, then ground, and screened to pass through a 10-mesh (2 mm) sieve. Soil samples were tested at the Soil, Water, and Plant Testing Laboratory at Colorado State University. Each soil sample was tested for:

- Boron
- Chloride
- Nitrate nitrogen (NO_3-N)
- Phosphorous
- Soil electrical conductivity (EC)
- Sodium
- Sodium absorption ratio (SAR)
- pH
- Calcium
- Magnesium
- Cation exchange capacity (CEC)
- Exchangeable sodium percentage (ESP)
- Potassium, zinc, iron, manganese, and copper content

Soil Boron and Chloride Content:

Soil boron and chloride content is extracted using hot water (1 g of soil to 10 ml of hot water). After filtering, Boron was measured by using an inductively-coupled plasma-atomic emission spectroscopy (ICP). Chloride was measured using ion chromatography (Dionex, 2000 I/SP ion chromatograph, Sunnyvale, CA).

Soil pH, Electrical Conductivity, Water Extractable Ca, Mg, and Na, and Sodium Absorption Ratio:

Soil pH and EC were analyzed using a saturated paste extract. Deionized water was added to ground and sieved soil and mixed uniformly until a saturated paste was obtained. The pH of the paste was taken directly by placing the pH electrode into the paste. The saturated paste was then transferred to a Buchner funnel with Whatman #1 filter paper (pore size =11 micron) and vacuum filtered. The filtrate (saturation paste extract) was collected in a liquid scintillation vial. The EC was taken by pouring the extract into the EC cell and recording the reading of the electrical conductivity meter. The saturated paste extracts were transferred to auto-sampler tubes and analyzed for Ca, Mg, K, and Na concentrations by ICP.

The SAR was calculated as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{[Ca^{++} + Mg^{++}]}{2}}}$$

Where values of Ca, Mg, and Na are expressed as meq/L.

Soil Organic Matter Content:

Soil organic matter was determined using a modified Walkley-Black method by reacting soil organic matter with potassium dichromate ($K_2Cr_2O_7^{2}$) and sulfuric acid. The redox reaction changes the original chrome 6 (orange) to chrome 3 (greenish). The mixture was allowed to settle and the liquid was poured off into spec20-tubes. The samples were then analyzed for percent transmittance at 610 nm using a Spectronic 20D Spectrophotometer.

Extractable Soil Nitrate, Phosphorus, Potassium, Zinc, Iron, Manganese, and Copper Content:

Soil samples were extracted using the ammonium bicarbonate-diethylenetriaminepentaacetic acid (AB-DTPA extractant). The AB-DTPA solution was made with 1M NH_4HCO_3 – 0.005 M DTPA at pH 7.6. Ten grams of air-dried soil was mixed with 20 ml AB-DTPA extracting solution and placed on a mechanical shaker for 15 minutes. After filtering, the extracts were measured for extractable P at 882 nm on a Spec 20 at an acidity of 0.18 M H_2SO_4 by reacting a sample aliquot with ammonium molybdate using ascorbic acid as a reductant in the presence of antimony.

Nitrate-N content was determined using flow-injection Cd reduction analysis. This method is based on the reduction of injected nitrate to nitrite and determination of nitrite spectrophotometrically at 540 nm.

In addition, AB-DTPA extracted K, Zn, Fe, Mn, and Cu were measured by ICP.

Cation Exchange Capacity (CEC) and Exchangeable Sodium Percentage (ESP):

CEC Measurements:

Cation exchange capacity (CEC) is defined as the number of milliequivalents of negative charges available to hold cations per 100g of soil. In this study, CEC was measured using a modified version of method 8-3 in Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Second edition. A.L. Page, et al. (eds). American Society of Agronomy, Inc. Soil Science Society of America, Inc. Madison, WI. 1982. Chapter 8. Cation Exchange Capacity. J.D. Rhodes. pp 152-154. A vacuum filtration device (Concept

Engineering, Lincoln, NE) was used where 2.5 g of soil was weighed into a 50 ml syringe containing approximately 1.5-2 cm of glass wool. The syringe was attached to the filtration device. An initial saturation step was performed where approximately 40mL of 0.5N sodium acetate - 0.1N sodium nitrate (pH 8.2) was added to the syringe containing the soil and allowed to pass through the soil when a vacuum was placed on the system. After the initial saturation step was completed, approximately 40mL of ethanol was passed through the soil to rinse out excess sodium. Following the alcohol rinse step, a final exchanging step was done where exactly 50 mL of 0.5N magnesium chloride was passed through the soil and retained for sodium and nitrate analysis. Sodium was analyzed by ICP and nitrate was analyzed by flow injection analysis. The CEC was determined by subtracting meq of nitrite entrained in the final exchanging step from meq of sodium and expressed as meq/100g.

Exchangeable Sodium and ESP Measurement:

Five grams of air-dried and sieved soil was weighed, and placed in a 40 ml centrifuge tube. Then 25 ml of 1 N ammonium acetate solution (pH 7.0) was added. The mixture was shaken for 30 minutes on a reciprocating shaker. The solution was allowed to settle and then filtered through Whatman #1 filter paper. The soil extract was then analyzed for exchangeable sodium by ICP.

Exchangeable sodium percentage (ESP) is calculated by dividing exchangeable sodium by CEC.

Soil Texture Estimation:

Soil texture was estimated using the "feel" method by a well experienced soil scientist.

The texture was determined when the soil scientist rolled, squeezed, and pressed the soil ball between his fingers. This method has the advantage of using small quantity of soil samples when compared to the other methods. This scientist has over 25 years experience in this technique, and he previously correlated the results with laboratory standard method (i.e. determination of percentage of sand, silt, and clay using particle size analysis).

Evaluating the Irrigation Uniformity and Compaction of Sampling Sites

Irrigation uniformity was assessed for all facilities except Denver Zoo. The very uneven contour, zoo animal behaviors, and the numerous visitors prohibited irrigation distribution measurement. For all other facilities, irrigation uniformity was evaluated for each soil sampling area after soil sampling using a 5 by 5 grid of cups (1 meter spacing). At each sampling location, 25 cups were laid out to determine irrigation uniformity. Irrigation uniformity around each sampling site was graphed using MadLab software (Appendix C).

Distribution Uniformity (DU) was calculated as:

DU = (average water output of the low quarter / average water output) 100%;

Christiansen's coefficient of uniformity (CU) was calculated as: CU = (1-D/M) 100, where

D= average absolute deviation from the mean of irrigation output, and

M = mean irrigation output.

Soil Compaction:

The compaction measurements were done in the same areas as for irrigation uniformity measurements. The soil compaction level was accessed on the same 5 by 5 grid (1 meter spacing) as irrigation uniformity test using a digital penetrometer. Compaction was measured at three different depths (1, 2, and 3 inches below soil surface) for each measurement point. Regression and correlation analysis were done to determine potential relationships between soil salinity, compaction, and irrigation uniformity.

RESULTS

SOIL ANALYSIS

Table 1 presents the average water quality values for recycled water leaving the recycling plant. All original soil baseline data (sampled in 2004) are presented in **APPENDIX A** (including datasheets #1-#9). Soil test data for samples collected in 2009 are presented in **APPENDIX B** (including datasheets #1-#9). Table 2-12 summarize the findings of soil analysis for each site.

For individual landscape facilities, soil chemical property data from 2004 and 2009 were subjected to the analysis of variance to test if significant changes have occurred for individual soil parameters during the 5 years of using recycled water irrigation (Table 3-12). In addition, data from all sites were pooled for 2004 and 2009, respectively, and the 2004 and 2009 averages of all sites are presented in Table 2. Before and after comparisons provide indications about the impacts of recycled water irrigation on soil chemical properties. A description about the interpretation of landscape irrigation water quality is presented in **Appendix D.**

Electrical conductivity (EC): Electrical conductivity of the saturated soil paste extract is the most reliable indicator of soil salinity level. In general, EC of soil higher than 4.0 mmho/cm (dS/m) is considered saline soil. However, salt sensitive plants may be injured below this value and salt tolerant plants may tolerate EC levels higher than 4 mmho/cm. All samples collected from the 10 sites in 2009 had low EC (< 1.8 mmho/cm). No consistent trend was observed. At some sites, including City Park, City Park Golf Course, Denver Zoo, Dunham Park, Washington Park, some degree of salt accumulation was observed. However, on other

Cations (exchangeable sodium, manganese, potassium, and magnesium): Soils in 2009 exhibited 66% higher concentration of exchangeable Na than soils sampled in 2004 (Table 3-12). The high Na content reflects Na addition via irrigation with recycled water; the average sodium concentration in the recycled water was 120 ppm (Table 1). In contrast to Na, soil Mn content was consistently lower in 2009 than in 2004 for all study sites (Table 3-12).

Although no persistent trend was observed across experimental sites for Mg and K, we observed a 10% higher concentration of AB-DTPA-extractable K and 30% decrease of AB-DTPA-extractable Mg when data from all sites were combined. The increase in soil K is desirable for turfgrasses. The higher K might be a result of the combination of K presented in recycled water (13 ppm) and the possible application of potassium fertilizers. The cation exchange site occupied by Mg and Mn was reduced, reflecting the replacement of these elements with Na.

Exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR): Both ESP and SAR are indicators of sodium hazard for soil. Exchangeable sodium percentage is calculated by dividing exchangeable sodium by cation exchange capacity (CEC). Sodium adsorption ratio is reported as a special ratio of sodium to calcium plus magnesium of saturated paste extraction. Soil hydraulic conductivity of a given soil decreases with increasing ESP. However, the exact levels of ESP at which soil hydraulic conductivity is appreciably reduced vary with soil type, soil clay content, soil bulk density, and salt concentrations of irrigation water or soil solution. The soil sensitivity to ESP increases with high clay content, high soil bulk density, and low irrigation water salinity.

A soil with ESP value of 12 or greater is classified as sodic soil with excessive sodium in soil particles. However, for fine textured soil and heavy traffic areas, an ESP > 6 - 9 will start to impose sodic effects, such as reduced soil hydraulic conductivity, soil sealing, and reduced water infiltration. For 2:1 clays, an ESP as low as 6% can impose sodic effect. (Note: A 2:1 clay consists of an octahedral sheet sandwiched between two tetrahedral sheets, and examples are illite, smectite, attapulgite, and montmorillonite soils. 2:1 clays are much more prone to sodium effect on soil structural deterioration than 1:1 clays.)

All samples collected from the 10 sites in 2004 had an average ESP of 2.65%. All sites except Park Hill Golf Course showed significant increases in ESP and SAR after 5 years irrigation with recycled water (Table 3-12). When data from all sites were combined, the average soil exchangeable sodium percentage increased from 2.65% in 2004 to 5.35% in 2009 (Table 2). Likewise sodium adsorption ratio (SAR) increased from 2.89 to 5.32.

On all park sites, soils were sampled for 2 depths (0-20 and 20-40 cm). At the three golf courses, however, soils were sampled to 1 m deep at 20 cm increments. The deeper sampling provided us the opportunity to examine soil profile changes more comprehensively. The ESP and SAR changes along the soil profile (from 1 to 100 cm) showed different patterns of change among the golf courses. The site description and management background information provided by golf course managers are very beneficial in assisting us to evaluate the potential relationship between management, site characteristics, and ESP and SAR changes along the soil profile.

At Denver Country Club, the increases in ESP and SAR from 2004 to 2009 at 0-20 cm and 20-40 cm depths were not statistically significant (Figure 1 A). The increase became significant from 40-60 cm, 60-80 cm, and 80-100 cm. The changes along the soil profile reflect the effectiveness of soil types, environmental conditions, and management that is conducive to leaching of sodium at Denver Country Club. The course was built on the alluvial sand deposits developed in association with Cherry Creek; soils at Denver Country Club are mostly sand or sandy and drain very well. Turf managers at DCC have employed aggressive aeration and gypsum addition programs. They generally aerate 1-2 times a year for fairways and apply about 30 lb/1000 sq ft/year gypsum following aerifications. Additional gypsum is also injected to irrigation water through a "Diamond K" injection system. Apparently, the aggressive soil aerification and gypsum addition plus the dominant presence of sandy soil effectively prevented a significant increase in soil ESP at the shallow soil depths (0-40 cm). This layer of soil (0-40 cm below soil surface) is important since most of the turfgrass roots are present in this layer. The effectiveness of gypsum treatment in reducing ESP may be less effective in fine textured soil and heavy traffic areas, because good permeability and drainage allow a turfgrass manager to leach excessive sodium from the rootzone by periodic gypsum treatment followed by leaching. Fine textured soils are slow to infiltrate, percolate and difficult to leach. To mitigate some of the negative issues associated with the high SAR of recycled water, the installation of drain tiles in predominantly fine textured soils would aid the drainage effectiveness.

At City Park Golf Course, the increases in ESP and SAR from 2004 to 2009 were significant at 0-60 cm depths; especially at 0-20 and 20-40 cm depths where the increase in ESP was tripled. The ESP and SAR increases became non-significant at 60 -80 cm and 80-100 cm. The changes in ESP and SAR were related to the quality of recycled water, the soil types, and management. City Park has fine textured soil (clay loam to clay). The ability of soil to retain cations is much higher for fine-textured soils compared to sandy soil. More sodium salts are required to raise the ESP of clay soil. As a result, ESP in fine-textured soil increases more slowly when compared to sandy soil. However, fine textured soil is more sensitive to increased ESP, and the correction of high ESP in clay soil is more difficult and takes longer than in sandy soil. City Park Golf Course is a public course. Aggressive aerification and calcium topdressing programs were not as feasible budgetary wise and we were not aware of any topdressing with gypsum being done. The high levels of sodium concentration in recycled water along with the fine textured soil, less aggressive aeration, and the lack of calcium addition resulted in increased soil ESP, especially at the shallow soil depths (Figure 1 B). In addition, we also observed an increase in soil EC from 2004 to 2009 (Table 5).

Park Hill Golf Course was previously irrigated with well water with high EC (1.17 mmho/cm) and SAR (2.44). The average soil SAR and ESP prior to recycled water irrigation was 5.4 and 5.2, respectively. Five years of irrigation with recycled water did not result in changes in soil ESP and SAR (Figure 1 C). The superintendant indicated that they have applied an aggressive aerification program. They have regularly injected acid and calcium products through the irrigation system. The fact that the soil texture in Park Hill Golf Course is mainly loamy sand and sandy loam may also have helped to prevent the further increase of soil ESP and SAR. Yet, due to the historic long-term exposure to poor quality well-water for irrigation, we observed salt injuries on many conifer trees and some stresses in turfgrasses.

When all data from the other park sites (Swansea Park, Dunham Park, Schaefer Park, City Park, and Washington Park) were combined, ESP increased from 2.5 to 5.2 at 0-20 cm depth and from 2.1 to 6.5 at 20-40 cm depth.

Our results suggested sodicity (as gauged by soil ESP) is more a concern than salinity (as gauged by soil EC) on the testing sites, since ESP and SAR are two parameters that exhibited the most significant changes from 2004 to 2009. Soil and /or water amendments with calcium or sometimes magnesium based products may help to displace Na and reduce ESP and SAR, especially at the surface depth. These treatments may be more effective in sandy soil than in clay soil. Continued increases of ESP and SAR could potentially cause long-term reductions in soil hydraulic conductivity in soils with high clay content. More research is needed in developing low cost, pre-irrigation water treatment strategies to decrease sodicity.

Soil B and Cl:

Mass (1978) provides criteria for B content in soils as follow: sensitive plants (such as some fruit trees) would show growth decline as soil B exceeds 0.5-1.0 mg/kg. Moderately sensitive plants will start to decline when soil B exceeds 1.0-2.0 mg/kg. Kentucky bluegrass can tolerate soil B content at 2.0-4.0 mg/kg.

The recycled water from Denver Water's recycled system contains about 0.27 ppm boron (Table 1). All soil samples collected from the 10 sites in 2009 had an average soil B content of 0.6 mg/kg and the range of B content was from 0.13 to 0.8 mg/kg, below levels that adversely affect plants (Table 2- 12). This average level of soil B content was similar to what was measured in 2004 (0.67 mg/kg). However, at Park Hill Golf Course, soil B content reduced from 2.0 mg/kg (which could result in decline of moderately sensitive plants) in 2004 to 0.8 mg/kg in 2009. In contrast, at Dunham and Swansea Parks, there was an increase in B content, although at a level well below the adverse effects.

Recycled water typically contains about 50 -200 ppm chloride. Chloride is a negatively charged ion and cannot be held up by the soil CEC sites. Therefore, chloride is highly mobile in soil, and will often move with the wetting front during infiltration and percolation. In addition to contributing to the total soluble salt concentration of irrigation water, chloride may have direct ion effects on plants when absorbed by roots and leaves, especially some trees and shrubs. Despite the fact that recycled water contains significant amount of Cl, we did not observe significant increases in soil Cl content from 2004 to 2009 on all sites except Washington Park, Dunham Park, and Denver Zoo. All samples combined, an average soil Cl content was 34 mg/kg in 2009 which is similar to the Cl content in 2004 (Table 2).

Soil P and nitrate-N: There are concerns that the nutrients left in recycled water can make their way into the ground or surface water supplies, when recycled water is used for landscape irrigation. Specific concerns are that nitrate will move through the soil structure and cause ground water contamination, and that phosphorus will run off into surface waters. As we discussed earlier, the deeper sampling at golf courses provided opportunities to examine nitrate and phosphorous movement in the soil profiles. Soil NO_3-N and P content at various soil depths from sites that are under years of recycled water irrigation would help to improve understanding of these issues and better address such environmental concerns.

Soil nitrate data from three golf courses are presented in Fig. 2. Nitrate–N content deceased significantly with soil depth, suggesting that turfgrass root system was very effective for nitrate uptake. Nitrate levels beyond the turfgrass rootzone were low in 2009 samples (< 3 mg kg^{-1}), well below the EPA standard for potable water quality (10 mg kg^{-1}). This indicates that dense, actively growing, and well-managed turfgrass areas are among the best bio-filtration systems available for removal of excess nitrate.

Phosphorus levels were, in general, lower at depths deeper than 20 cm (Figure 3), this is because phosphorus is often considered immobile (Bray, 1954). However, movement of phosphorus through the soil structure is possible in sandy soils. With the AB-DTPA test, the critical values for determining soil P levels (to 8- inch soil depth) has been set as low (0-3 ppm), medium (4-7 ppm), high (8-11 ppm), and very high (exceeding 11 ppm). Of all the soils sampled both in 2004 and 2009, 44% were ranked in the very high P category (>11 ppm) (Appendix A and B). 67% of the 0-20 cm soil samples were ranked in the very high P category. Although recycled water also contains P, there was not an increase in soil P over 5 years with recycled water irrigation for all sites except Schafer Park.

Recycled waters contain macro-nutrients [nitrogen (N), phosphorus (P), and potassium (K)] essential for plant growth, to figure significantly in a fertilization program. The economic value of these nutrients can be substantial. When recycled water is used for irrigation, regular testing will allow adjustment in N and P applications. For example, an N content in recycled water of 10 ppm adds 27 lb nitrogen per acre with each acre-foot of irrigation water. This amount of N should be deducted from the fertilization program.

When compared to agricultural sites, a properly managed turfgrass site would have less problem with nitrate leaching down into groundwater, or phosphorus running off to surface waters if best management practices are utilized, including fertilizing in several smaller applications instead of one large one.

Irrigation Uniformity

The irrigation precipitation rate along with irrigation distribution uniformity (DU) and Christiansen's coefficient of irrigation uniformity (CU) for all sites are presented in **Appendix C.** For urban landscape industry, DU is much more commonly used than CU due to the calculation simplicity of DU. DU is a measure of how evenly water is applied during irrigation. DU is expressed as a percentage between 0 and 100%, although it is virtually impossible to attain

100% in practice. DUs of less than 70% are considered poor, DUs of 70 - 90% are good, and DUs greater than 90% are excellent. Although, we did not find statistical significance of DU among different landscape facilities, the two sites that had slightly lower DU than 70% uniformity were at public parks. Denver Country Club and City Park Golf Course showed excellent irrigation uniformity. All other sites had good irrigation uniformity. Clear relationships between DU and CU vs. measured soil parameters were not observed. The high precipitation in 2009 might have suppressed such relationships.

Soil Compaction

In general, when penetrometer readings are greater than 300-400 psi, plant root growth would be slowed due to their difficulty in penetrating the soil. Plant roots are frequently found only in soil where compaction is less than 300-400 psi. All the penetration readings at City Park Golf Course, Denver Country Club, Washington Park, and Denver Zoo were well below 300 psi. For all 10 landscape facilities, greater soil resistance was observed at 3 inches below soil surface than 1 inch below soil surface. Compaction problems existed at 3 inch depth at Schaefer Park, Dunham Park, Fairways 2 and 10 at Park Hill Golf Course, 2 sample locations at Bruce R. Middle School playground. Only one sampling location at City Park and Swansea Park showed compaction problem.

SUMMARY AND RECOMMENDATIONS

The issues surrounding recycled water irrigation are complex. Municipalities and communities promote water reuse in landscape irrigation for regional water resource and environment sustainability. Water reuse in urban landscapes is a powerful means of water conservation and nutrient recycling, thereby reducing the demands of freshwater and mitigating pollution of surface and ground water. In the meantime, it is necessary for landscape managers to practice sustainable landscape management to minimize potential problems. History and current experience illustrate that use of water with high sodium absorption ratio for irrigation will increase the potential to degrade soil unless specific infrastructure and management practices are implemented.

In this experiment, the average soil exchangeable sodium percentage increased from 2.65% in 2004 to 5.35% in 2009. Likewise sodium adsorption ratio (SAR) increased from 2.89 to 5.32. Results suggest that sodicity is the primary concern on these landscape soils when recycled water is used for irrigation. An ESP or SAR value of 12 or greater indicates a sodic soil with excessive sodium on soil particles. However, for 2:1 clays, a soil ESP as low as 6% can impose sodic effect, causing soil aggregates to deteriorate into smaller particles. Further studies are needed to determine if these parameters would continue to increase or stabilize. Continued increase in sodicity can lead to soil structural deterioration and clay particle dispersion.

Soil structural deterioration will reduce leaching effectiveness and increase salinity problems in the future. To correct sodicity, leaching alone is not sufficient, relatively soluble Ca sources need to be regularly applied to provide displacement ions for Na on soil CEC sites. More research is needed to develop low cost, pre-irrigation water treatment strategies and on-site landscape management techniques to decrease sodicity.

The sites that are most susceptible to sodium and salinity are sites with expanding clay, shallow water table, poor drainage, and great soil compaction. Management practices that reduce water table, cap the topsoil with sand (especially for sports practice fields), improve drainage, and reduce compaction have been recommended in the literature to reduce the potential sodium problems (Lazarova and Asano, 2005). The primary salinity management tool is leaching. However, excessive leaching may increase water table. A rising water table can bring salts up into the root zone.

In the 10 water-reuse sites that we studied, many sites have sandy soil texture, which have the advantage of reducing salinity or delaying the occurrence of soil salinity problems. Based on our previous experiments and literature review, the following are some of the best management practices that may be employed when appropriate:

<u>Water and soil quality monitoring:</u>

- ✓ Regular monitoring of water and soil quality using a soil and water testing program. Water quality must also be evaluated thoroughly to develop appropriate management strategies.
- ✓ Due to the relatively high levels of phosphorous and nitrogen in recycled water, storage of recycled water in onsite irrigation pond could lead to increased algae populations, causing water quality degradations, including increasing water pH and turbidity. If possible, a direct connection of recycled water to the irrigation sprinkler system will reduce algae issues and subsequent problems.

  If storage pond is essential, then smaller irrigation pond that facilitates faster turnover with a good aeration system would be preferred.

Irrigation:

- ✓ Provide adequate leaching and sufficient drainage to remove excess Na and salts from the root zone;
- ✓ Careful irrigation based on evapotranspiration and leaching requirements;
- ✓ On sites where shallow water tables may rise to cause salt accumulation in root zone, it may be helpful to investigate means of lowering the water table, possibly add additional drainage lines with possible sump pumps to deposit the excess rising water into drainage canals.
- ✓ Blending conventional water with recycled water or use the two sources in rotation.

Compaction controls:

- ✓ More intensive cultivation programs (deep aeration and water injection) to maintain oxygen diffusion and water movement;
- ✓ More vigorous traffic control programs.

Fertilization:

- ✓ Reduced nitrogen and phosphorous fertilization, accounting for the fertilizer value present in recycled water;
- ✓ Fertilizing based on soil chemical tests to alleviate nutrient imbalance;

Amendments:

- ✓ Adding chemical amendments (e.g. gypsum or other soluble calcium products) to soil or injecting into irrigation water to reduce sodicity problems.

- ✓ Modifying rootzone for better drainage and salt leaching. Turfgrasses grown on a well-drained sand based root zone are less susceptible to soil sodicity problems than those grown on clay soils.

Plant selection:

- ✓ Replacing susceptible plants with adapted, salt tolerant species and cultivars;
- ✓ Maintain healthy plants – healthy plants withstand environmental stresses better.

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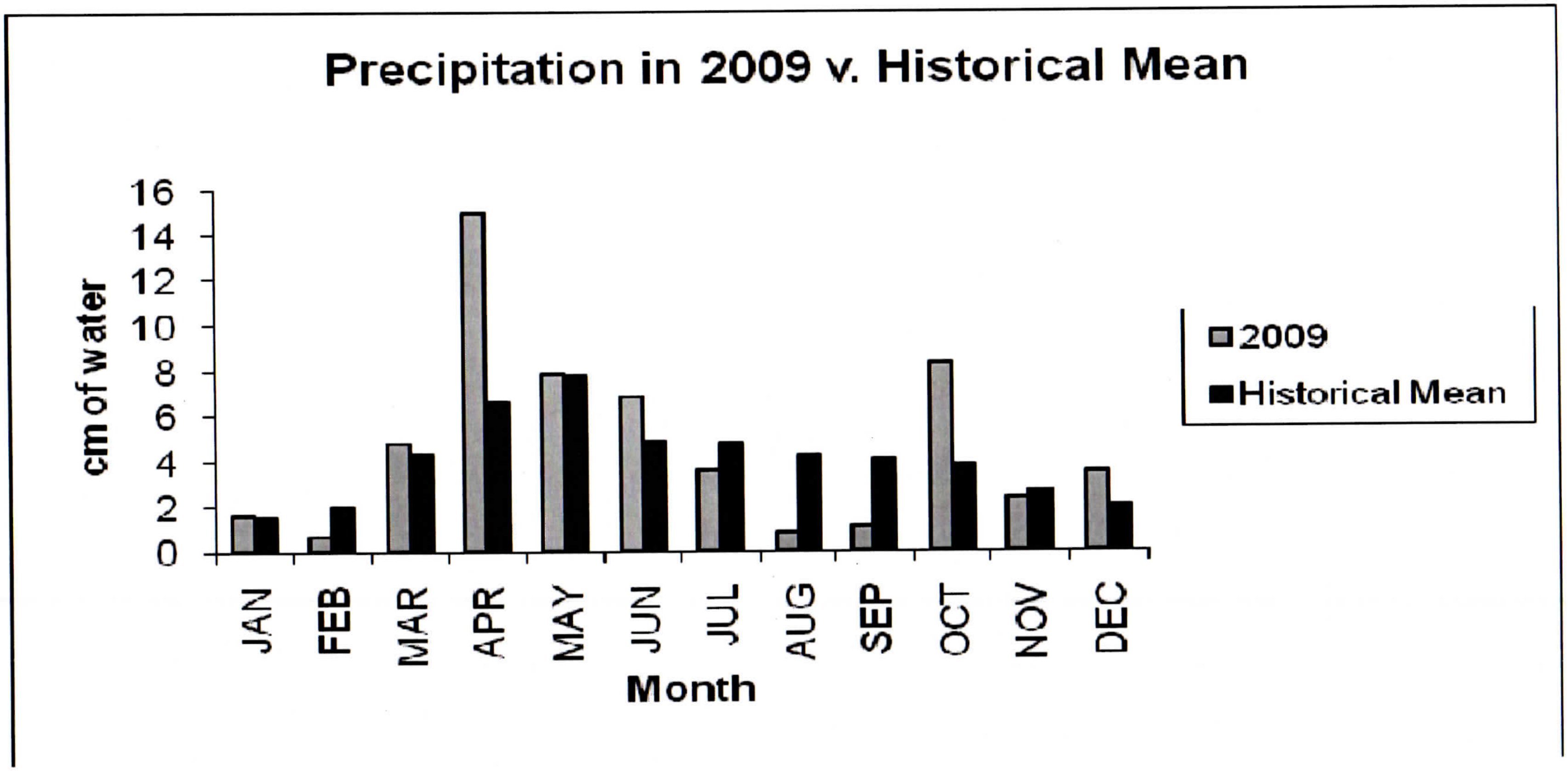


Figure 1. Monthly precipitation in 2009 compared to historical average.

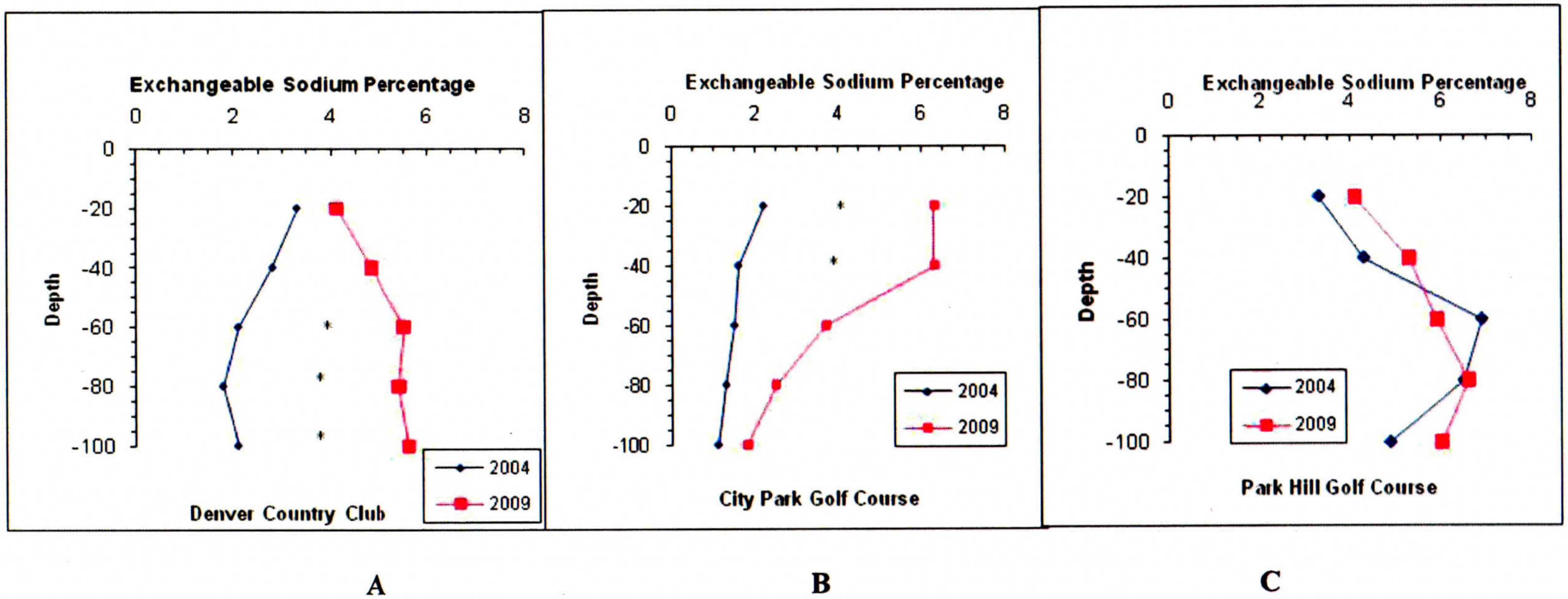


Figure 2: Exchangeable sodium percentage at five soil depths at the initiation (2004) and 5 years after recycled water irrigation (2009). Each data point is the mean of 3 replications. Asterisks denote a significant difference between 2004 and 2009 samples at $P < 0.05$.

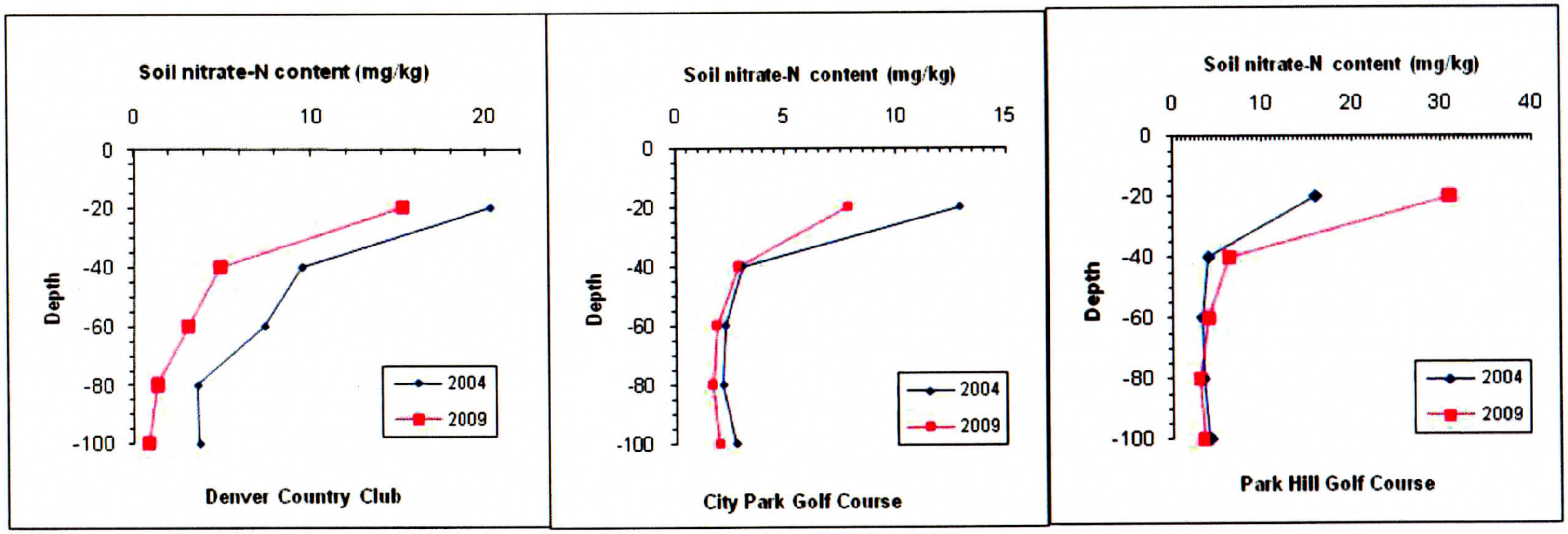


Figure 3: Soil nitrate-N content at five soil depths at the initiation (2004) and 5 years after recycled water irrigation (2009). Each data point is the mean of 3-4 replications. No significant difference was found between 2004 and 2009 samples at $P <$ 0.05.

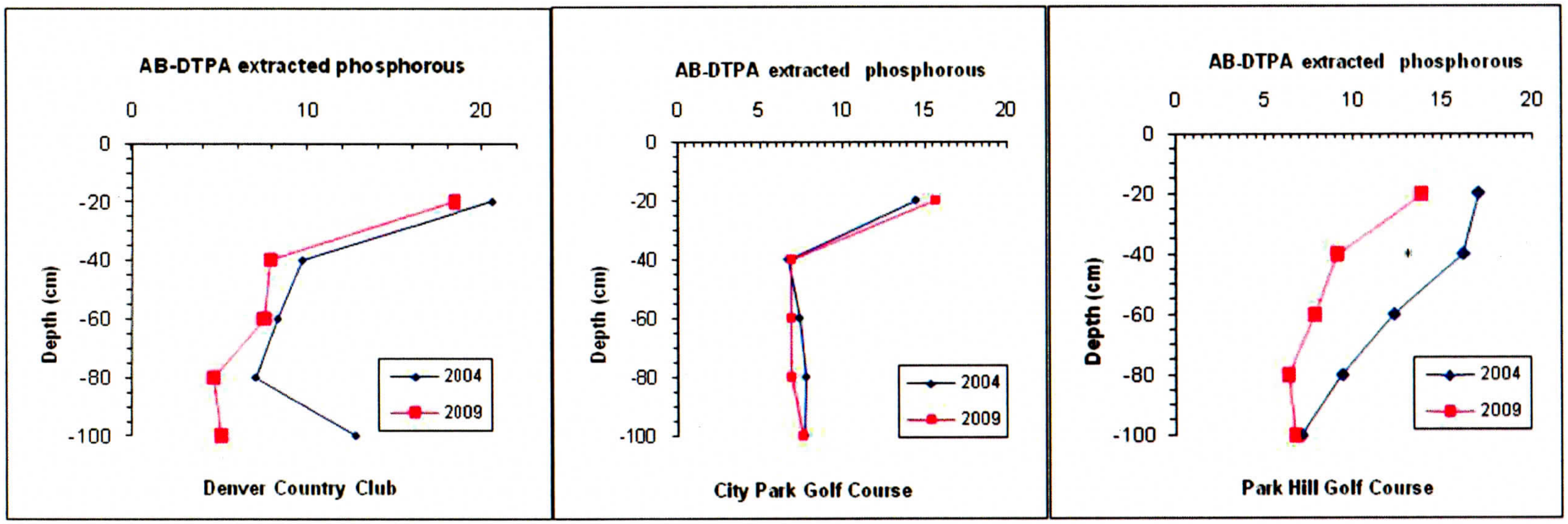


Figure 4: Soil phosphorous content (AB-DTPA extracted) at five soil depths at the initiation (2004) and 5 years after recycled water irrigation (2009). Each data point is the mean of 3-4 replications. Asterisks denote a significant difference between 2004 and 2009 samples at individual depths at $P < 0.05$.

Table 1. Average water quality values of recycled water vs. potable water provided by Denver Water.

Water parameter	Recycled water	Potable water
pH	7.16	-
NH_4-N (ppm)	0.25	-
NO_3-N (ppm)	11.8	0.1
Total P	0.15	-
Total dissolved solids (ppm)	-	187
Electrical conductivity (EC) (dS m^{-1})	0.86	0.23
Ca (ppm)	50	-
Mg (ppm)	12	-
Na (ppm)	121	21
Cl (ppm)	106	29
Bicarbonate (ppm)	92	-
Sulfate (ppm)	142	56
Boron (ppm)	0.27	-
K (ppm)	13	-
Fe (ppm)	0.22	-
Sodium absorption ratio	1.7	-

Table 2. Mean soil chemical properties from the ten landscape facilities at all depths at the initiation (baseline) and 5 years after recycled water irrigation (soil were sampled to 1 m at golf courses and 0.4 m at parks).

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	20.8	18.5
pH	7.26b	7.55a
SOM (%)	2.0	2.0
Electrical conductivity (EC) dS m^{-1})	0.88	0.84
Ca (mg kg^{-1})	3.0	3.1
Mg (mg kg^{-1})	1.3a	0.9b
Na (mg kg^{-1})	3.9b	6.5a
Mn (mg kg^{-1})	2.3a	1.4b
Cu (mg kg^{-1})	4.4	4.0
Zn (mg kg^{-1})	13.9	13.0
Extractable P (mg kg^{-1})	13.7	11.9
NO3-N	6.2	6.2
Boron (mg kg^{-1})	0.67	0.60
Cl (mg kg^{-1})	27.7	34.0
K (mg kg^{-1})	228b	251a
K paste	0.58b	0.86a
Exchangable sodium percentage (ESP)	2.7b	5.3a
Sodium absorption ratio	2.8b	5.3a

The mean followed by a letter "a" is significantly higher than the mean followed by a letter "b" for individual parameters at $P < 0.05$.

Table 3. Mean soil chemical properties from Bruce Randolph Middle School at 0-20 and 20-40 cm soil depths at the initiation (baseline) and 5 years after recycled water irrigation.

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	18.7	20.7
pH	7.58b	7.90a
SOM (%)	1.28	1.15
Electrical conductivity (EC) dS m^{-1})	1.15	0.65
Ca (meq L^{-1})	6.0	2.3
Mg (meq L^{-1})	1.8	0.5
Na (meq L^{-1})	4.4	5.1
Mn (mg kg^{-1})	2.87	1.65
Cu (mg kg^{-1})	3.85	2.58
Zn (mg kg^{-1})	6.4	4.3
Fe (mg kg^{-1})	29.4	25.9
Extractable P (mg kg^{-1})	30.3	19.5
NO_3-N	1.5b	12.7a
Boron (mg kg^{-1})	0.43	0.35
Cl (mg kg^{-1})	37.95	20.02
K (mg kg^{-1})	206	127
K paste	0.77	0.62
Exchangable sodium percentage (ESP)	2.37b	4.4a
Sodium absorption ratio	2.45b	4.55a

The mean followed by a letter "a" is significantly higher than the mean followed by a letter "b" on the same row at $P < 0.05$.

Table 4. Mean soil chemical properties from City Park at 0-20 and 20-40 cm soil depths at the initiation (baseline) and 5 years after recycled water irrigation.

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	24.1a	15.8b
pH	7.0b	7.35a
SOM (%)	2.7	2.7
Electrical conductivity (EC) dS m^{-1})	0.63b	0.93a
Ca (meq L^{-1})	2.1b	3.64a
Mg (meq L^{-1})	1.03	1.29
Na (meq L^{-1})	2.95b	7.1a
Mn (mg kg^{-1})	2.93	2.28
Cu (mg kg^{-1})	3.26	4.24
Zn (mg kg^{-1})	9.8	13.2
Fe (mg kg^{-1})	18.2b	24.8a
Extractable P (mg kg^{-1})	4.82	4.87
NO3-N	5.26b	8.67a
Boron (mg kg^{-1})	0.47a	0.13b
Cl (mg kg^{-1})	22.5	26.8
K (mg kg^{-1})	222b	314a
K paste	0.33b	0.65a
Exchangable sodium percentage (ESP)	2.3b	4.8a
Sodium absorption ratio	2.4b	4.8a

The mean followed by a letter "a" is significantly higher than the mean followed by a letter "b" on the same row at $P < 0.05$.

Table 5. Mean soil chemical properties from City Park Golf Course at all depths at the initiation (baseline) and 5 years after recycled water irrigation (soil were sampled to 1 m at 20 cm increments).

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	25.7	32.8
pH	7.42b	7.59a
SOM (%)	1.48	1.8
Electrical conductivity (EC) dS m^{-1})	0.75b	1.12a
Ca (meq L^{-1})	3.4b	5.9a
Mg (meq L^{-1})	1.33	1.47
Na (meq L^{-1})	2.55b	6.58a
Mn (mg kg^{-1})	1.70a	1.21b
Cu (mg kg^{-1})	3.0b	3.8
Zn (mg kg^{-1})	5.8	5.7
Fe (mg kg^{-1})	16.3b	24.0a
Extractable P (mg kg^{-1})	8.82	8.80
NO3-N	4.58	3.6
Boron (mg kg^{-1})	0.30	0.53
Cl (mg kg^{-1})	24.5	26.3
K (mg kg^{-1})	239b	305a
K paste	0.43b	0.69a
Exchangable sodium percentage (ESP)	1.55b	4.12a
Sodium absorption ratio	1.63b	4.12a

The mean followed by a letter "a" is significantly higher than the mean followed by a letter "b" on the same row at $P < 0.05$.

Table 6. Mean soil chemical properties from Denver Country Club at all depths at the initiation (baseline) and 5 years after recycled water irrigation (soil were sampled to 1 m at 20 cm increments).

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	18.0	16.0
pH	7.26b	7.57a
SOM (%)	1.41	0.90
Electrical conductivity (EC) dS m^{-1})	1.1a	0.7b
Ca (meq L^{-1})	3.8	2.2
Mg (meq L^{-1})	1.65a	0.61b
Na (meq L^{-1})	4.0	4.9
Mn (mg kg^{-1})	1.45a	0.78b
Cu (mg kg^{-1})	2.8	3.4
Zn (mg kg^{-1})	6.8	8.7
Fe (mg kg^{-1})	14.5	18.3
Extractable P (mg kg^{-1})	11.2	8.7
NO_3-N	10.2a	5.1b
Boron (mg kg^{-1})	0.48	0.35
Cl (mg kg^{-1})	31.3	23.4
K (mg kg^{-1})	163	129
K paste	0.85	0.91
Exchangable sodium percentage (ESP)	2.4	5.1
Sodium absorption ratio	2.54	5.04

The mean followed by a letter “a” is significantly higher than the mean followed by a letter “b” on the same row at $P < 0.05$.

Table 7. Mean soil chemical properties from Denver Zoo at 0-20 and 20-40 cm soil depths at the initiation (baseline) and 5 years after recycled water irrigation.

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	29.3a	19.7b
pH	7.78b	7.97a
SOM (%)	1.78b	3.52a
Electrical conductivity (EC) dS m^{-1})	0.55b	0.88a
Ca (meq L^{-1})	2.0	3.6
Mg (meq L^{-1})	0.9	1.2
Na (meq L^{-1})	1.8b	6.5a
Mn (mg kg^{-1})	4.7a	2.7b
Cu (mg kg^{-1})	4.3	4.3
Zn (mg kg^{-1})	7.8	10.6
Fe (mg kg^{-1})	23.3	16.5
Extractable P (mg kg^{-1})	22.1	16.1
NO_3-N	2.40	6.58
Boron (mg kg^{-1})	0.66	0.65
Cl (mg kg^{-1})	18.9b	29.1a
K (mg kg^{-1})	420	453
K paste	0.9	1.28
Exchangable sodium percentage (ESP)	1.38b	4.33a
Sodium absorption ratio	1.47b	4.28a

The mean followed by a letter "a" is significantly higher than the mean followed by a letter "b" on the same row at $P < 0.05$.

Table 8. Mean soil chemical properties from Dunham Park at 0-20 and 20-40 cm soil depths at the initiation (baseline) and 5 years after recycled water irrigation.

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	15.4	17.1
pH	6.57b	7.07a
SOM (%)	3.0	2.8
Electrical conductivity (EC) dS m^{-1})	0.55b	0.97a
Ca (meq L^{-1})	1.38	1.95
Mg (meq L^{-1})	0.63	0.62
Na (meq L^{-1})	3.1	8.7
Mn (mg kg^{-1})	1.76a	1.22b
Cu (mg kg^{-1})	9.9	8.8
Zn (mg kg^{-1})	32	43
Fe (mg kg^{-1})	54.9	50.8
Extractable P (mg kg^{-1})	15.3	18.6
NO_3-N	5.56a	2.27b
Boron (mg kg^{-1})	0.28b	0.65a
Cl (mg kg^{-1})	18.6b	25.2a
K (mg kg^{-1})	160b	227a
K paste	0.37b	1.03a
Exchangable sodium percentage (ESP)	3.1	7.9a
Sodium absorption ratio	3.2b	7.9a

The mean followed by a letter "a" is significantly higher than the mean followed by a letter "b" on the same row at $P < 0.05$.

Table 9. Mean soil chemical properties from Park Hill Golf Course at all depths at the initiation (baseline) and 5 years after recycled water irrigation (soil were sampled to 1 m at 20 cm increments).

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	16.2	11.2
pH	7.8b	8.0a
SOM (%)	1.27	1.17
Electrical conductivity (EC) dS m^{-1})	1.1a	0.8b
Ca (meq L^{-1})	2.42	2.59
Mg (meq L^{-1})	1.56	0.92
Na (meq L^{-1})	6.9	5.8
Mn (mg kg^{-1})	1.8a	0.9b
Cu (mg kg^{-1})	2.2	1.5
Zn (mg kg^{-1})	5.6	2.9
Fe (mg kg^{-1})	9.7	11.3
Extractable P (mg kg^{-1})	12.2	8.6
NO_3-N	5.89	9.54
Boron (mg kg^{-1})	2.0a	0.8b
Cl (mg kg^{-1})	34.7a	19.7b
K (mg kg^{-1})	259	208
K paste	0.48	0.75
Exchangable sodium percentage (ESP)	5.2	5.5
Sodium absorption ratio	5.4	5.4

The mean followed by a letter "a" is significantly higher than the mean followed by a letter "b" on the same row at $P < 0.05$.

Table 10. Mean soil chemical properties from Schaefer Park at 0-20 and 20-40 cm soil depths at the initiation (baseline) and 5 years after recycled water.

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	22.5	22.1
pH	7.0b	7.4a
SOM (%)	3.65	3.18
Electrical conductivity (EC) dS m^{-1})	0.9	1.1
Ca (meq L^{-1})	3.5	3.0
Mg (meq L^{-1})	1.5	0.8
Na (meq L^{-1})	3.5b	8.8a
Mn (mg kg^{-1})	2.2a	0.98b
Cu (mg kg^{-1})	8.0	6.8
Zn (mg kg^{-1})	21.1	17.6
Fe (mg kg^{-1})	30.0	26.7
Extractable P (mg kg^{-1})	17.7b	26.0a
NO_3-N	8.6a	3.1b
Boron (mg kg^{-1})	0.55	0.93
Cl (mg kg^{-1})	29.4	27.3
K (mg kg^{-1})	226b	353a
K paste	0.55b	1.08a
Exchangable sodium percentage (ESP)	2.2b	6.5a
Sodium absorption ratio	2.3b	6.4a

The mean followed by a letter "a" is significantly higher than the mean followed by a letter "b" on the same row at $P < 0.05$.

Table 11. Mean soil chemical properties from Swansea Park at 0-20 and 20-40 cm soil depths at the initiation (baseline) and 5 years after recycled water irrigation.

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	17.0	15.5
pH	6.5b	7.1a
SOM (%)	2.4	2.3
Electrical conductivity (EC) dS m^{-1})	0.8	0.9
Ca (meq L^{-1})	2.52	2.0
Mg (meq L^{-1})	1.3	0.7
Na (meq L^{-1})	4.0b	8.1a
Mn (mg kg^{-1})	2.43	2.17
Cu (mg kg^{-1})	5.55	5.06
Zn (mg kg^{-1})	17.8	19.9
Fe (mg kg^{-1})	39.4	36.3
Extractable P (mg kg^{-1})	12.6	17.3
NO_3-N	6.4a	3.6b
Boron (mg kg^{-1})	0.3b	0.62a
Cl (mg kg^{-1})	25.8	23.4
K (mg kg^{-1})	178	201
K paste	0.48b	0.87a
Exchangable sodium percentage (ESP)	2.9b	7.9a
Sodium absorption ratio	3.0b	7.8a

The mean followed by a letter "a" is significantly higher than the mean followed by a letter "b" on the same row at $P < 0.05$.

Table 12. Mean soil chemical properties from Washington Park at 0-20 cm soil depth at the initiation (baseline) and 5 years after recycled water irrigation.

Soil Parameter	Baseline	5 years after the initiation of recycled water irrigation
Cation Exchange Capacity (meg/100g)	23.3	12.6
pH	6.8b	7.0a
SOM (%)	4.1	4.3
Electrical conductivity (EC) dS m^{-1})	0.7b	1.0a
Ca (meq L^{-1})	2.6	2.7
Mg (meq L^{-1})	1.1	1.0
Na (meq L^{-1})	3.2b	7.8a
Mn (mg kg^{-1})	4.2a	1.6b
Cu (mg kg^{-1})	10.7	7.5
Zn (mg kg^{-1})	61	53
Fe (mg kg^{-1})	40.7	42
Extractable P (mg kg^{-1})	22.9	14.6
NO_3-N	6.8	6.5
Boron (mg kg^{-1})	0.49a	0.32b
Cl (mg kg^{-1})	24.5b	47.6a
K (mg kg^{-1})	273	352
K paste	0.68b	1.25a
Exchangable sodium percentage (ESP)	2.2b	5.9a
Sodium absorption ratio	2.4b	5.8a

The mean followed by a letter "a" is significantly higher than the mean followed by a letter "b" on the same row at $P < 0.05$.

APPENDIX A (Data from 2004) (Datasheet #1 -#9)
Soil Baseline Study Datasheet #1

Facility	Site	depth	---Paste--- pH	---Paste--- EC mmhos/cm	% OM	AB-DTPA ppm NO$_3$-N	P	K	Zn	Fe	Mn	Cu	Texture Estimate
Swansea park	1	0-20	7.0	0.8	3.1	12.8	19.6	270	20.5	46.6	3.28	4.71	Sandy Loam
Swansea park	1	20-40	6.9	0.4	0.9	2.5	15.6	181	9.5	19.0	2.75	4.41	Sandy Loam
Swansea park	2	0-20	6.4	0.9	4.4	10.2	16.8	184	31.7	68.7	2.19	7.94	Sandy Loam
Swansea park	2	20-40	6.6	0.9	1.0	3.4	7.8	118	12.9	18.5	1.72	5.84	Sandy Loam
Swansea park	3	20-40	6.6	0.8	3.7	6.9	9.3	208	19.3	60.0	2.39	4.69	Sandy Loam
Swansea park	3	0-20	6.4	1	1.3	2.8	6.2	108	12.7	23.5	2.23	5.72	Sandy Loam
Dunham park	1	20-40	6.4	0.5	3.4	8.0	16.8	181	37.5	90.0	1.68	10.6	Sandy Loam
Dunham park	1	0-20	6.5	0.5	1.2	1.9	14.3	114	31.7	32.6	1.89	10.8	Sandy Loam
Dunham park	2	20-40	6.5	0.6	5.0	7.6	22.4	216	43.1	84.1	1.90	11.0	Sandy Loam
Dunham park	2	0-20	6.8	0.4	1.0	2.0	12.4	130	19.6	21.4	1.69	7.74	Sandy Loam
Dunham park	3	0-20	6.5	0.7	5.9	10.8	16.8	200	40.1	73.3	1.52	11.4	Sandy Loam
Dunham park	3	20-40	6.7	0.6	1.7	3.0	9.3	122	22.4	27.9	1.90	7.93	Sandy Loam
Schaefer park	1	0-20	6.4	1.1	4.1	15.9	32.4	314	27.6	44.5	3.27	8.92	Sandy Loam
Schaefer park	1	20-40	6.8	1.3	1.2	6.3	14.9	180	9.92	14.5	2.45	3.89	Sandy Loam
Schaefer park	2	0-20	6.7	0.7	7.5	8.9	19.9	241	24.6	52.9	2.12	7.56	Sandy Loam
Schaefer park	2	20-40	6.9	0.8	1.5	2.7	11.2	200	9.94	16.7	1.77	3.73	Sandy Loam
Schaefer park	3	0-20	7.4	0.7	5.9	14.1	19.3	226	28.4	37.4	2.26	15.0	Sandy Loam
Schaefer park	3	20-40	7.6	0.7	1.7	3.8	8.7	196	26.2	14.0	1.27	8.70	Sandy Loam
Bruce R School	1	0-20	7.7	0.8	0.9	1.1	26.2	183	4.30	15.3	1.89	2.91	Sandy Loam
Bruce R School	1	20-40	7.5	1	0.6	1.0	9.3	133	7.82	8.42	1.10	5.57	Sandy Loam
Bruce R School	2	0-20	7.4	2.2	2.3	1.3	48.6	255	10.2	64.9	6.01	4.98	Sandy Loam
Bruce R School	2	20-40	7.4	1.8	1.1	1.6	13.7	229	5.09	25.4	3.02	3.39	Sandy Loam

Note: Denver CC = Denver Country Club; Bruce R School = Bruce Randolph Middle School; Park Hill GC = Park Hill Golf Course, City Park GC = City Park Golf Course.

Datasheet #2

Facility	Site	depth	---Paste--- pH	EC mmhos/cm	% OM	AB-DTPA ppm NO3-N	P	K	Zn	Fe	Mn	Cu	Texture Estimate
Bruce R School	3	0-20	7.6	0.6	2.5	2.7	78.0	249	9.23	57.4	4.47	4.80	Sandy Loam
Bruce R School	3	20-40	7.9	0.5	0.3	1.3	6.2	188	1.96	4.84	0.756	1.47	Loamy Sand
Park Hill GC	1	0-20	7.7	1.0	2.4	11.1	10.6	151	4.95	16.9	2.69	2.95	Loamy Sand
Park Hill GC	1	20-40	7.8	0.5	0.6	2.7	8.7	155	2.66	7.24	2.06	2.88	Loamy Sand
Park Hill GC	1	40-60	7.8	0.6	0.5	2.3	10.6	230	2.16	6.53	1.82	1.58	Loamy Sand
Park Hill GC	1	60-80	7.8	0.8	0.5	2.8	10.6	242	1.76	7.28	1.24	1.46	Loamy Sand
Park Hill GC	1	80-100	7.5	2.1	0.4	3.8	8.7	177	25.4	9.04	2.04	2.03	Loamy Sand
Park Hill GC	2	0-20	7.7	0.9	4.1	14.8	19.3	361	6.58	16.6	3.87	1.75	Sandy Loam
Park Hill GC	2	20-40	8.0	0.8	1.0	5.2	19.3	353	5.47	10.2	2.64	2.95	Loamy Sand
Park Hill GC	2	40-60	8.0	0.7	0.7	4.0	19.3	374	4.49	8.48	2.45	2.68	Loamy Sand
Park Hill GC	2	60-80	7.7	1.2	0.6	2.5	13.4	327	3.21	7.65	1.64	2.44	Sandy Loam
Park Hill GC	2	80-100	7.6	1.3	0.7	5.1	8.6	317	3.20	13.6	2.00	2.60	Sandy Loam
Park Hill GC	3	0-20	7.6	0.9	4.6	19.1	21.2	308	12.7	15.1	1.71	2.34	Sandy Loam
Park Hill GC	3	20-40	8.1	0.7	1.1	4.2	17.7	281	5.91	11.9	1.13	2.84	Sandy Loam
Park Hill GC	3	40-60	8.0	1.3	0.7	3.5	7.1	305	2.00	7.22	0.735	2.03	Sandy Loam
Park Hill GC	3	60-80	7.9	1.5	0.6	4.9	4.3	190	1.59	4.45	0.66	1.18	Sandy Loam
Park Hill GC	3	80-100	7.8	1.9	0.6	3.7	4.0	122	1.18	3.64	0.35	1.24	Loamy Sand
City Park GC	1	0-20	7.1	1.5	4.5	19.2	24.6	372	12.2	39.33	2.13	3.79	Loam
City Park GC	1	20-40	7.5	1.0	1.5	2.7	13.7	273	7.43	11.85	1.30	2.81	Sandy Loam
City Park GC	1	40-60	7.6	0.7	0.7	2.0	13.9	260	2.18	7.51	1.07	2.24	Clay Loam
City Park GC	1	60-80	7.6	0.7	0.7	2.2	11.5	239	4.51	6.89	0.952	2.00	Clay Loam

Datasheet #3

Facility	Site	depth	---------Paste---------		%			-----AB-DTPA----- ppm					Texture
			pH	EC mmhos/ cm	OM	NO3-N	P	K	Zn	Fe	Mn	Cu	Estimate
City Park GC	1	80-100	7.5	0.6	0.7	3.3	10.6	244	3.57	7.90	0.611	2.74	Clay Loam
City Park GC	2	0-20	7.2	1.1	3.4	10.9	9.6	276	12.7	68.4	2.26	5.00	Sandy Loam
City Park GC	2	20-40	7.3	0.5	1.3	2.2	2.1	188	3.24	10.9	1.82	3.32	Clay Loam
City Park GC	2	40-60	7.6	0.5	0.9	2.3	3.4	156	2.35	8.46	1.24	2.82	Clay Loam
City Park GC	2	60-80	7.7	0.6	0.5	1.5	4.6	139	3.41	5.71	0.755	2.26	Clay
City Park GC	2	80-100	7.7	0.4	0.4	1.9	5.3	132	1.96	4.75	0.494	2.03	Clay
City Park GC	3	0-20	7.1	0.8	4.2	8.7	9.3	387	13.4	41.3	3.23	5.13	Loam
City Park GC	3	20-40	7.0	0.9	1.3	4.1	4.3	298	4.77	9.88	2.14	3.44	Clay Loam
City Park GC	3	40-60	7.3	0.6	0.8	2.2	4.9	228	3.47	7.34	2.97	2.68	Sandy Clay
City Park GC	3	60-80	7.5	0.6	0.7	2.7	7.4	213	3.64	6.56	2.14	2.32	Clay
City Park GC	3	80-100	7.6	0.8	0.6	2.9	7.1	189	7.73	7.60	2.34	1.76	Sandy Clay
Denver CC	1	0-20	6.8	1.0	3.7	12.6	22.4	382	18.0	55.93	2.27	5.45	Sandy Loam
Denver CC	1	20-40	7.0	0.9	1.3	3.7	7.8	259	3.44	9.69	2.57	1.98	Sandy Loam
Denver CC	1	40-60	7.0	0.8	0.7	2.8	7.1	149	1.79	6.95	1.91	2.00	Loamy Sand
Denver CC	1	60-80	7.0	1.2	0.4	2.2	7.8	76.3	14.4	7.25	2.16	1.23	Loamy Sand
Denver CC	1	80-100	7.1	1.0	0.7	1.7	7.4	50.4	6.07	5.85	1.84	1.83	Loamy Sand
Denver CC	2	0-20	7.5	1.7	3.5	16.8	17.7	424	11.3	32.5	2.55	6.07	Sandy Loam
Denver CC	2	20-40	7.7	1.2	1.3	3.4	7.4	179	3.30	13.2	0.935	2.57	Loamy Sand
Denver CC	2	40-60	7.8	1.1	0.3	2.1	5.9	85.2	1.63	6.77	0.801	1.18	Loamy Sand
Denver CC	2	60-80	7.7	1.1	0.6	2.2	5.9	65.7	2.56	14.7	0.826	1.59	Loamy Sand
Denver CC	3	0-20	7.0	1.0	5.9	32.7	30.8	315	23.5	33.2	2.77	8.27	Sandy Loam
Denver CC	3	20-40	7.3	0.6	0.5	17.4	12.1	124	3.43	6.40	1.32	2.43	Loamy sand

Datasheet #4

Facility	Site	depth	Paste pH	Paste EC mmhos/cm	% OM	AB-DTPA ppm NO3-N	P	K	Zn	Fe	Mn	Cu	Texture Estimate
Denver CC	3	40-60	7.1	0.7	0.3	6.9	10.9	107	4.56	6.24	1.61	1.73	Loamy Sand
Denver CC	3	60-80	7.2	0.8	0.2	5.3	7.4	58.6	1.50	5.88	1.06	0.658	Loamy Sand
Denver CC	3	80-100	7.5	0.9	0.3	3.9	7.1	58.9	1.74	8.02	0.693	0.894	Loamy Sand
Denver CC	4	0-20	6.9	1.0	4.9	31.6	21.8	293	22.4	34.7	1.91	8.13	Sandy Loam
Denver CC	4	20-40	7.3	0.9	1.3	13.4	11.5	206	6.85	7.937	0.8066	3.77	Sandy Loam
Denver CC	4	40-60	7.2	1.5	0.5	25.7	9.3	143	1.37	6.53	0.509	1.66	Loamy Sand
Denver CC	4	60-80	7.4	0.8	0.3	4.8	7.1	69.9	1.14	7.25	0.527	0.798	Loamy Sand
Denver CC	4	80-100	7.4	0.6	0.2	4.6	5.3	43.7	1.09	6.55	0.471	0.757	Loamy Sand
Washington park	1	0-20	7.0	0.8	4.4	10.4	36.5	383	26.8	61.5	2.96	6.68	Loam
Washington park	2	0-20	6.7	0.7	3.7	9.7	5.3	211	19.8	34.7	2.58	3.43	Loam
Washington park	3	0-20	6.8	0.6	4.2	1.2	16.8	305	108	45.7	7.46	13.8	Loam
Washington park	4	0-20	6.9	0.9	4.4	2.4	42.4	357	200	47.9	5.96	29.2	Loam
Washington park	5	0-20	6.7	0.6	4.3	9.4	40.8	183	37.9	38.0	2.86	12.2	Loam
Washington park	6	0-20	6.9	0.7	3.6	6.3	13.1	252	26.1	24.0	2.81	6.04	Loam
City park	1	0-20	6.7	0.7	3.8	8.3	5.3	222	11.6	33.2	4.56	3.41	Clay Loam
City park	1	20-40	6.6	0.6	1.3	2.7	2.1	202	3.92	12.5	3.91	2.43	Clay
City park	2	0-20	6.6	0.6	3.9	7.2	7.4	251	8.66	32.6	4.71	2.97	Clay Loam
City park	2	20-40	6.8	0.4	1.5	2.0	4.9	191	3.64	11.1	3.03	2.42	Clay Loam
City park	3	0-20	7.2	0.8	4.1	7.8	5.9	269	15.0	20.8	3.59	5.19	Clay Loam
City park	3	20-40	7.4	0.7	1.2	1.4	3.7	177	7.13	11.3	1.55	3.10	Clay Loam
City park	4	0-20	6.8	0.7	4.6	7.5	5.3	268	17.5	33.0	4.87	4.70	Clay Loam

Datasheet #5

						AB-DTPA							
Facility	Site	depth	Paste		%	ppm							Texture
			pH	EC mmhos/cm	OM	NO3-N	P	K	Zn	Fe	Mn	Cu	Estimate
City park	4	20-40	7.3	0.7	1.6	2.2	1.8	192	8.60	13.5	2.05	3.62	Clay Loam
City park	5	0-20	6.9	0.6	4.1	7.8	4.9	259	10.7	19.9	2.36	3.01	Clay Loam
City park	5	20-40	7.1	0.6	1.4	2.9	3.4	154	4.67	10.1	1.58	2.26	Clay Loam
City park	6	0-20	7.1	0.6	4.0	8.5	9.0	263	16.1	20.0	2.32	3.48	Loam
City park	6	20-40	7.2	0.6	2.1	7.8	4.6	211	11.6	15.3	2.31	2.66	Clay Loam
Denver Zoo	1	0-20	7.6	0.4	3.0	0.8	17.4	274	6.04	15.3	6.55	2.33	Sandy Loam
Denver Zoo	1	20-40	7.9	0.7	1.7	1.8	19.6	495	6.15	8.20	3.13	2.64	Sandy Loam
Denver Zoo	2	0-20	7.8	0.4	1.8	0.8	16.8	189	9.89	16.1	3.16	3.73	Sandy Loam
Denver Zoo	2	20-40	7.9	0.5	1.6	1.1	36.1	693	7.96	54.5	6.57	3.70	Sandy Loam
Denver Zoo	3	0-20	7.6	0.7	1.0	8.4	12.7	177	8.62	14.9	2.29	9.668	Sandy Loam
Denver Zoo	3	20-40	7.9	0.6	1.6	1.4	30.1	693	7.96	30.5	6.57	3.70	Sandy Loam

Datasheet #6

Facility	Site	depth	Ca	Mg	Na	K	SAR	Exchangeable CEC	Exchangeable Na	ESP	Hot Water Cl	Hot Water B
			Saturated Paste Extract ---------meq/L----------------					meq/100 g	meq/100 g	%	------ mg/kg -------	
Swansea park	1	0-20	2.8	1.3	3.4	0.9	2.4	21.3	0.49	2.3	26.7	0.31
Swansea park	1	20-40	0.9	0.4	2.2	0.2	2.7	14.2	0.37	2.6	13.2	0.31
Swansea park	2	0-20	2.7	1.4	5.1	0.7	3.5	18.5	0.63	3.4	28.9	0.39
Swansea park	2	20-40	3.1	1.6	4.3	0.2	2.8	15.6	0.42	2.7	27.5	0.20
Swansea park	3	20-40	1.7	0.9	4.4	0.6	3.9	15.9	0.59	3.7	26.4	0.35
Swansea park	3	0-20	3.9	2.0	4.7	0.3	2.7	16.5	0.43	2.6	32.1	0.22
Dunham park	1	20-40	1.1	0.5	3.2	0.4	3.6	14.3	0.50	3.5	16.8	0.30
Dunham park	1	0-20	1.3	0.5	3.0	0.2	3.2	13.2	0.41	3.1	15.4	0.22
Dunham park	2	20-40	1.5	0.7	3.6	0.6	3.5	15.3	0.55	3.6	21.3	0.39
Dunham park	2	0-20	0.8	0.4	2.1	0.2	2.6	14.6	0.35	2.4	13.2	0.10
Dunham park	3	20-40	1.5	0.7	3.8	0.6	3.6	16.0	0.56	3.5	24.5	0.43
Dunham park	3	20-40	2.1	1.0	3.0	0.2	2.4	18.7	0.43	2.3	20.4	0.25
Schaefer park	1	0-20	3.7	1.8	4.3	1.0	2.6	21.3	0.51	2.4	36.7	0.48
Schaefer park	1	20-40	6.5	2.9	4.2	0.7	1.9	22.4	0.38	1.7	42.7	0.29
Schaefer park	2	0-20	1.9	0.8	3.5	0.4	3.0	20.3	0.59	2.9	23.5	0.40
Schaefer park	2	20-40	3.7	1.5	3.2	0.3	2.0	25.0	0.45	1.8	26.8	0.33
Schaefer park	3	0-20	2.3	0.9	3.1	0.5	2.5	21.7	0.52	2.4	24.9	0.94
Schaefer park	3	20-40	2.7	1.1	2.5	0.4	1.8	24.1	0.41	1.7	21.6	0.88
Bruce R School	1	0-20	3.0	0.6	4.3	0.4	3.2	17.1	0.53	3.1	26.8	0.44
Bruce R School	1	20-40	5.6	1.6	2.5	0.4	1.3	22.9	0.32	1.4	32.8	0.22
Bruce R School	2	0-20	12.9	2.7	8.7	1.5	3.1	20.0	0.58	2.9	71.5	0.71
Bruce R School	2	20-40	11.0	4.4	4.5	1.0	1.6	29.3	0.44	1.5	58.6	0.48

Datasheet #7

Facility	Site	depth	Ca	Mg	Na	K	SAR	CEC	Na	ESP	Cl	B
					Saturated Paste Extract			Exchangeable			Hot	Water
				---------meq/L-------------				meq/100 g	meq/100 g	%	----- mg/kg -----	
Bruce R School	3	0-20	2.1	0.7	3.4	0.7	2.9	11.8	0.33	2.8	21.3	0.46
Bruce R School	3	20-40	1.5	0.6	2.7	0.6	2.6	10.8	0.27	2.5	16.7	0.27
Park Hill GC	1	0-20	2.9	1.8	5.0	1.2	3.3	12.3	0.38	3.1	33.5	1.65
Park Hill GC	1	20-40	0.8	0.5	4.0	0.2	4.9	9.6	0.43	4.5	15.4	1.41
Park Hill GC	1	40-60	0.9	0.5	5.3	0.2	6.5	9.8	0.63	6.4	21.9	1.87
Park Hill GC	1	60-80	1.1	0.6	6.3	0.2	6.9	11.2	0.75	6.7	24.5	1.67
Park Hill GC	1	80-100	8.8	6.6	8.9	0.6	3.2	17.4	0.54	3.1	65.2	0.99
Park Hill GC	2	0-20	2.6	1.6	5.3	1.1	3.7	16.4	0.59	3.6	29.2	3.07
Park Hill GC	2	20-40	1.5	0.8	7.6	0.6	7.1	9.0	0.63	7.0	26.5	2.07
Park Hill GC	2	40-60	0.9	0.5	6.1	0.5	7.3	9.4	0.67	7.1	23.8	1.45
Park Hill GC	2	60-80	2.2	1.3	8.7	0.4	6.6	12.5	0.80	6.4	37.5	1.70
Park Hill GC	2	80-100	3.4	1.3	8.2	0.4	5.4	18.7	0.99	5.3	42.6	2.11
Park Hill GC	3	0-20	2.3	1.3	5.0	0.6	3.7	20.3	0.65	3.2	28.9	3.59
Park Hill GC	3	20-40	0.2	0.1	0.5	0.1	1.6	51.4	0.72	1.4	22.4	2.22
Park Hill GC	3	40-60	1.9	1.3	10	0.4	7.8	15.6	1.12	7.2	45.6	2.64
Park Hill GC	3	60-80	2.6	1.9	10	0.3	6.6	16.2	1.05	6.5	42.3	2.10
Park Hill GC	3	80-100	4.2	3.3	13	0.4	6.6	13.1	0.84	6.4	61.0	1.41
City Park GC	1	0-20	5.9	2.2	5.7	1.5	2.8	22.6	0.61	2.7	48.3	0.46
City Park GC	1	20-40	5.0	1.6	3	0.7	1.7	24.0	0.36	1.5	32.8	0.32
City Park GC	1	40-60	2.9	1.0	2.8	0.4	2.0	18.4	0.35	1.9	23.5	0.31
City Park GC	1	60-80	2.9	1.1	2.2	0.4	1.6	27.7	0.36	1.3	22.4	0.41
City Park GC	1	80-100	2.6	1.2	1.8	0.3	1.3	27.5	0.33	1.2	19.8	0.39
City Park GC	2	0-20	5.3	2.1	3.7	0.6	1.9	27.4	0.52	1.9	35.9	0.26
City Park GC	2	20-40	2.3	0.8	1.9	0.2	1.5	26.4	0.37	1.4	17.5	0.18
City Park GC	2	40-60	2.4	0.8	1.4	0.1	1.1	26.7	0.32	1.2	15.4	0.22
City Park GC	2	60-80	2.7	1.0	1.6	0.1	1.2	23.1	0.30	1.3	18.5	0.22

Datasheet # 8

Facility	Site	depth	Ca	Mg	Na	K	SAR	CEC	Na	ESP	Cl	B
					Saturated Paste Extract			Exchangeable			Hot	Water
				---------meq/L------------ ----				meq/100 g	meq/100 g	%	------ mg/kg ----- --	
City Park GC	2	80-100	2.1	0.8	1.3	0.1	1.1	28.0	0.28	1.0	13.4	0.19
City Park GC	3	0-20	2.7	1.3	3.0	0.8	2.2	26.2	0.55	2.1	26.5	0.35
City Park GC	3	20-40	4.1	2.1	2.9	0.5	1.7	21.1	0.38	1.8	27.3	0.37
City Park GC	3	40-60	3.0	1.3	2.4	0.2	1.6	29.3	0.41	1.4	20.8	0.26
City Park GC	3	60-80	3.3	1.0	2.2	0.2	1.5	27.7	0.36	1.3	21.2	0.25
City Park GC	3	80-100	4.4	1.6	2.3	0.3	1.3	29.2	0.35	1.2	24.6	0.30
Denver CC	1	0-20	2.8	1.3	5.2	1.2	3.6	21.2	0.72	3.4	32.8	0.81
Denver CC	1	20-40	3.5	1.7	4.2	0.5	2.6	21.2	0.53	2.5	29.9	0.58
Denver CC	1	40-60	3.5	1.8	3.1	0.3	1.9	22.2	0.40	1.8	24.5	0.49
Denver CC	1	60-80	7.3	3.5	2.7	0.4	1.2	25.8	0.31	1.2	38.9	0.34
Denver CC	1	80-100	5.7	3.0	2.7	0.3	1.3	24.5	0.27	1.1	31.8	0.26
Denver CC	2	0-20	6.0	2.7	8.1	1.6	3.9	29.1	0.93	3.2	55.6	0.96
Denver CC	2	20-40	4.4	2.1	5.1	1.1	2.8	17.9	0.43	2.4	39.4	0.58
Denver CC	2	40-60	4.4	2.3	3.7	0.8	2.0	17.9	0.34	1.9	34.8	0.31
Denver CC	2	60-80	4.3	2.3	3.9	0.9	2.1	13.5	0.27	2.0	37.8	0.44
Denver CC	3	0-20	2.6	1.0	4.9	1.4	3.7	17.8	0.64	3.6	33.5	1.24
Denver CC	3	20-40	1.5	0.6	3.6	0.8	3.5	10.3	0.35	3.4	18.5	0.46
Denver CC	3	40-60	2.2	0.8	3.0	0.9	2.4	12.3	0.27	2.2	21.6	0.28
Denver CC	3	60-80	3.0	1.1	2.9	0.9	2.0	13.0	0.26	2.0	24.6	0.22
Denver CC	3	80-100	4.2	1.5	2.9	0.7	1.7	18.0	0.27	1.5	24.9	0.20
Denver CC	4	0-20	2.9	1.1	5.1	1.1	3.6	20.6	0.66	3.2	31.3	0.97
Denver CC	4	20-40	2.8	0.9	4.2	0.9	3.1	16.9	0.49	2.9	25.1	0.53
Denver CC	4	40-60	6.6	2.1	5.6	1.2	2.7	14.0	0.35	2.5	48.9	0.29

Datasheet #9

Facility	Site	depth	Ca	Mg	Na	K	SAR	CEC	Na	ESP	Hot Cl	Water B
					Saturated Paste Extract				Exchangeable			
				---------meq/L---------------				meq/100 g	meq/100 g	%	------ mg/kg -------	
Denver CC	4	60-80	2.8	0.9	3.0	0.6	2.2	12.4	0.26	2.1	24.6	0.14
Denver CC	4	80-100	2.0	0.7	2.4	0.5	2.0	12.5	0.25	2.0	15.8	0.08
Washington park	1	0-20	2.9	1.5	3.7	0.8	2.5	22.7	0.50	2.2	26.7	0.54
Washington park	2	0-20	2.0	1.0	3.1	0.6	2.5	19.5	0.41	2.1	23.4	0.40
Washington park	3	0-20	1.8	0.8	2.7	0.7	2.4	20.9	0.46	2.2	20.8	0.55
Washington park	4	0-20	3.1	1.2	3.1	1.0	2.1	22.5	0.45	2.0	29.4	0.46
Washington park	5	0-20	2.1	1.0	2.9	0.6	2.3	24.5	0.49	2.0	21.6	0.55
Washington park	6	0-20	4.1	1.1	3.1	0.7	1.9	29.4	0.50	1.7	23.8	0.39
City park	1	0-20	2.3	1.1	3.9	0.4	3.0	23.8	0.69	2.9	25.8	0.51
City park	1	20-40	1.9	0.9	3.2	0.2	2.7	24.4	0.61	2.5	21.9	0.37
City park	2	0-20	2.0	0.9	3.2	0.5	2.6	22.1	0.53	2.4	21.6	0.45
City park	2	20-40	1.1	0.5	2.0	0.2	2.2	21.0	0.44	2.1	13.9	0.33
City park	3	0-20	2.6	1.4	3.6	0.5	2.5	26.3	0.63	2.4	26.6	0.69
City park	3	20-40	2.3	1.3	3.1	0.2	2.3	23.8	0.50	2.1	23.5	0.59
City park	4	0-20	2.0	1.0	3.4	0.4	2.7	26.4	0.66	2.5	21.4	0.65
City park	4	20-40	2.7	1.3	2.6	0.2	1.8	27.6	0.47	1.7	28.9	0.40
City park	5	0-20	1.3	0.6	4.0	0.4	4.0	13.7	0.52	3.8	21.2	0.44
City park	5	20-40	2.2	1.0	2.5	0.2	2.0	25.5	0.51	2.0	22.3	0.38
City park	6	0-20	2.3	1.1	2.4	0.5	1.8	28.8	0.49	1.7	21.5	0.44
City park	6	20-40	2.6	1.3	2.4	0.3	1.7	26.1	0.47	1.8	24.5	0.40
Denver Zoo	1	0-20	1.9	0.9	1.2	0.6	1.0	35.0	0.35	1.0	13.4	0.25
Denver Zoo	1	20-40	2.3	1.0	1.7	1.2	1.1	35.0	0.35	1.0	23.9	0.78
Denver Zoo	2	0-20	2.2	0.9	1.2	0.3	1.0	34.4	0.31	0.9	14.5	0.46
Denver Zoo	2	20-40	1.3	0.6	1.9	1.5	1.9	22.2	0.40	1.8	17.6	1.01
Denver Zoo	3	0-20	3.0	1.4	2.9	0.3	1.9	26.7	0.48	1.8	23.5	0.5
Denver Zoo	3	20-40	1.3	0.6	1.9	1.5	1.9	22.2	0.40	1.8	20.3	0.95

APPENDIX _B (Data from 2009)_ (Datasheets # 1- # 9)
Datasheet 1

Sample ID #	Site	Depth (cm)	paste pH	paste EC mmhos/cm	Moisture %	% OM	AB-DTPA ppm NO$_3$-N	P	K	Zn	Fe	Mn	Cu	Texture Estimate
Swansea	1	0-20	6.6	1.3	7.2	3.2	7.7	23.0	269	30.0	46.2	7.47	5.67	Sandy Loam
Swansea	1	20-40	7.3	0.7	5.4	1.2	2.4	21.8	150	40.9	35.8	1.23	8.94	Sandy Loam
Swansea	2	0-20	7.2	0.9	15.4	3.5	5.2	18.7	221	19.1	50.5	1.33	4.71	Sandy Loam
Swansea	2	20-40	7.0	0.9	10.4	1.0	0.9	12.7	154	8.64	19.6	0.84	3.23	Sandy Loam
Swansea	3	0-20	7.1	0.9	11.0	3.7	4.0	17.4	267	14.6	45.8	1.31	4.45	Sandy Loam
Swansea	3	20-40	7.4	0.7	9.3	1.1	1.3	9.9	146	6.21	19.9	0.84	3.35	Sandy Loam
Dunham	1	0-20	7.1	0.9	12.0	3.0	3.5	17.4	253	43.5	79.0	0.83	10.4	Sandy Loam
Dunham	1	20-40	6.9	0.8	9.8	0.9	3.0	14.3	130	23.7	25.1	1.02	7.83	Sandy Loam
Dunham	2	0-20	7.1	1.0	8.2	4.9	1.8	19.9	323	52.5	71.0	1.24	8.28	Sandy Loam
Dunham	2	20-40	7.4	0.9	5.8	0.9	1.9	14.3	128	24.3	24.6	0.83	6.49	Sandy Loam
Dunham	3	0-20	6.8	1.1	8.4	5.3	2.0	26.8	352	78.6	65.5	1.97	10.9	Sandy Loam
Dunham	3	20-40	7.1	1.1	6.8	1.7	1.4	18.7	178	36.6	39.3	1.44	8.76	Sandy Loam
Schafer	1	0-20	7.2	1.1	17.9	3.6	3.5	36.1	423	14.8	30.6	1.32	7.08	Sandy Loam
Schafer	1	20-40	7.5	1.0	8.5	0.8	1.6	19.9	198	3.56	9.62	0.90	3.65	Sandy Loam
Schafer	2	0-20	7.1	1.0	8.6	4.5	4.4	35.5	471	22.9	42.3	1.07	9.22	Sandy Loam
Schafer	2	20-40	7.3	1.3	9.3	1.1	1.0	15.6	278	3.61	15.2	0.71	2.46	Sandy Loam
Schafer	3	0-20	7.5	1.0	11.0	6.9	4.9	33.0	479	31.7	39.0	1.02	10.3	Sandy Loam
Schafer	3	20-40	7.9	1.1	9.7	2.2	3.2	15.6	271	29.1	23.3	0.87	7.92	Sandy Loam
Bruce R Middle	1	0-20	8.0	0.6	11.6	1.2	8.4	18.7	171	3.0	15.8	1.6	1.7	Sandy Loam
Bruce R Middle	1	20-40	7.9	0.5	10.1	0.8	14.5	14.9	132	4.2	6.2	0.62	3.2	Sandy Loam
Bruce R Middle	2	0-20	7.7	0.8	14.5	2.3	12.9	23.0	167	8.3	67.0	3.7	4.2	Sandy Loam
Bruce R Middle	2	20-40	7.9	0.6	13.0	0.9	10.1	13.7	182	3.0	26.3	2.1	2.2	Sandy Loam

Datasheet 2

Sample ID #	Site	Depth (cm)	paste pH	paste EC mmhos/cm	Moisture %	% OM	AB-DTPA ppm NO_3-N	P	*K*	*Zn*	*Fe*	*Mn*	*Cu*	*Texture Estimate*
Bruce R Middle	3	0-20	7.8	1.0	8.0	1.4	19.9	36.8	229	7.4	36.9	1.6	3.5	Sandy Loam
Bruce R Middle	3	20-40	8.1	0.4	5.1	0.3	10.3	9.9	151	0.4	3.0	0.28	0.66	Sandy Loam
Park Hill GC	1	0-20	7.8	1.5	12.1	1.9	8.1	7.4	238	2.95	11.4	1.29	1.45	Loamy Sand
Park Hill GC	1	20-40	8.1	0.7	8.63	0.6	3.7	6.8	164	0.84	6.11	0.63	1.28	Loamy Sand
Park Hill GC	1	40-60	8.3	0.4	11.3	0.6	3.2	7.4	132	0.40	5.14	0.47	0.86	Loamy Sand
Park Hill GC	1	60-80	8.3	0.6	11.7	0.7	2.3	9.3	195	0.32	8.21	0.58	0.95	Sandy Loam
Park Hill GC	1	80-100	8.5	0.4	8.12	0.5	2.0	8.7	128	0.43	4.61	0.46	1.11	Sandy Loam
Park Hill GC	2	0-20	7.7	1.3	19.9	2.5	17.8	7.4	292	3.33	17.7	1.52	1.52	Loamy Sand
Park Hill GC	2	20-40	8.0	0.8	12.4	0.9	2.6	3.7	275	1.04	8.75	0.80	1.64	Sandy Loam
Park Hill GC	2	40-60	8.2	0.6	11.0	0.6	2.6	3.7	199	0.56	5.39	0.45	1.27	Loamy Sand
Park Hill GC	2	60-80	8.4	0.5	8.37	0.5	1.8	4.3	144	1.25	4.32	0.37	1.09	Sandy Loam
Park Hill GC	2	80-100	8.4	0.6	6.53	0.4	1.3	3.7	98.1	1.14	3.25	0.30	1.01	Sandy Loam
Park Hill GC	3	0-20	7.3	1.1	6.24	4.0	66.9	26.8	325	16.1	56.5	3.39	2.96	Sandy Loam
Park Hill GC	3	20-40	7.7	0.8	10.4	1.5	12.6	16.8	251	8.8	15.9	1.49	2.40	Sandy Loam
Park Hill GC	3	40-60	7.6	0.9	11.8	1.2	6.2	12.7	288	4.45	11.6	1.07	1.86	Sandy Loam
Park Hill GC	3	60-80	7.7	0.8	9.57	0.8	4.8	5.6	222	1.33	5.25	0.49	1.67	Loamy Sand
Park Hill GC	3	80-100	7.9	0.6	10.3	0.9	7.3	4.9	171	1.15	5.09	0.44	1.51	Sandy Loam
City park GC	1	0-20	6.9	1.3	14.0	4.5	6.8	13.1	628	16.8	59.3	2.85	5.93	Loam
City park GC	1	20-40	7.0	1.5	14.5	1.4	1.7	4.9	419	6.30	16.9	1.81	3.80	Sandy Clay Loam
City park GC	1	40-60	7.1	1.6	12.0	0.8	1.5	3.1	312	1.33	9.38	0.92	2.62	Clay Loam
City park GC	1	60-80	7.5	1.5	12.4	1.1	1.2	4.3	259	0.75	7.65	0.63	2.66	Clay Loam

Datasheet 3

Sample ID #	Site	Depth (cm)	paste pH	paste EC mmhos/cm	Moisture %	% OM	AB-DTPA ppm NO$_3$-N	P	K	Zn	Fe	Mn	Cu	Texture Estimate
City park GC	1	80-100	7.6	1.4	14.9	1.1	1.6	7.4	241	0.97	11.2	1.12	4.21	Clay Loam
City park GC	2	0-20	7.3	1.3	16.0	6.2	12.6	8.1	394	26.5	79.7	1.69	7.78	Sandy Clay Loam
City park GC	2	20-40	7.7	0.9	14.8	1.3	4.5	2.8	225	5.70	17.5	1.24	3.85	Clay Loam
City park GC	2	40-60	7.8	1.0	13.7	1.0	2.6	3.4	168	1.51	11.9	0.83	3.28	Clay Loam
City park GC	2	60-80	7.7	1.2	15.1	1.0	1.8	3.4	150	1.18	7.40	0.60	2.46	Clay
City park GC	2	80-100	7.7	1.4	13.8	0.8	1.8	4.9	143	1.04	7.70	0.56	2.54	Clay
City park GC	3	0-20	7.5	1.0	18.8	4.0	3.9	25.5	513	15.7	90.3	2.85	7.41	Clay Loam
City park GC	3	20-40	8.0	1.1	17.5	1.2	2.1	13.1	384	4.92	18.3	0.99	3.40	Sandy Clay Loam
City park GC	3	40-60	8.1	0.6	15.7	0.9	1.3	14.3	264	1.71	8.87	0.85	2.54	Clay Loam
City park GC	3	60-80	8.0	0.5	17.0	0.9	1.8	13.1	241	0.88	6.94	0.65	2.10	Sandy Clay Loam
City park GC	3	80-100	8.0	0.5	17.9	0.8	2.2	10.6	236	0.85	6.24	0.62	2.63	Clay
Denver CC	1	0-20	6.9	1.2	25.0	3.7	12.8	22.4	382	21.5	73.0	1.58	6.36	Sandy Loam
Denver CC	1	20-40	7.1	0.9	17.8	1.7	4.5	15.6	298	12.7	32.7	0.92	3.96	Sandy Loam
Denver CC	1	40-60	7.2	0.8	16.3	0.5	5.0	9.9	89.4	1.08	7.93	0.93	0.97	Sandy Loam
Denver CC	1	60-80	7.3	0.4	7.2	0.1	1.2	4.3	42.9	0.39	4.98	0.67	1.52	Sandy Loam
Denver CC	1	80-100	7.4	0.4	4.5	0.1	0.6	7.4	28.9	0.60	6.79	0.63	0.80	Loamy Sand
Denver CC	2	0-20	7.1	1.6	37.6	2.6	9.3	19.3	343	9.76	58.3	2.22	6.24	Sandy Loam
Denver CC	2	20-40	8.0	1.1	6.0	0.2	2.1	3.7	77.6	0.96	7.32	0.82	1.26	Sandy Loam
Denver CC	2	40-60	8.0	0.4	3.6	0.1	0.5	8.1	55.6	0.40	5.98	0.45	2.24	Loamy Sand
Denver CC	2	60-80	8.0	0.3	5.8	0.1	0.5	4.3	51.8	0.59	12.2	0.89	1.28	Sandy Loam
Denver CC	2	80-100	8.1	0.3	4.3	0.1	0.5	2.8	49.7	0.42	11.0	0.76	0.67	Sandy Loam
Denver CC	3	0-20	6.7	1.2	31.4	2.2	17.4	17.4	225	17.3	33.9	1.29	6.69	Loamy Sand
Denver CC	3	20-40	7.4	1.8	5.1	0.3	5.4	6.2	79.4	2.25	6.57	0.41	1.36	Loamy Sand

Datasheet 4

Sample ID #	Site	Depth (cm)	paste pH	paste EC mmhos/cm	Moisture %	% OM	AB-DTPA ppm NO$_3$-N	P	K	Zn	Fe	Mn	Cu	Texture Estimate
Denver CC	3	40-60	7.2	0.5	6.4	0.1	4.0	5.6	70.2	0.92	5.85	0.58	1.60	Loamy Sand
Denver CC	3	60-80	7.7	0.4	4.6	0.1	2.3	6.2	55.8	0.64	10.2	0.50	1.14	Loamy Sand
Denver CC	3	80-100	8.0	0.3	6.5	0.1	1.6	6.2	42.3	0.25	9.58	0.51	0.69	Loamy Sand
Denver CC	4	0-20	6.5	0.4	24.7	4.3	21.3	14.3	307	16.4	49.0	1.09	6.27	Sandy Loam
Denver CC	4	20-40	7.2	0.8	9.2	0.9	7.6	6.2	166	3.47	10.2	0.44	2.15	Sandy Loam
Denver CC	4	40-60	8.1	0.5	6.7	0.5	3.1	6.2	117	1.30	7.03	0.34	1.10	Loamy Sand
Denver CC	4	60-80	8.6	0.3	2.9	0.1	1.1	3.7	56.6	0.51	8.10	0.29	0.49	Loamy Sand
Denver CC	4	80-100	8.8	0.2	3.2	0.2	0.8	3.7	41.5	0.38	6.54	0.37	0.49	Loamy Sand
Washington park	1	0-20	6.9	0.9	14.9	4.5	2.8	3.1	242	36.0	37.4	1.46	4.26	Sandy Loam
Washington park	2	0-20	6.8	1.0	18.2	4.3	9.5	6.2	371	27.6	45.9	1.15	3.50	Loam
Washington park	3	0-20	6.9	1.0	20.4	4.0	8.0	11.2	344	40.7	44.9	1.44	5.60	Loam
Washington park	4	0-20	7.0	1.2	11.6	4.6	4.3	28.0	431	87.5	48.5	2.09	11.5	Sandy Clay
Washington park	5	0-20	7.1	0.8	29.9	3.7	4.4	26.2	284	106	48.0	1.36	16.3	Loam
Washington park	6	0-20	7.1	1.0	13.2	4.7	10.2	13.1	440	19.9	27.2	1.98	3.71	Sandy Clay
City Park	1	0-20	7.1	0.9	14.7	3.5	8.2	6.8	383	20.3	34.6	2.35	4.57	Clay Loam
City Park	1	20-40	7.4	1.2	18.6	1.2	2.2	4.9	196	4.60	12.6	1.77	2.77	Clay Loam
City Park	2	0-20	7.0	0.8	18.3	3.4	9.6	2.1	409	9.49	31.2	3.68	3.89	Clay Loam
City Park	2	20-40	7.2	0.7	20.6	1.8	3.4	0.6	316	4.45	16.7	1.97	3.13	Clay Loam
City Park	3	0-20	7.5	0.9	24.3	4.7	14.1	8.7	408	35.3	43.3	3.13	8.18	Clay Loam
City Park	3	20-40	7.7	0.8	18.4	1.2	6.2	5.6	257	16.3	27.0	2.02	5.15	Clay Loam
City Park	4	0-20	7.1	0.7	21.5	4.1	7.7	4.0	357	24.1	39.6	2.71	5.26	Clay Loam

Datasheet 5

Sample ID #	Site	Depth (cm)	----------paste---------- pH	EC mmhos/cm	Moisture %	% OM	AB-DTPA ppm NO3-N	P	K	Zn	Fe	Mn	Cu	Texture Estimate
City Park	4	20-40	7.3	0.9	17.6	1.3	5.5	2.5	240	8.03	18.3	2.00	2.97	Clay Loam
City Park	5	0-20	7.0	0.8	9.13	4.6	8.4	7.1	441	15.0	31.7	3.31	4.83	Clay Loam
City Park	5	20-40	7.6	1.1	10.0	1.5	10.9	1.8	243	4.13	13.3	1.60	2.53	Clay Loam
City Park	6	0-20	7.6	0.9	10.8	3.7	9.0	8.7	344	12.4	19.4	1.52	4.75	Clay Loam
City Park	6	20-40	7.7	1.4	11.3	1.4	18.8	5.6	175	4.06	10.1	1.33	2.88	Clay
Denver Zoo	1	0-20	7.8	0.9	11.4	5.4	12.4	11.2	510	17.0	23.6	4.96	5.26	Sandy Loam
Denver Zoo	1	20-40	8.0	1.2	10.5	3.5	11.5	10.6	614	12.7	10.7	2.93	3.96	Sandy Loam
Denver Zoo	2	0-20	8.0	1.0	12.2	2.2	7.0	13.7	531	6.73	10.3	2.05	3.40	Sandy Loam
Denver Zoo	2	20-40	8.0	0.6	11.5	1.9	3.8	8.1	391	9.90	6.80	1.37	2.76	Sandy Loam
Denver Zoo	3	0-20	7.9	0.9	10.9	3.0	2.6	25.5	328	8.07	19.8	2.25	5.63	Sandy Loam
Denver Zoo	3	20-40	8.1	0.7	9.56	5.1	2.2	27.4	345	9.10	27.9	2.39	4.57	Sandy Loam

Datasheet 6

Sample ID #	Site	Depth (cm)	Ca	Mg	Na	K	SAR	CEC	Exchangeable Na	ESP	---Hot Water------ Cl	B	Texture Estimate
			------meq/L------					----meq/100g------		%	-------mg/kg-------		
Swansea	1	0-20	4.5	1.8	10.1	1.9	5.7	21.5	1.20	5.6	28.2	1.0	Sandy Loam
Swansea	1	20-40	1.5	0.4	7.9	0.3	8.1	15.3	1.26	8.2	11.6	0.5	Sandy Loam
Swansea	2	0-20	2.0	0.7	7.5	0.9	6.5	19.6	1.29	6.6	22.4	0.7	Sandy Loam
Swansea	2	20-40	1.4	0.4	9.3	0.5	9.8	10.6	1.05	9.9	19.4	0.4	Sandy Loam
Swansea	3	0-20	1.6	0.6	7.0	1.2	6.5	16.8	1.07	6.4	41.9	0.7	Sandy Loam
Swansea	3	20-40	0.8	0.2	7.0	0.4	10.4	9.3	0.98	10.5	16.8	0.4	Sandy Loam
Dunham	1	0-20	2.2	0.8	7.2	1.4	5.8	22.6	1.33	5.9	32.1	0.8	Sandy Loam
Dunham	1	20-40	1.2	0.3	7.4	0.5	8.5	12.4	1.04	8.4	14.3	0.3	Sandy Loam
Dunham	2	0-20	2.1	0.7	8.1	1.4	6.8	19.3	1.33	6.9	33.8	0.9	Sandy Loam
Dunham	2	20-40	1.4	0.4	9.6	0.5	10.3	9.7	1.01	10.4	16.4	0.5	Sandy Loam
Dunham	3	0-20	2.7	0.9	8.5	1.9	6.3	22.6	1.45	6.4	30.2	0.9	Sandy Loam
Dunham	3	20-40	2.1	0.6	11.1	0.5	9.5	16.1	1.51	9.4	24.4	0.5	Sandy Loam
Schaefer park	1	0-20	3.0	0.9	8.8	1.6	6.3	23.6	1.46	6.2	27.0	0.8	Sandy Loam
Schaefer park	1	20-40	2.8	0.6	9.5	0.6	7.3	16.1	1.19	7.4	26.9	0.4	Sandy Loam
Schaefer park	2	0-20	2.1	0.6	7.7	1.2	6.5	22.6	1.47	6.5	25.5	0.7	Sandy Loam
Schaefer park	2	20-40	4.2	1.2	11.0	0.7	6.7	21.6	1.42	6.6	30.1	0.2	Sandy Loam
Schaefer park	3	0-20	2.6	0.8	6.9	1.7	5.4	28.9	1.59	5.5	32.7	1.7	Sandy Loam
Schaefer park	3	20-40	3.2	0.8	9.0	0.7	6.4	19.9	1.29	6.5	21.5	1.8	Sandy Loam
Bruce R Middle	1	0-20	2.5	0.6	4.7	0.7	3.7	23.9	0.86	3.6	14.8	0.6	Sandy Loam
Bruce R Middle	1	20-40	1.5	0.2	3.9	0.3	4.3	18.3	0.77	4.2	13.8	0.1	Sandy Loam
Bruce R Middle	2	0-20	3.1	0.7	5.9	0.6	4.3	27.0	0.98	4.1	22.9	0.2	Sandy Loam
Bruce R Middle	2	20-40	1.9	0.4	5.6	0.4	5.3	18.8	0.96	5.1	26.1	0.1	Sandy Loam

Datasheet 7

Sample ID #	Site	Depth (cm)	Ca	Mg	Na	K	SAR	CEC	Exchangeable Na	ESP	----Hot Water------ Cl	B	Texture Estimate
			----------------------meq/L----------------------					----meq/100g------		%	--------mg/kg--------		
Bruce R Middle	3	0-20	4.1	1.0	6.8	1.2	4.3	21.1	0.89	4.2	29.7	0.7	Sandy Loam
Bruce R Middle	3	20-40	0.8	0.1	3.7	0.5	5.4	15.1	0.78	5.2	12.8	0.4	Sandy Loam
Park Hill GC	1	0-20	6.1	1.9	9.1	3.4	4.5	11.1	0.51	4.6	50.8	1.3	Loamy Sand
Park Hill GC	1	20-40	2.0	0.6	5.8	0.6	5.1	8.2	0.43	5.2	29.8	0.8	Loamy Sand
Park Hill GC	1	40-60	0.7	0.1	4.6	0.2	7.0	8.2	0.58	7.1	12.1	0.7	Loamy Sand
Park Hill GC	1	60-80	0.9	0.2	5.5	0.2	7.2	10.9	0.79	7.3	10.2	0.8	Sandy Loam
Park Hill GC	1	80-100	0.6	0.1	4.0	0.1	7.0	9.0	0.64	7.1	7.8	0.8	Sandy Loam
Park Hill GC	2	0-20	5.2	1.8	9.4	1.5	5.0	13.3	0.68	5.1	37.3	1.5	Loamy Sand
Park Hill GC	2	20-40	1.8	0.6	8.6	0.5	7.8	12.0	0.94	7.8	16.4	1.2	Sandy Loam
Park Hill GC	2	40-60	1.1	0.4	6.9	0.3	8.0	10.6	0.86	8.1	10.6	1.3	Loamy Sand
Park Hill GC	2	60-80	0.6	0.2	5.3	0.2	8.3	8.3	0.68	8.2	9.9	1.2	Sandy Loam
Park Hill GC	2	80-100	0.8	0.3	6.0	0.3	8.0	11.1	0.9	8.1	8.8	0.7	Sandy Loam
Park Hill GC	3	0-20	5.9	1.7	5.1	1.3	2.6	14.2	0.38	2.7	31.1	1.1	Sandy Loam
Park Hill GC	3	20-40	3.3	1.4	4.4	0.7	2.9	11.9	0.33	2.8	17.0	0.5	Sandy Loam
Park Hill GC	3	40-60	3.9	2.0	4.2	0.9	2.5	12.6	0.3	2.4	18.6	0.3	Sandy Loam
Park Hill GC	3	60-80	3.1	1.6	4.2	0.6	2.7	12.3	0.32	2.6	18.7	0.1	Loamy Sand
Park Hill GC	3	80-100	2.8	0.9	3.6	0.4	2.7	14.0	0.39	2.8	16.4	0.1	Sandy Loam
City Park GC	1	0-20	3.4	1.3	11.4	1.6	7.4	11.5	2.03	7.5	54.0	0.9	Loam
City park GC	1	20-40	5.2	1.9	11.2	1.0	5.9	12.8	1.52	6.0	34.8	0.3	Sandy Clay Loam
City park GC	1	40-60	9.7	3.4	8.1	0.7	3.2	35.8	1.16	3.1	28.8	0.2	Clay Loam
City park GC	1	60-80	11.1	3.1	4.8	0.6	1.8	50.4	0.81	1.9	34.9	0.1	Clay Loam
City park GC	1	80-100	12.2	3.2	3.3	0.6	1.2	80.6	0.68	1.1	38.2	0.2	Clay Loam
City park GC	2	0-20	4.2	1.1	9.7	1.0	6.0	13.3	1.55	5.9	26.3	0.9	Sandy Clay Loam
City park GC	2	20-40	3.1	0.6	7.7	0.3	5.7	25.0	1.45	5.8	19.8	0.3	Clay Loam
City park GC	2	40-60	5.4	1.0	6.7	0.3	3.7	34.2	1.23	3.6	18.7	2.0	Clay Loam
City park GC	2	60-80	9.6	1.8	4.8	0.3	2.0	63.0	0.89	2.1	24.1	0.2	Clay

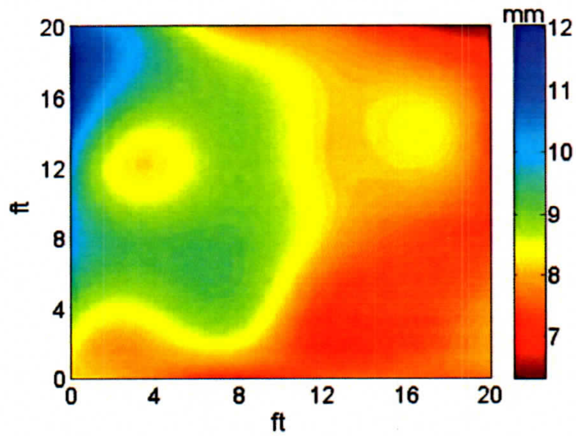
Datasheet 8

Sample ID #	Site	Depth (cm)	Ca	Mg	Na	K	SAR	CEC	Exchangeable Na	ESP %	Hot Water Cl	Hot Water B	Texture Estimate
			meq/L					meq/100g			mg/kg		
City park GC	2	80-100	12.7	2.7	2.7	0.3	1.0	46.2	0.70	1.1	36.4	0.2	Clay
City park GC	3	0-20	3.0	0.8	7.5	1.4	5.4	25.7	1.42	5.5	18.0	1.1	Clay Loam
City park GC	3	20-40	2.9	0.5	9.4	0.9	7.2	18.9	1.34	7.1	20.9	0.5	Sandy Clay Loam
City park GC	3	40-60	1.8	0.2	4.7	0.5	4.6	23.4	1.05	4.5	17.2	0.6	Clay Loam
City park GC	3	60-80	1.5	0.2	3.2	0.4	3.5	25.5	0.89	3.5	10.0	0.2	Sandy Clay Loam
City park GC	3	80-100	2.1	0.3	3.5	0.4	3.2	25.0	0.77	3.1	11.9	0.2	Clay
Denver CC	1	0-20	4.7	1.6	8.3	1.4	4.7	34.1	1.63	4.8	26.6	0.7	Sandy Loam
Denver CC	1	20-40	3.2	1.1	8.1	0.8	5.5	23.4	1.31	5.6	17.2	0.4	Sandy Loam
Denver CC	1	40-60	2.5	0.8	6.0	0.3	4.7	16.7	0.80	4.8	14.1	0.1	Sandy Loam
Denver CC	1	60-80	1.0	0.2	3.3	0.1	4.2	15.1	0.62	4.1	8.0	0.1	Sandy Loam
Denver CC	1	80-100	1.0	0.3	2.9	0.2	3.6	17.0	0.63	3.7	6.9	0.1	Loamy Sand
Denver CC	2	0-20	7.0	2.2	10.9	2.1	5.1	26.8	1.34	5.0	31.1	1.1	Sandy Loam
Denver CC	2	20-40	2.9	0.8	8.9	1.3	6.6	9.7	0.65	6.7	12.2	0.2	Sandy Loam
Denver CC	2	40-60	0.5	0.0	3.7	0.4	7.4	7.0	0.52	7.5	6.9	0.1	Loamy Sand
Denver CC	2	60-80	0.3	0.0	2.9	0.3	6.7	9.0	0.60	6.6	5.8	0.5	Sandy Loam
Denver CC	2	80-100	0.3	0.0	3.0	0.4	7.0	7.8	0.55	7.1	35.6	0.2	Sandy Loam
Denver CC	3	0-20	5.7	1.7	6.4	2.5	3.3	22.7	0.77	3.4	29.8	0.9	Loamy Sand
Denver CC	3	20-40	2.1	0.6	3.6	1.3	3.1	16.6	0.53	3.2	16.5	0.4	Loamy Sand
Denver CC	3	40-60	1.2	0.3	4.0	1.0	4.6	11.4	0.54	4.7	10.4	0.3	Loamy Sand
Denver CC	3	60-80	0.7	0.1	3.3	0.7	5.2	10.2	0.54	5.3	8.07	0.3	Loamy Sand
Denver CC	3	80-100	0.3	0.0	2.2	0.4	5.9	9.3	0.54	5.8	60.4	0.2	Loamy Sand
Denver CC	4	0-20	6.6	1.8	7.0	2.5	3.4	32.7	1.08	3.3	40.4	0.5	Sandy Loam
Denver CC	4	20-40	2.6	0.5	4.6	1.1	3.7	17.3	0.66	3.8	23.1	0.3	Sandy Loam
Denver CC	4	40-60	1.5	0.1	4.3	0.8	4.8	14.6	0.72	4.9	15.5	0.3	Loamy Sand

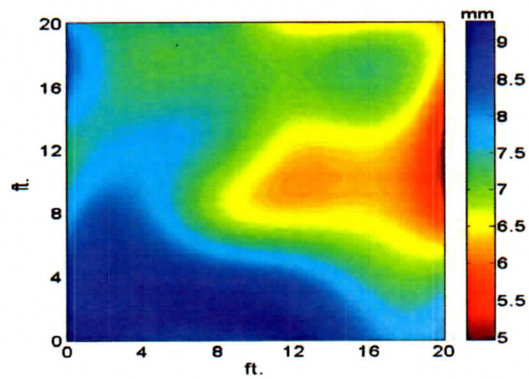
Datasheet 9

Sample ID #	Site	Depth (cm)	Ca	Mg	Na	K	SAR	CEC	Exchangeable Na	ESP	Hot Water Cl	Hot Water B	Texture Estimate
			meq/L					meq/100g		%	mg/kg		
Denver CC	4	60-80	0.4	0.0	2.6	0.4	5.5	8.7	0.49	5.6	14.2	0.2	Loamy Sand
Denver CC	4	80-100	0.2	0.0	1.9	0.2	5.7	9.8	0.57	5.8	12.8	0.1	Loamy Sand
Washington park	1	0-20	3.1	1.1	6.7	0.7	4.7	12.0	0.58	4.8	26.1	0.1	Sandy Loam
Washington park	2	0-20	2.7	1.0	7.8	1.4	5.7	12.6	0.73	5.8	41.5	0.3	Loam
Washington park	3	0-20	2.5	0.9	8.3	1.3	6.4	11.9	0.77	6.5	51.3	0.3	Loam
Washington park	4	0-20	3.6	1.4	10.1	1.8	6.4	13.3	0.88	6.6	55.5	0.5	Sandy Clay
Washington park	5	0-20	1.9	0.6	6.3	0.9	5.6	11.9	0.68	5.7	41.4	0.4	Loam
Washington park	6	0-20	2.5	1.0	7.6	1.4	5.8	13.5	0.77	5.7	69.5	0.3	Sandy Clay
City Park	1	0-20	3.1	1.0	7.4	0.9	5.1	15.8	0.82	5.2	8.6	0.1	Clay Loam
City Park	1	20-40	5.0	1.6	9.3	0.3	5.1	12.7	0.63	5.0	23.1	0.1	Clay Loam
City Park	2	0-20	2.8	1.0	5.8	0.8	4.2	15.2	0.66	4.3	20.9	0.1	Clay Loam
City Park	2	20-40	1.9	0.6	6.3	0.3	5.6	10.8	0.62	5.7	17.6	0.1	Clay Loam
City Park	3	0-20	3.3	1.1	7.0	0.9	4.8	18.8	0.88	4.7	18.0	0.4	Clay Loam
City Park	3	20-40	2.8	1.2	6.8	0.9	4.8	15.2	0.74	4.9	12.9	0.1	Clay Loam
City Park	4	0-20	1.6	0.6	6.4	0.6	6.1	14.3	0.86	6.0	25.1	0.2	Clay Loam
City Park	4	20-40	2.0	0.7	8.2	0.4	7.0	13.3	0.94	7.1	58.7	0.1	Clay Loam
City Park	5	0-20	3.4	1.3	5.2	1.2	3.4	16.2	0.57	3.5	31.8	0.1	Clay Loam
City Park	5	20-40	4.7	1.9	7.1	0.4	3.9	18.5	0.74	4.0	35.3	0.1	Clay Loam
City Park	6	0-20	4.2	1.4	6.2	0.8	3.7	18.0	0.65	3.6	23.7	0.1	Clay Loam
City Park	6	20-40	8.9	3.1	9.5	0.3	3.9	20.7	0.78	3.8	46.1	0.1	Clay
Denver Zoo	1	0-20	4.3	1.1	5.9	1.7	3.6	22.7	0.82	3.6	30.4	0.9	Sandy Loam
Denver Zoo	1	20-40	3.6	1.2	9.0	2.0	5.9	21.7	1.3	6.0	26.9	1.0	Sandy Loam
Denver Zoo	2	0-20	4.6	1.4	6.3	1.6	3.6	18.5	0.68	3.7	32.0	0.7	Sandy Loam
Denver Zoo	2	20-40	2.6	1.1	6.7	0.8	4.9	18.9	0.94	5.0	27.5	0.4	Sandy Loam
Denver Zoo	3	0-20	3.7	1.2	5.6	0.8	3.6	19.1	0.67	3.5	32.6	0.4	Sandy Loam
Denver Zoo	3	20-40	2.7	1.0	5.6	0.8	4.1	17.5	0.73	4.2	25.1	0.5	Sandy Loam

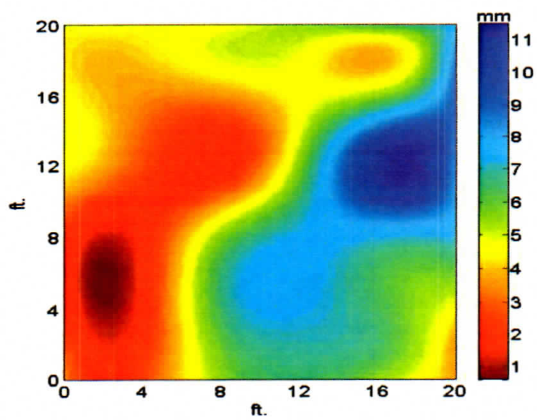
APPENDIX C
Irrigation Uniformity



Schaefer Site 1: DU: 92%, CU: 90%

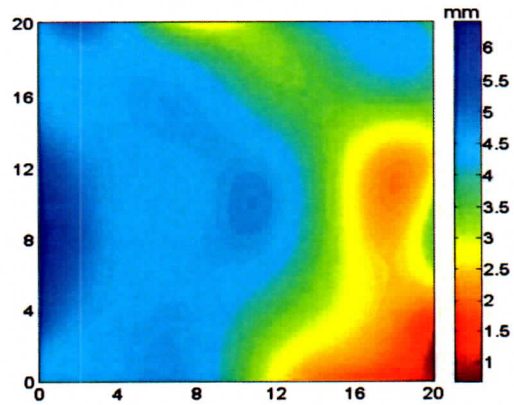


Schaefer Site 2: DU: 86%, CU: 89%

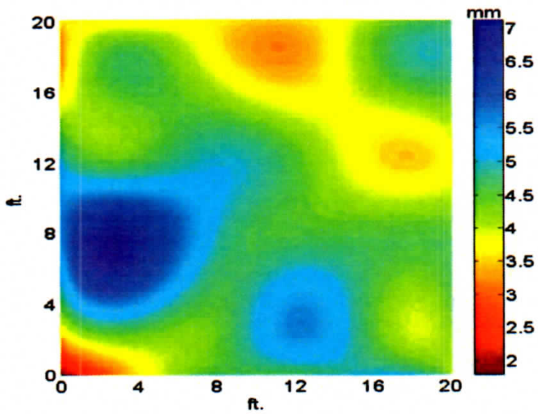


Schaefer Site 3: DU:71%; CU: 68%.

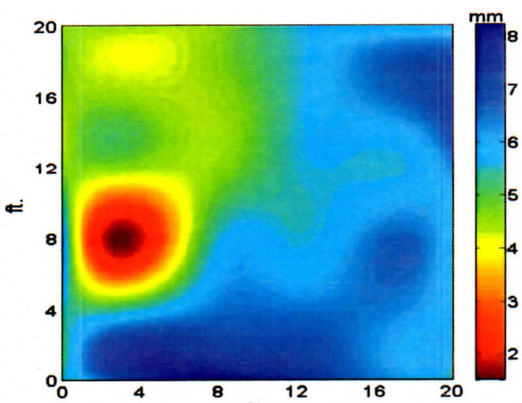
1. Uniformity Map of Water Spatial Distribution after 30 mins Irrigation at **Schaefer Park**



Dunham Site 1: DU 87%; CU 77%

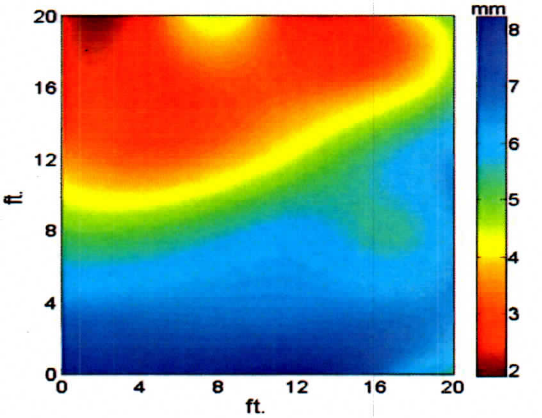


Dunham Site 2: DU 86%; CU 87%

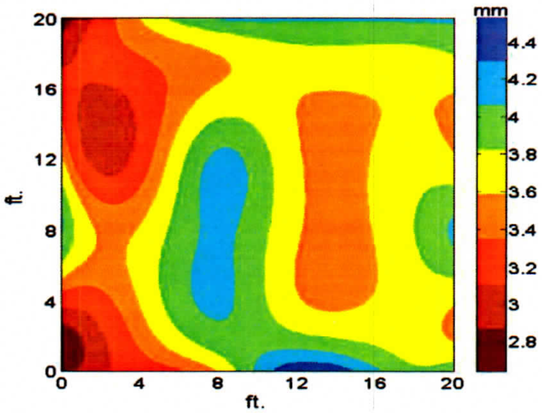


Dunham Site 3: DU 82%, CU 86%

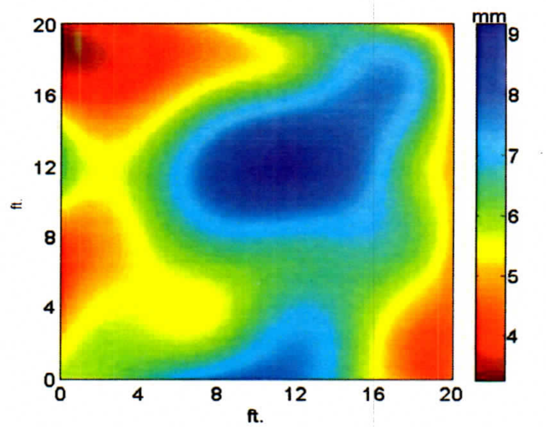
2. Uniformity Map of Water Spatial Distribution after 30 mins Irrigation at **Dunham Park**



Swansea Site 1: DU 69%, CU 72%

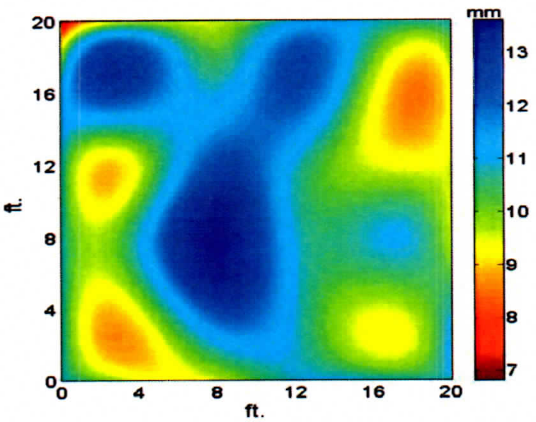


Swansea Site 2: DU 90%, CU 92%

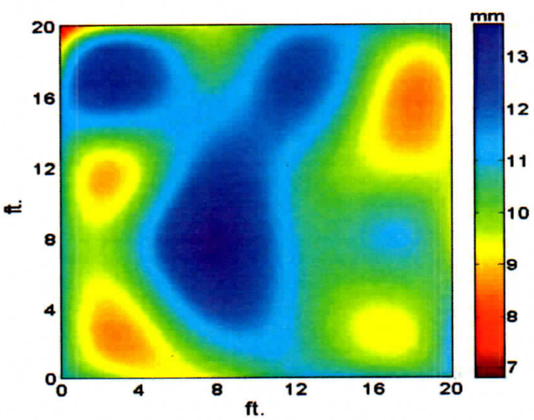


Swansea Site 3: DU 83%, CU 83%

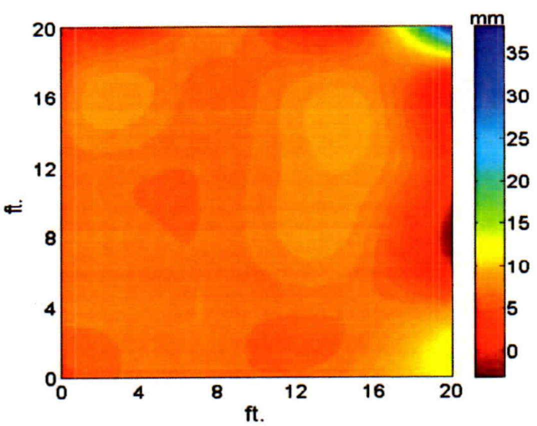
3. Uniformity Map of Water Spatial Distribution after 30 mins Irrigation at **Swansea Park**



City Park Golf Course fairway 3: DU 97%, CU 91%



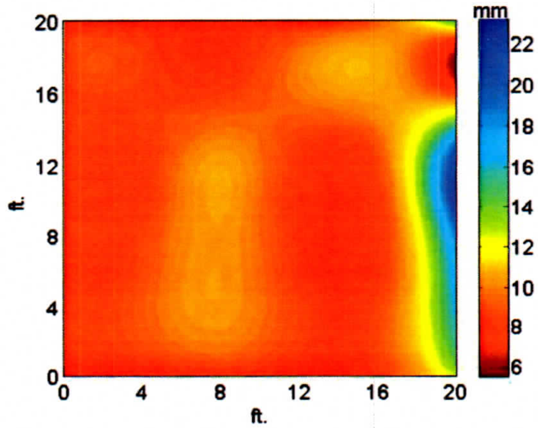
City Park Golf Course fairway 14: DU 90%, CU 92%



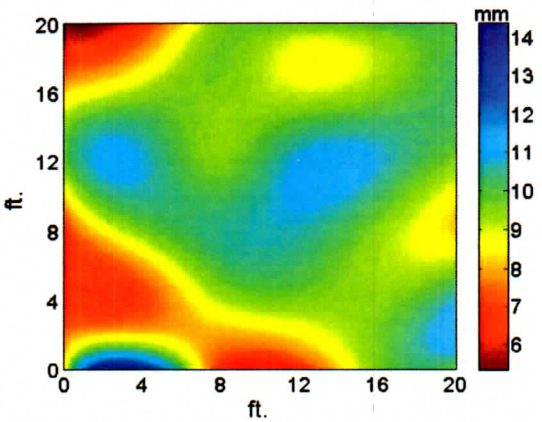
City Park Golf Course fairway 17: DU 99%, CU 91%)

4. Uniformity Map of Water Spatial Distribution after 30 mins Irrigation at

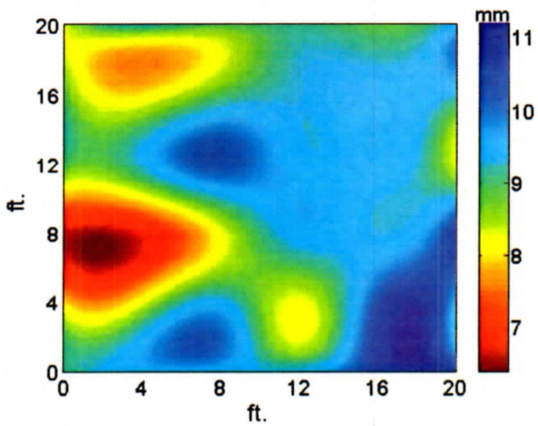
City Park Golf Course



Denver Country Club Fairway 2: DU 93%, CU 94%

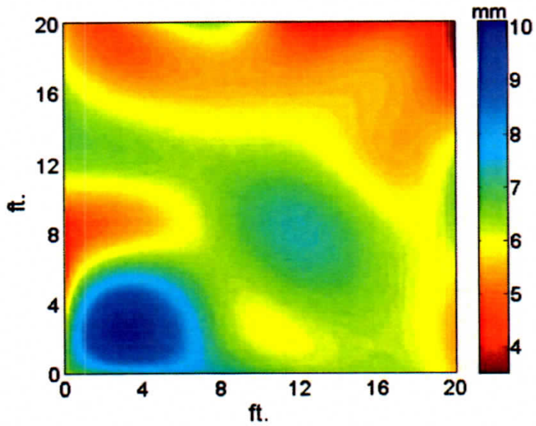


Denver Country Club Fairway 14: DU 89%, CU 87%

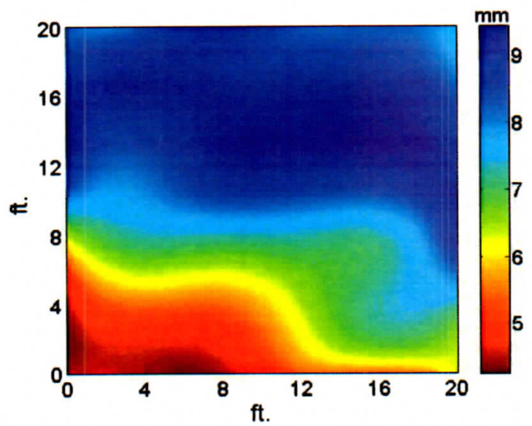


Denver Country Club Fairway 16: DU 95%, CU 92%

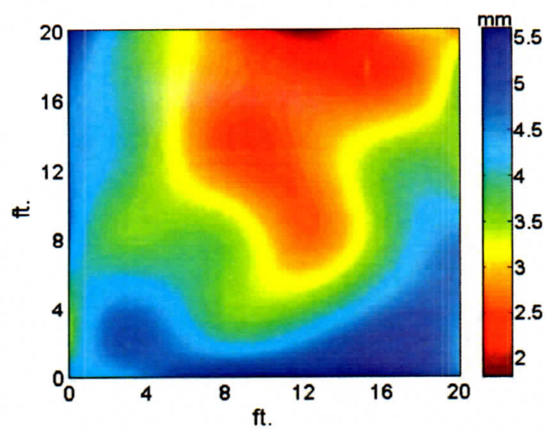
5. Uniformity Map of Water Spatial Distribution after 30 mins Irrigation at
Denver Country Club



Park Hill Golf Course Fairway 2: DU 92%, CU 87%

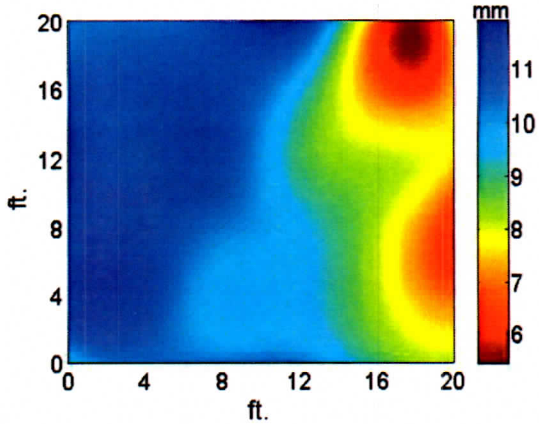


Park Hill Golf Course Fairway 8: DU 85%, CU %82

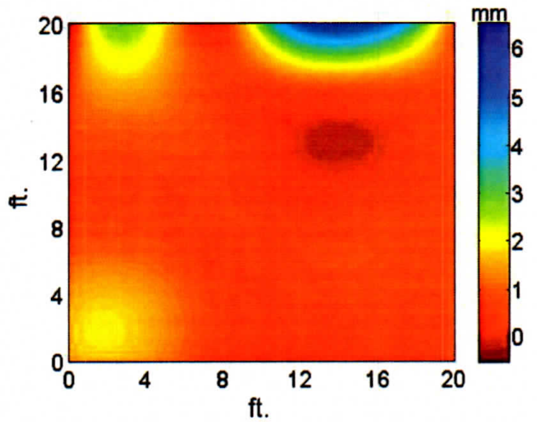


Park Hill Golf Course Fairway 10: DU 72%, CU 80%

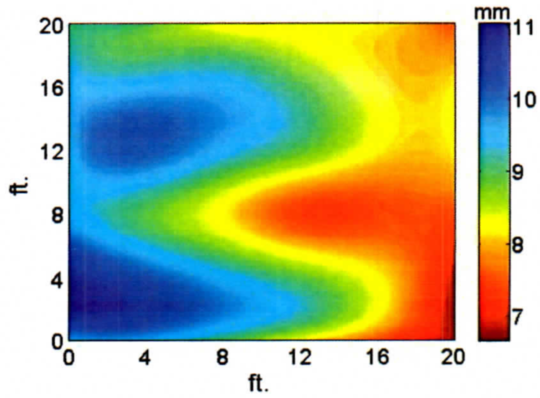
6: Uniformity Map of Water Spatial Distribution after 30 mins Irrigation at
Park Hill Golf Course



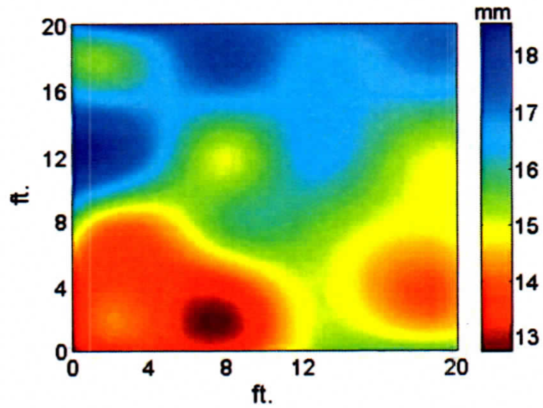
Washington Park Site 1: DU 86%, CU 86%



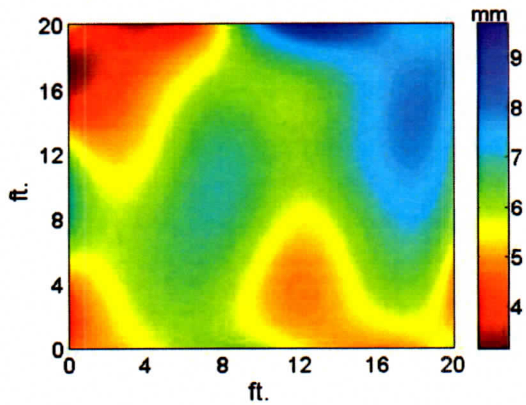
Washington Park Site 2: DU 91%, CU 73%



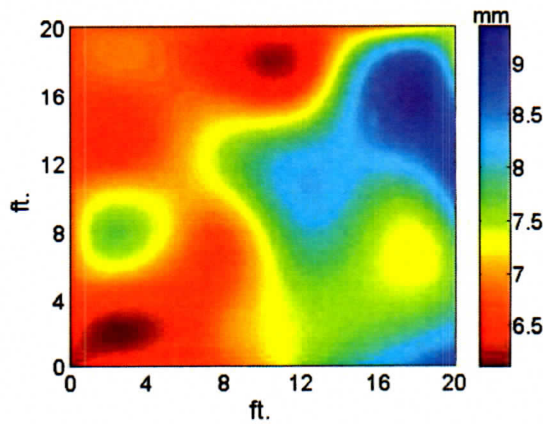
Washington Park Site 3: DU 94%, CU 91%



Washington Park Site 4: DU 95%, CU 93%

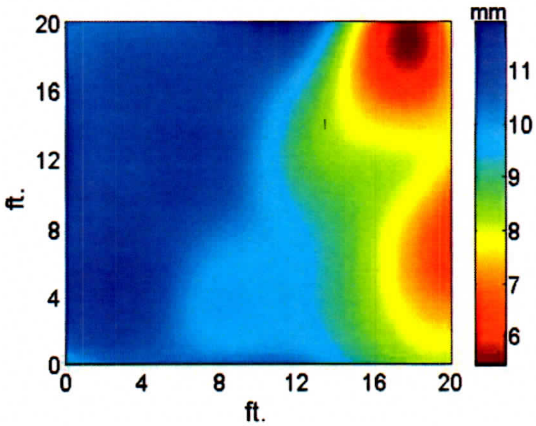


Washington Park Site 5: DU 90%, CU 85%

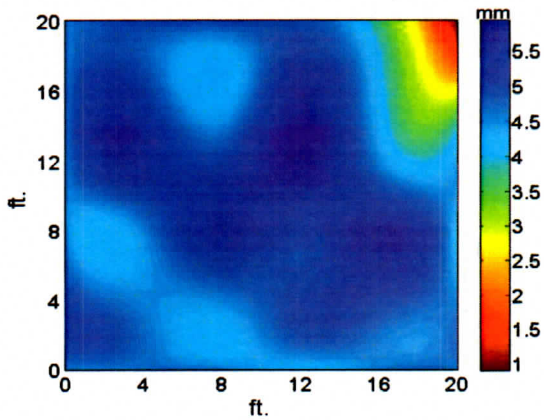


Washington Park Site 6: DU 93%, CU 92%

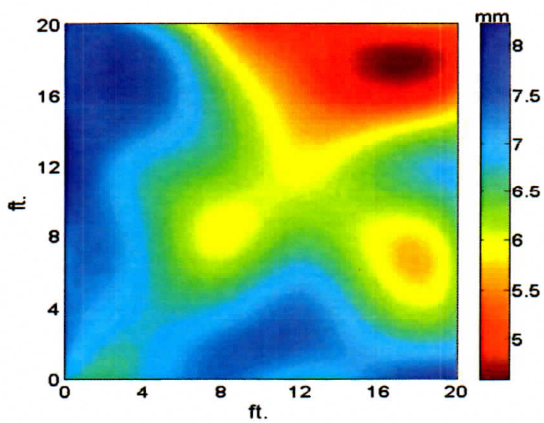
7. Uniformity Map of Water Spatial Distribution after 30 mins Irrigation at **Washington Park.**



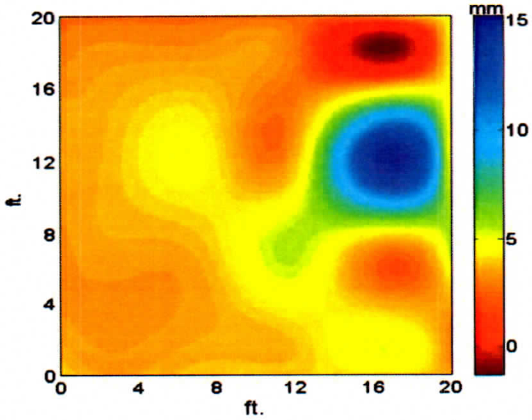
City Park Site 1: DU 69%, CU 64%



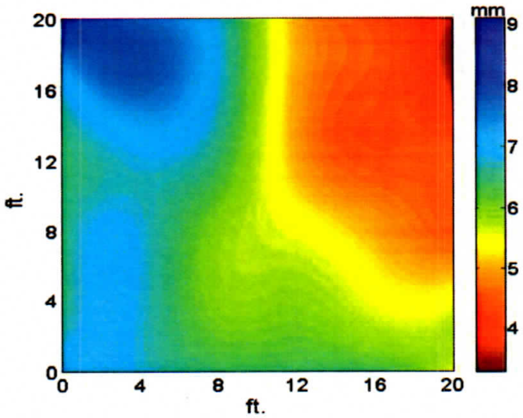
City Park Site 2: DU 90%, CU 89%



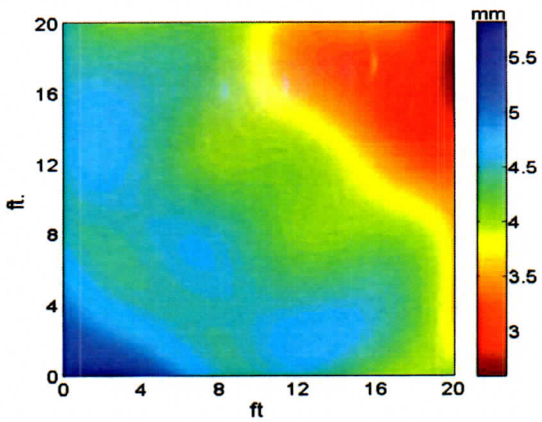
City Park Site 3: DU 90%, CU 90%



City Park Site 4: DU 79%, CU 78%

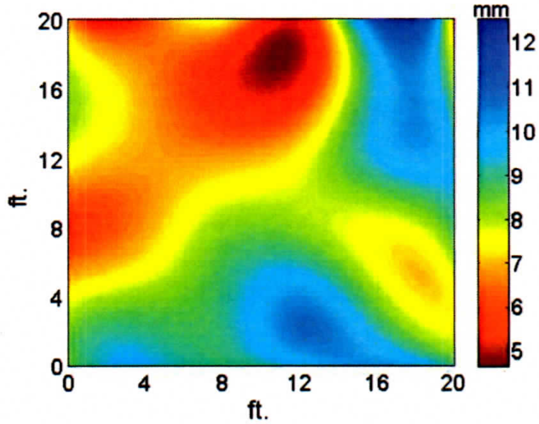


City Park Site 5: DU 84%, CU 84%

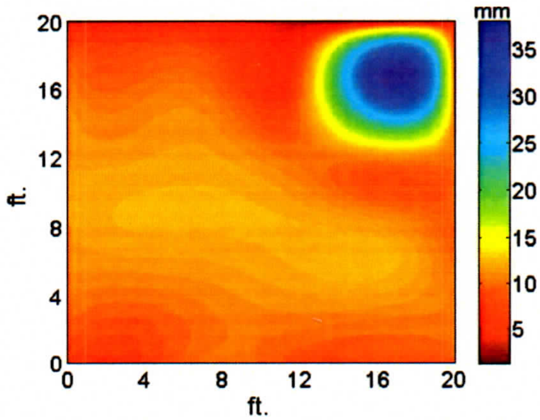


City Park Site 6: DU 87%, CU 88%

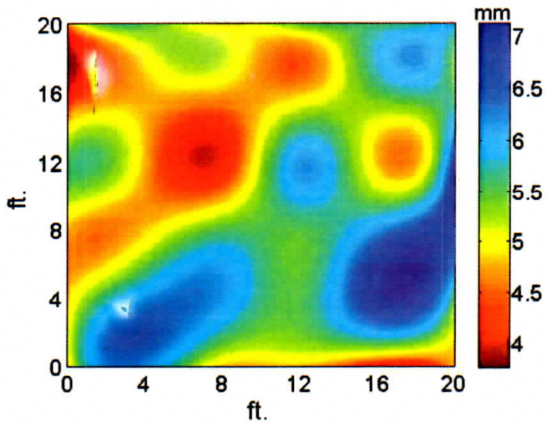
8. Uniformity Map of Water Spatial Distribution after 30 mins Irrigation at **City Park.**



Bruce Randolph Middle School Site 1: DU 86%, CU 85%



Bruce Randolph Middle School Site 2: DU 87%, CU 77%



Bruce Randolph Middle School Site 3: DU 90%, CU 88%

9. Uniformity Map of Water Spatial Distribution after 30 mins Irrigation at
Bruce Randolph Middle School

APPENDIX D

Interpretation of Landscape Irrigation Water Quality

The use of recycled water in Colorado is regulated by the Water Quality Control Division under Regulation No. 84, Reclaimed Water Control Regulation. Regulation 84 uses human health related parameters such as E-coli count, turbidity, and total suspended solids to evaluate water quality. In additions to the parameters outlined in Regulation 84, the following agronomic-related water quality parameters that affect soil salinity, sodicity, and other chemical properties need to be evaluated.

a. Salinity

Water salinity is most commonly measured by electrical conductivity (EC) and is reported in units of dS/m or mmhos/cm. These units are synonymous. Water with an electrical conductivity (EC) value less than 0.75 mmho/cm are safe for irrigation. Water with an EC above 3 dSm^{-1} should be avoided or diluted with less saline water before use.

However, salt accumulation in the soil profile is not a function of water salinity alone. The accumulation potential also depends on the amount of water applied annually, annual precipitation, and a particular soil's physical/chemical characteristics. Good permeability and drainage allow salt leaching from the rootzone by periodic heavy irrigations. Only careful management can prevent deleterious salt accumulation in a soil irrigated with high EC water. Soil physical characteristics and drainage must also be considered in determining the suitability of a given recycled irrigation water.

b. Sodium and Sodium Adsorption Ratio (SAR)

Sodicity refers the high sodium effect on soils or plants. Although sodium can be directly toxic to plants, its most frequent damage is due to its effect on soil structure. High sodium content can cause deflocculation or breakdown of soil clay particles, making such a soil less permeable to both water and air. The likely effect of a particular irrigation water on soil permeability is best gauged by the water's sodium adsorption ratio (SAR), a measure of the concentration of sodium in water relative to that of calcium and magnesium.

Complicating the SAR interpretation is bicarbonate level. In addition to increasing soil pH, bicarbonate combines with calcium and/or magnesium and forms precipitates, thereby lowering calcium and magnesium concentrations in the soil solution. For water high in bicarbonate, adjusted SAR can be calculated. Adjusted SAR decreases with increasing calcium, magnesium, and the water's total salinity and rises as sodium, bicarbonate, and carbonate concentrations increase.

We can use adjusted SAR to assess the sodium permeability hazard. An adjusted SAR > 6-9 gradually leads to soil structure deterioration, including soil sealing, crusting, and reduced water penetration after long-term use for irrigation. Such effects are more severe in fine textured soil and heavy traffic areas.

c. Hydrogen Ion Activity (pH)

The desirable pH of most irrigation water ranges from 6.5 to 8.4. A very high or low pH of water warns users that water needs evaluation for other constituents. For example, increased pH may signal a high bicarbonate concentration in the water. High algae populations that build up in irrigation ponds may also alter water pH (rise during the daytime and drop at night). This is because photosynthesis of algae removes CO_2 (carbonic acid) from the water causing the pH to rise during daytime. Consistently high pH can cause iron and/or manganese deficiencies in landscape plants, resulting in plant chlorosis.

d. Specific Ions

In addition to contributing to the total soluble salt concentration of irrigation water, particular ions (sodium, chloride, and boron) may be directly toxic to plants, especially some trees and shrubs. Chloride (Cl), sodium (Na), and boron (B) can be absorbed by plant roots and translocated to leaves, where they accumulate in sensitive plants. This accumulation leads to leaf margin scorch in minor cases, total leaf kill and abscission in severe situations. Irrigation waters with Na and Cl content above 100 and 355 ppm, respectively, are considered toxic to sensitive plants when absorbed by roots. Boron concentrations as low as 1 to 2 ppm in irrigation water can be toxic to many sensitive ornamental plants.

With sprinkler irrigation, Na and Cl frequently accumulate by direct absorption through the leaves that are moistened by irrigation water. Trees and shrubs are more sensitive to sodium and chloride sprayed directly onto plant leaves vs. root absorption. Sodium and Cl toxicity could occur on sensitive plants when Na and Cl concentrations exceed 70 and 100 ppm, respectively, when the water is sprayed directly on the foliage.

e. Nutrients

Recycled waters contain a range of micro-elements at levels sufficient to satisfy the need of most turfgrasses for these substances. They may also contain enough macro-nutrients, nitrogen (N), phosphorus (P), and potassium (K) to figure significantly in a fertilization program. The economic value of these nutrients can be substantial. When effluent water is used for irrigation, regular testing will allow adjustment in N and P applications. For example, an N content in effluent water of 10 ppm adds 27 lb nitrogen per acre with each acre-foot of irrigation water. This amount of N should be deducted from the fertilization program. However, high nutrient content in water will increase irrigation pond algae population.

Chemical composition of effluent water varies significantly, even within the same geological area. The suitability of a given water for irrigation must, therefore, be evaluated separately for each site. Landscape managers should regularly monitor water quality. In addition, soil type, turf type, shrub and tree species, and irrigation efficiency should also be considered.