PRZ SPORTS TURF CONSULTING

4/5/2011

Abigail Holmquist, PE
Recycled Water Program Manager
Denver Water.
1600 W 12th Ave.
Denver, CO 80204

RE: PRZ Recycled Water Study and Economic Analysis
10 Sites

Dear Abby:

In September of 2010 PRZ Consulting and THK Associates visited 9 of the 10 sites that Denver Water had included in a 5 year soils analysis study by Colorado State University. In speaking with maintenance directors and supervisors at each site, the PRZ/THK team discovered several interesting new pieces of information that were not identified in the 5 year study. This information will be covered in the body of this assessment.

Our major findings:

1. The soil parameters associated with sodium have all increased in the soils at these 10 sites even though in most cases there was little visual evidence. This report includes the triggers that should be followed to begin monitoring and to prevent sodium accumulation.

2. The PRZ/THK Team recommends that the clay percentage in the soils and plasticity index of the soil should be monitored as well as the other soil characteristics. The higher the clay percentage combined with a higher plasticity index, the quicker the sodium accumulates. Soils with clay percentages of 25% or higher should be tested every other year and soils with less than 25% clay should be tested every 4 years.

3. After visiting the sites and reviewing the CSU Soils and Tissue Culture reports & Denver's soil results, it appears that the direct spray of the recycled water onto trees and vegetation rather than the sodium accumulation in the soils is causing the observed tree damage.

4. Recycled water rates are substantially lower than potable water rates, which results in savings for recycled water users. These savings could be put towards additional maintenance practices recommended when irrigating with recycled water. An economic analysis is provided in this report.

PRZ Consulting and THK Associates look forward to helping you understand and implement the ideas found in this assessment.

Sincerely,

Larry Musser
President, PRZ Consulting

Kevin Shanks
Principal, THK Associates

Mark Wilson
Senior Associate THK Associates

A Study for:

Reclaimed Water and Economic Implications for 10 Sites

for the

Denver Water

DENVER WATER

April 5, 2011

PRZ SPORTS TURF CONSULTING

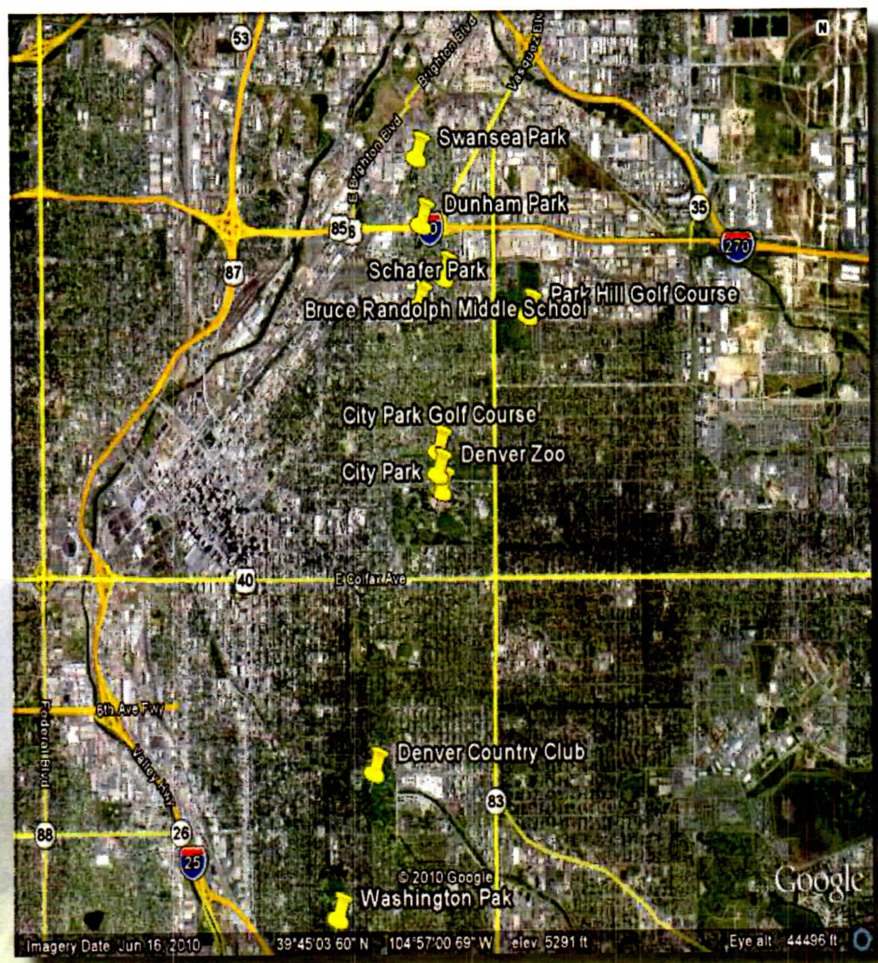
THK associates, inc.
2953 South Peoria Street, Suite 101
Aurora, Colorado 80014
303.770.7201 fax 303.770.7132

Executive Summary

The Project

The purpose of this study was to examine the effects of reclaimed water for 10 park/golf course sites in the City of Denver. This study was to examine soil and site conditions and to make recommendations on methods and treatments to help alleviate the potential problems created by using reclaimed water for irrigation.

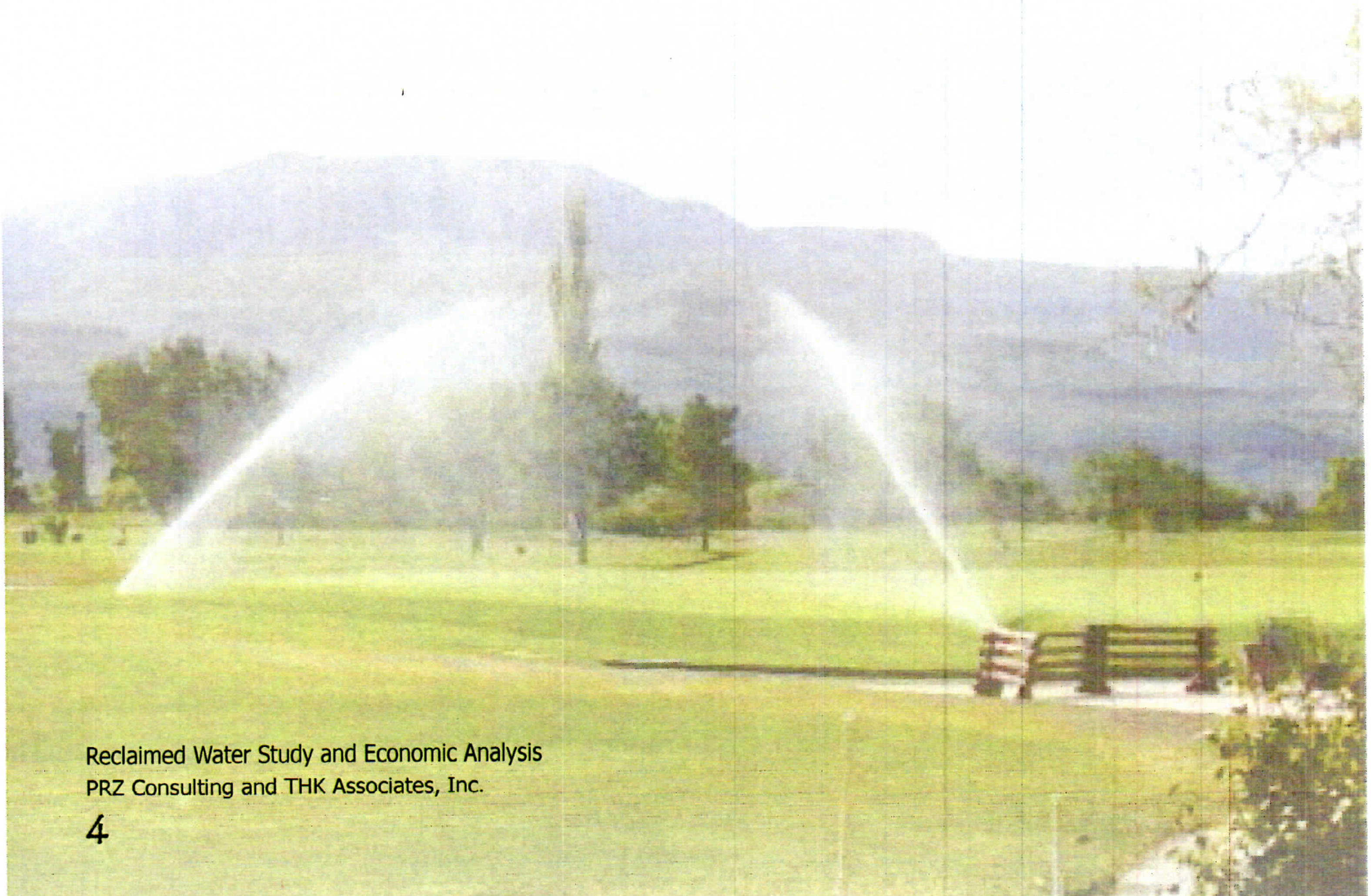
The 10 sites were located in the Denver area. The design team visited 9 of the 10 sites. The map on this page generally depicts each site location (see page 6 for a more detailed map). Several soil borings were taken at each site as well as a visual inspection of site conditions and an assessment of turf and landscape elements. A photo inventory of potential problem areas is also included.



The Results

After visiting the sites, meeting with park superintendents/supervisors, analyzing the soil conditions and field conditions, and reviewing past studies, it became apparent that reclaimed water has an impact on soils, turf viability, landscape elements (trees, shrubs, vines) and maintenance budgets.

Two types of water delivery systems were identified. The first was classified as a "closed system," where reclaimed water was delivered to a project site through pipes and directly to the irrigation system. The second category was an "open system" and classified as reclaimed water delivered to a site and put into either an open channel or a pond, then into the irrigation system. At sites with "open systems", the recycled water had a more noticeable impact on landscapes and operations.



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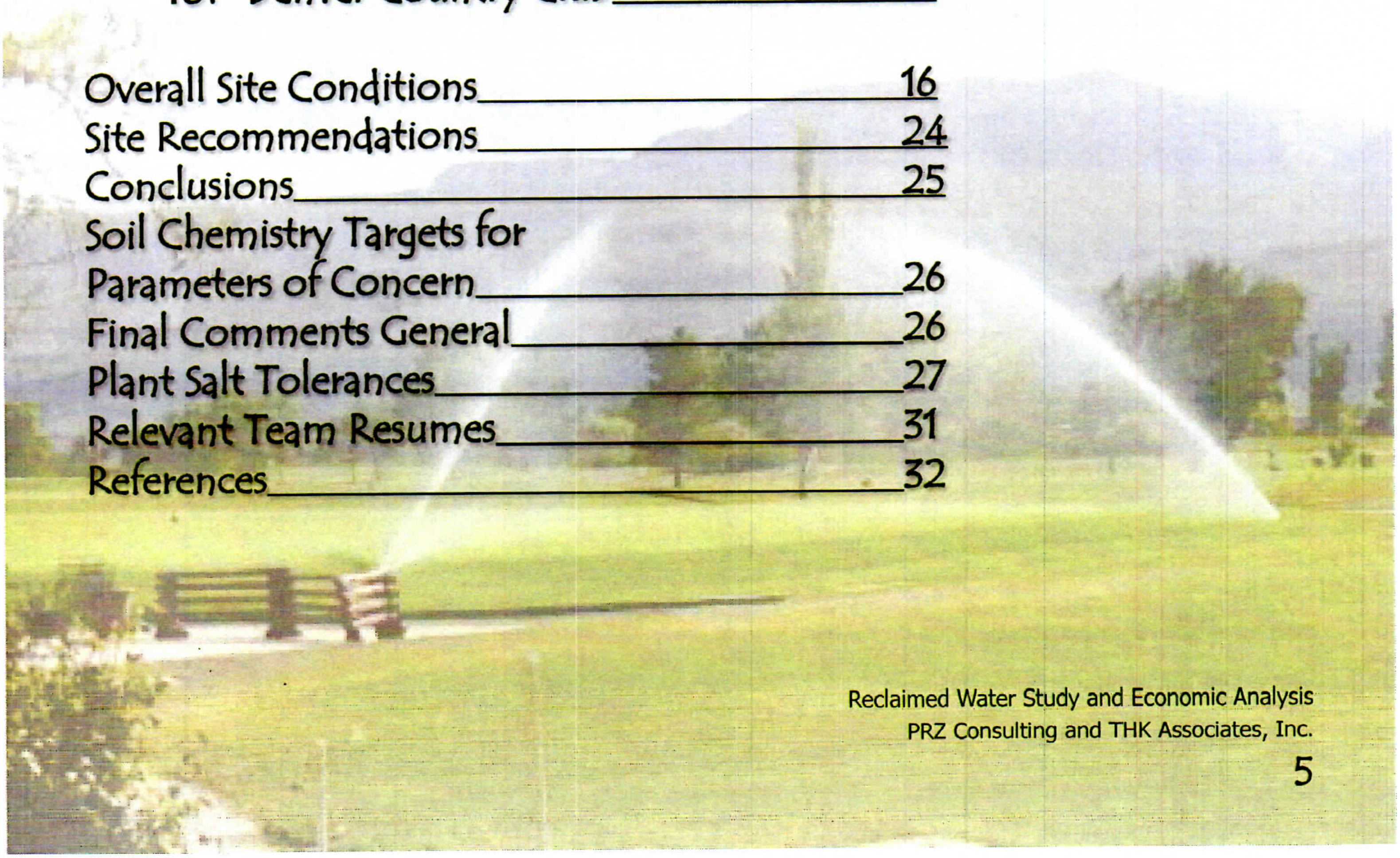
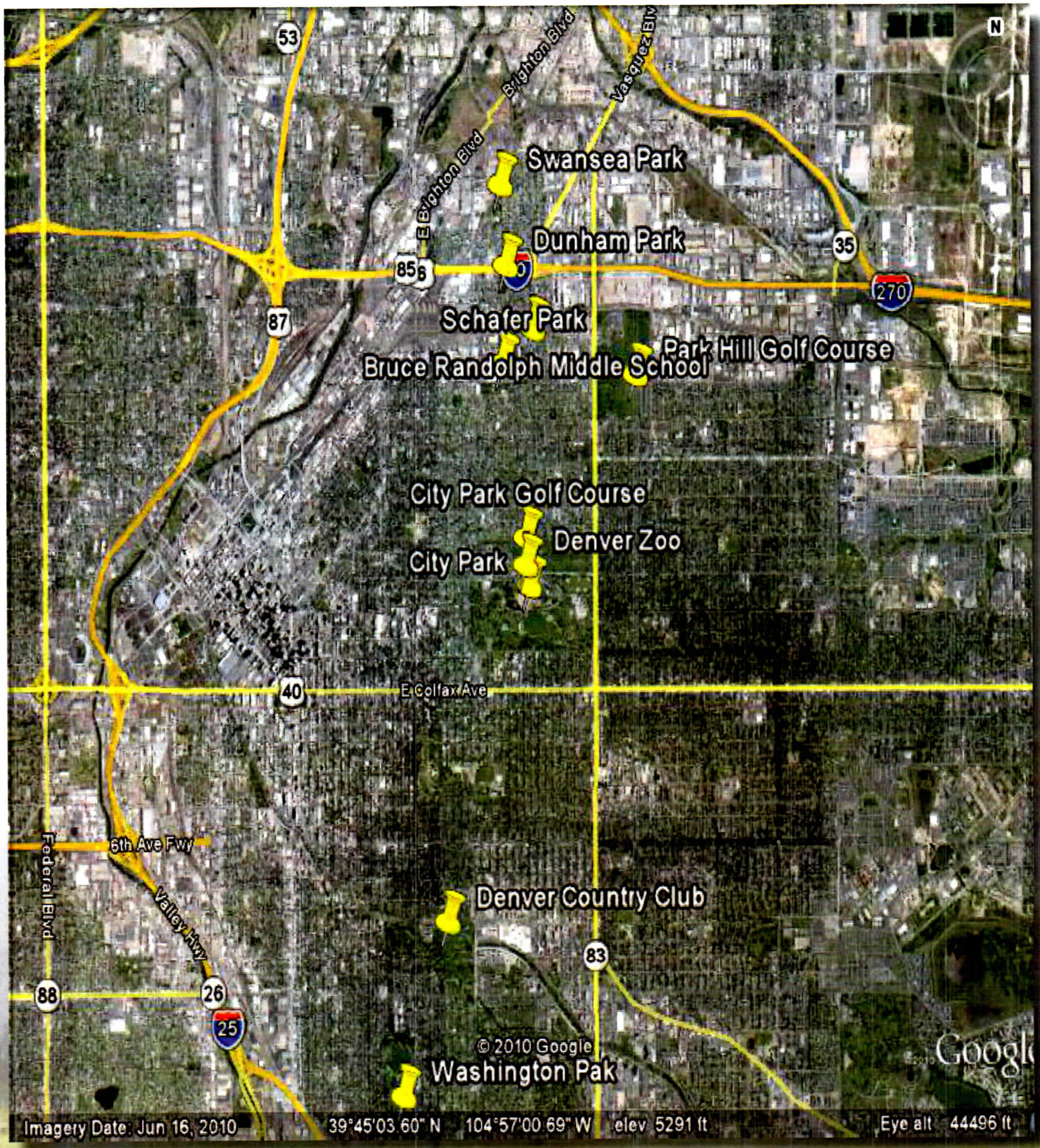




Project Site Locations

Introduction

Denver Water introduced recycled water to many of Denver's parks and golf courses in 2004. The trend to convert from potable water sources to recycled water sources for irrigation is being embraced by most communities.

Denver Water has obtained the services of PRZ Consulting and THK Associates, Inc. to evaluate the following 10 sites:

1. City Park Golf Course
2. Park Hill Golf Course
3. City Park
4. Washington Park
5. Denver Zoo
6. Dunham Park
7. Swansea Park
8. Schafer Park
9. Bruce Randolph Middle School
10. Denver Country Club did not visit. Have soil data to compare.

Site visits were conducted on September 9th and 10th, 2010. Soil borings were collected at each site. The sites were also photographed and observed for site conditions such as drainage patterns, irrigation patterns, micro-climates etc.

The purpose of this assessment is to:
1. Determine the best methods for predicting future problems.
2. Determine best practices for preventing these problems.
3. Determine the economic ramifications of each of these practices.

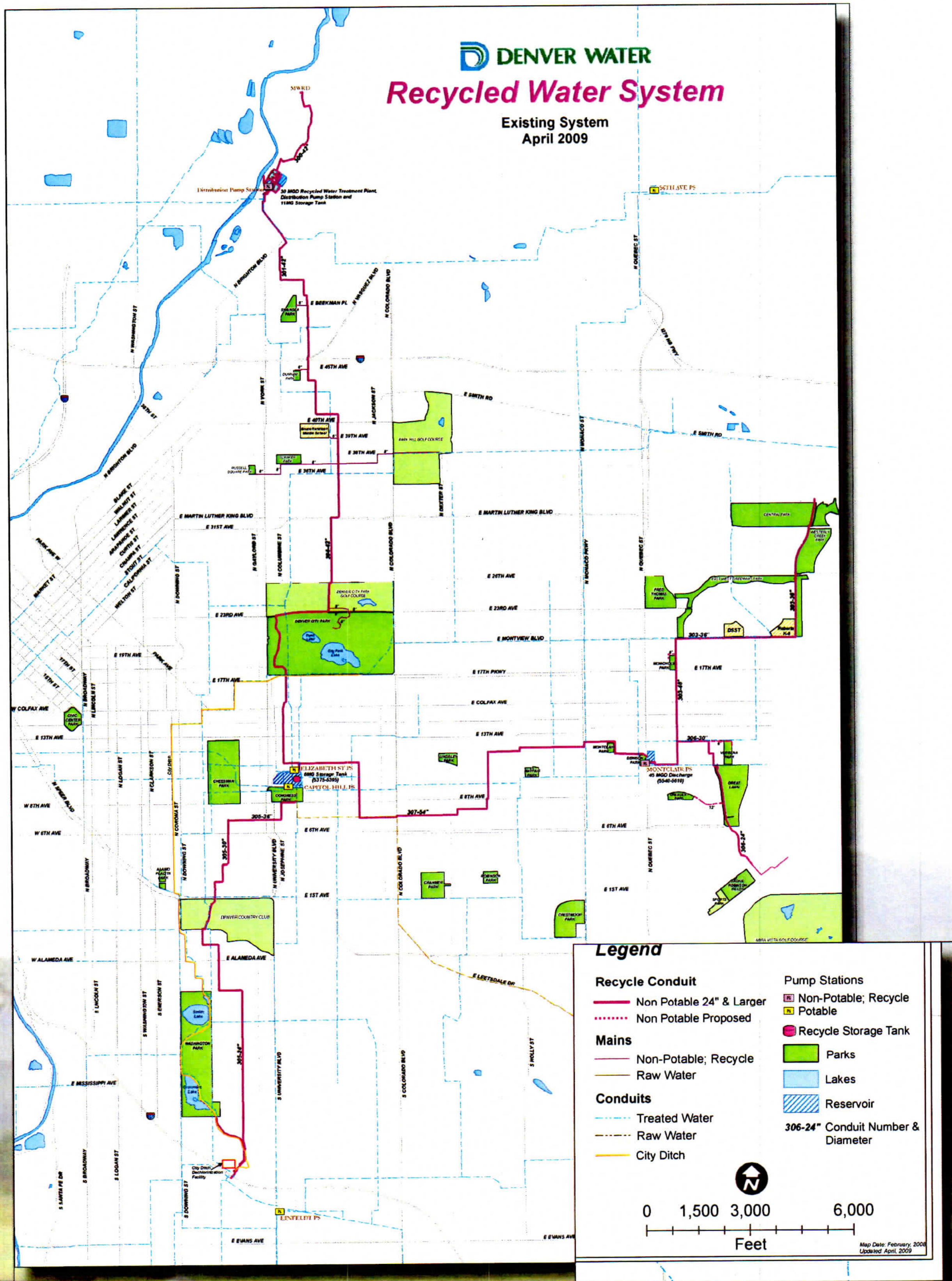
Background

This chart demonstrates soil root and leaf toxicities. The red line on the chart below indicates that a water quality parameter in the soil, root and leaf are in a toxicity zone. This parameter and the parameters of the normal column levels were derived from Servitech Labs in Dodge City, Kansas.

Denver's recycled water, like those cities listed below, have levels of nitrogen that are beneficial to all plants. This benefit must be considered in any turf fertilization programs.

RECYCLED & POTABLE IRRIGATION WATER ANALYSIS COMPARISON

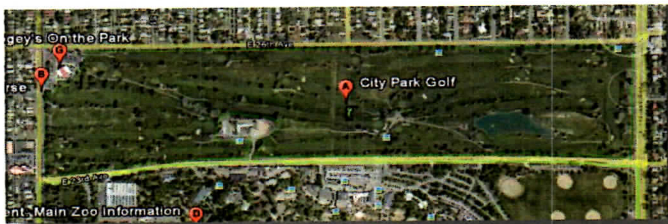
Analysis		Units	Normal Levels	Soil ,Root & Leaf Toxicity	5 year Recycled Average	5 Year Potable Average	Multiplier Recycled Higher than Potable
Total Nitrogen	N03-N	mg/l	5-50		14.1	0.11	128.2
Chloride	Cl	mg/l	0-70	>100	106	13.1	8.1
Sulfate	S04	mg/l	30-90		142	36.21	3.9
Sulfate-Sulfur	S04-S	mg/l			55.45		
Bicarbonate	HC03	mg/l	0-90	>500	110.5	53.1	2.1
Carbonate	C03	mg/l			<10	<10	
Hydroxide, OH		mg/l	<10		<10	<10	
Total Alkalinity	CaC03	mg/l			90.5	43.59	2.1
Hardness	CaC03	mg/l			150	71.69	2.1
Hardness	Grains	gr./gl	0-200	>200	9	4	2.1
Total Calcium	Ca	mg/l	20-60		50	20.92	2.4
Total Magnesium	Mg	mg/l	10-25		12	4.96	2.4
Total Potassium	K	mg/l	5-20		13	1.39	9.4
Total Sodium	Na	mg/l	0-70	>210	130	13.8	9.4
Sodium Absorption Ratio SAR			<6	>9	1.7	0.8	2.1
Adjusted SAR	SARa				5.2	1.1	4.7
Sodium,	% of Cations				64.06%	25.15%	2.5
Boron	B	mg/l	<.7	>3	0.30	0.09	3.1
Total Iron,	Fe	mg/l			0.22	0.05	4.4
Total Manganese,	Mn	Mn			0.0395	0.005	7.9
Toatal Zinc		Zn			0.031	0.005	6.2
Phosphorus	PO4	mg/l	.3-1.21	>1.21	0.0171		
Electrical Conductivity mmho/cm EC			70	>1000	805	206.28	3.9
Total Dissolved Solids		mg/l	<450	>500	515	126.51	4.1
Water pH					7.16	7.6	
Water pHc					7.9	8.0	



Reclaimed Water System

Individual Park Descriptions

1. City Park Golf Course



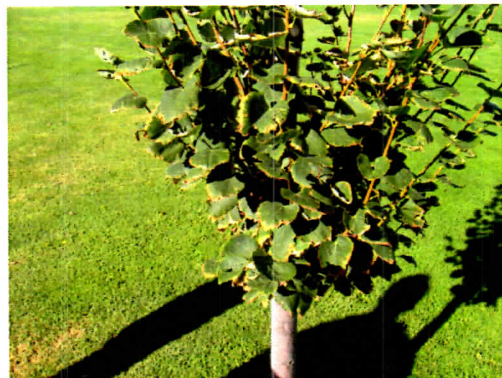
a. Location:
Site is located between 26th Ave. and 23rd Ave., between York St. and Colorado Blvd.

b. General Character/Site Conditions:
Manicured public golf course. Many mature trees. A large pond helps to serve as a site detention area as well provide irrigation for the course.

c. Turf/Plant Material Appearance:
Several stressed and dying/dead trees were evident. Primarily Spruce and Pine species. Several large turf areas had little or no grass coverage.

Dead Pine Tree at City Park Golf Course

Stressed evergreen trees along City Park Golf Course perimeter



Stressed Little Leaf Linden (leaf burn) at City Park Golf Course

2. Park Hill Golf Course

a. Location:
Located south of Smith Rd. between Colorado Blvd. and Dahlia St.

b. General Character/Site Conditions:
Manicured public golf course. Many mature trees with several irrigation/ detention ponds. Additional research indicates that this park was

irrigated with saline wells prior to the introduction of recycled water.

c. Turf/Plant Material Appearance:
Many stressed and dying dead trees were evident, primarily Spruce, Pine and some oak species. Turf Areas were stressed in several areas.

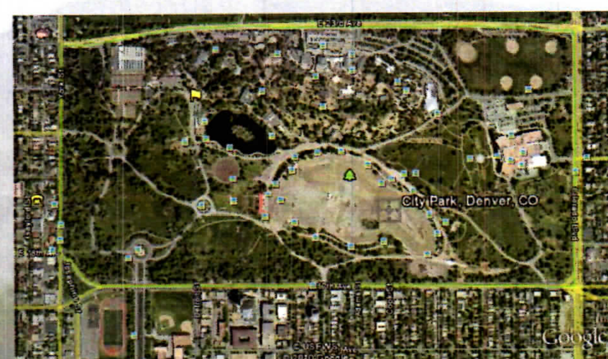
d. Additional Information:
The park superintendent indicated that valve seats, clogged heads etc. were requiring replacement at an unusually high rate and that Park Hill Golf Course lost approximately 40 trees (mostly evergreens) during 2010. Most of the Park Hill Golf Course problems were attributed to an antiquated irrigation system (low head pressure and no head-to-head coverage). In addition, information from the CSU study indicated that Park Hill Golf Course had a history of using saline well water for irrigation before recycled water was introduced, which was likely responsible for much of the tree and turf damage observed.

Leaf edge burn on Oak Tree at Park Hill Golf Course

Poor Turf Condition at Park Hill Golf Course

Stressed Ponderosa Pine at Park Hill Golf Course

3. City Park



a. Location:
Located south of City Park Golf Course, bounded by 23rd Ave and 17th Ave (north and south) with Colorado Boulevard to the east and York Street to the west

b. General Character/Site Conditions: Large park area with irrigated/manicured areas and natural, more xeric areas located throughout the park. Several large ponds and open channels also exist and serve to irrigate the park.

c. Turf/Plant Material Appearance: Stressed and dying evergreen trees.

d. Additional Information: The Park Superintendent indicated that there were issues with irrigation part replacement and problems with the pump room that pumped recycled water into the fountains. Valve seats, pump seals were reported to be degrading at a rapid rate and occurred after recycled water was introduced to that system.

This damage was primarily observed right after the system is turned on in the spring, possibly due to organic residue that has dried in the system after shut down in the fall that is causing a chemical reaction. Testing in the spring is recommended to determine the cause of this unique problem.

Dead/dying evergreen trees at City Park

4. Washington Park

a. Location: Large park located between Downing and Franklin Streets, south of Virginia Ave. and north of Louisiana Ave.

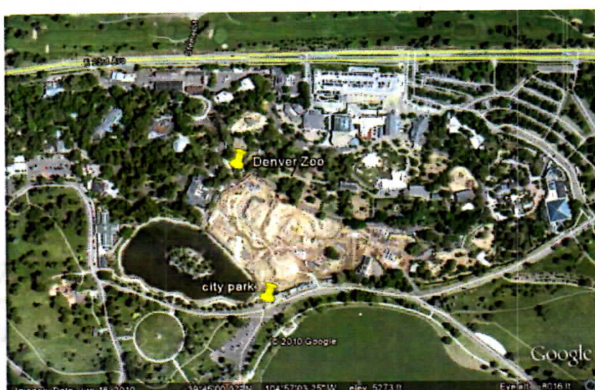
b. General Character/Site Conditions: Large manicured park with large ponds and open channels for the conveyance of water. Additional research indicates that Washington Park has used "raw water" water for many years prior to the introduction of recycled water.

c. Turf/Plant Material Appearance: Vast expanses of turf have little or no stressed growth patterns.

d. Additional Information: Tree problems were specifically noted along one of the recycled water storage ponds along Franklin Street. A large Horn Bean and several evergreens were in a stressed condition, possibly due to having the root system that extends into the pond or being impacted by direct irrigation spray.

Stressed Ponderosa Pine and Horn Beam along Franklin Street (Existing irrigation pond is located to the left, off picture)

5. Denver Zoo



a. Location:
The Denver Zoo is located at the northern edge of Denver City Park along 23rd Avenue.

b. General Character/Site Conditions:
The Zoo has several grass open areas with mature trees.

c. Turf/Plant Material Appearance:
No specific problems were noticed.

d. Additional Information:
Soil samples were taken at one location where previous samples were taken. No problems were noticed from any of the staff regarding the recycled water usage.

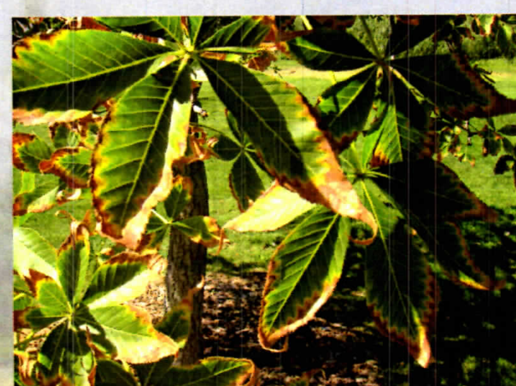
6. Dunham Park

a. Location:
This northeast Denver park is located between 44th Ave. and 45th Ave. along Clayton St.

b. General Character/Site Conditions:
Manicured park site with sport fields and mature trees.

c. Turf/Plant Material Appearance:
Minor visible problems with turf and vegetation. Burned leaf edges were prevalent.

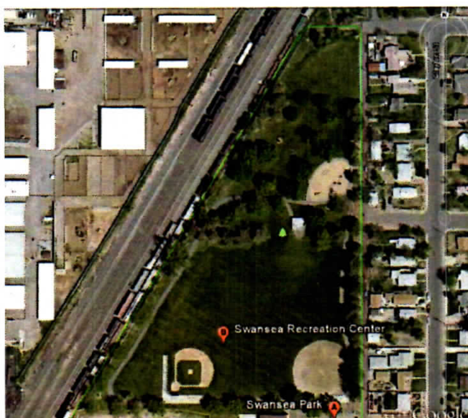
d. Additional Information:
The park superintendent indicated that this park has not had any major problems since recycled water was introduced.



Leaf Burn on several deciduous trees at Dunham Park

Stressed turf areas at Dunham Park

7. Swansea Park



a. Location:
Located at 37th Ave. and Clayton St.

b. General Character/Site Conditions:
Manicured park with ball fields, open play and mature stands of trees.

c. Turf/Plant Material Appearance:
No visible problems with turf or vegetation.

d. Additional Information:
Soil borings were taken and a site inventory was conducted. No park staff was available.

8. Schafer Park

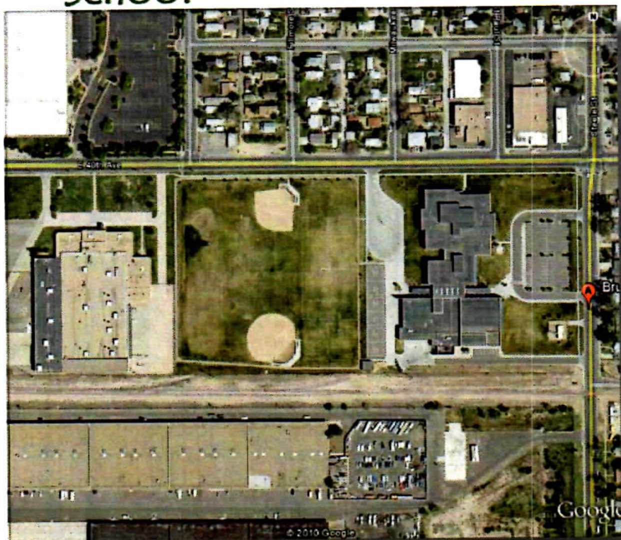
a. Location:
37th Ave and Clayton St.

b. General Character/Site Conditions:
Manicured park site with tennis courts, ball fields and open play.

c. Turf/Plant Material Appearance:
No specific problems seen as related to recycled water.

d. Additional Information:
Phone conversation with park superintendent said that there were no known problems with using recycled water.

9. Bruce Randolph Middle School



a. Location:
Existing Middle School located at Steele St. and 45th Ave.

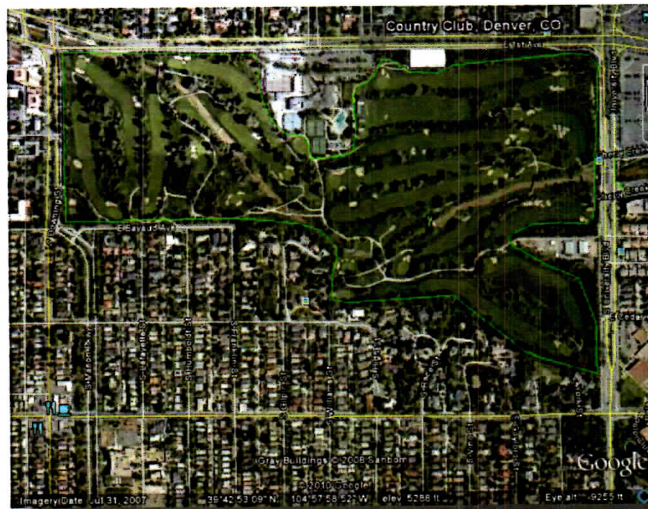
b. General Character/Site Conditions:
Intensely used sport field complex consisting of ball fields, soccer fields and football fields

c. Turf/Plant Material Appearance:
Extreme high use of turf areas. Extensive turf area wear.

d. Additional Information:
Field superintendent indicated there were no known problems pertaining to recycled water.

Extreme Turf Wear at
Bruce Randolph Middle School

10. Denver Country Club



a. Location:
1st Ave. and University Blvd.

b. General Character/Site Conditions:
Finely manicured golf course.

c. Turf/Plant Material Appearance:
No known plant or turf abnormalities as a result of recycled water based on a phone conversation with the golf superintendent. Did not visit the site or meet with anyone from Denver Country Club.

d. Additional Information:
Site visit was not conducted. Soil analysis data was sent to PRZ Consulting for this effort.

Overall Site Conditions

After inspecting the sites, the visual differences between "closed systems" and "open systems" became apparent. The "closed system" sites include:

- Denver Zoo
- Dunham Park
- Swansea Park
- Schafer Park
- Bruce Randolph Middle School

The "closed system" sites had little or no visible effects from the recycled water usage.

Affects of recycled water on landscapes and equipment were more prominent when the recycled water was put into a pond or open channel before being introduced to the irrigation system. These areas are referred to as "open systems." These sites include:

- City Park Golf Course
- Park Hill Golf Course
- City Park
- Washington Park

The observed and reported problems with these sites included a number of dead and dying trees and vast expanses of damaged turf areas. Superintendents also reported an increased amount of irrigation maintenance required for these sites ranging from clogged irrigation heads to pump seals replacement.

City Park Pump Facility is reported to require frequent maintenance for seals and replacing parts.

Soil Analysis

The Plasticity Index plus the clay percentage indicate the swelling potential of these soils. Normally higher clay percentages and Plasticity Index result in a greater potential for swelling and for

		Soil Analysis 2010		Paste	PPM			These don't change		Plasticity
	pH	Salts EC	ESP	Na	Cl	CEC	SAR	Texture	Clay%	Index
City Park	7.35	0.93	4.8	7.1	26.8	15.8	4.8	Clay Loam	30%	29
City Park Golf Course	7.59	1.12	4.1	6.6	26.3	32.8	4.1	Loam	27%	23
Park Hill Golf Course	8	0.8	5.5	5.8	19.7	11.2	5.4	Loam	13%	10
Denver Country Club	7.57	0.7	5.1	4.9	23.4	16.0	5.0	Silty Sand	9%	17
Bruce Randolph Middle School	7.9	0.65	4.4	5.1	20.0	20.7	4.6	Sandy Loam	17%	6
Denver Zoo	7.97	0.88	4.3	6.5	29.1	19.7	4.3	Sandy Loam	17%	12
Dunham Park	7.07	0.97	7.9	8.7	25.2	17.1	7.9	SiltySand	8%	11
Schafer Park	7.4	1.1	6.5	8.8	27.3	22.1	6.4	Sandy Loam	15%	11
Washington Park	7	1	5.9	7.8	47.6	23.3	5.8	SiltySand	13%	13
Swansea Park	7.1	0.9	7.9	8.1	23.4	15.5	7.8	Sandy Loam	17%	12

attracting and holding sodium. City Park shows to be medium swelling potential between 1.25-2.5%. The rest have a very low potential.

When recycled water is applied to western US Montmorillonitic clay (swelling type) soils, over time these water quality salts tend to accumulate. The higher the concentration of the salt, the greater the impact on the plants growing in these areas.

It has been our experience while viewing soil samples from all over the US for 20 years that there is some correlation between the levels of increase of the soil parameters, particularly salts, and the percentage of clay and the plasticity index.

For this reason additional tests should be required for these two salts as well as for any future sites as a better predictor of adverse affects at these sites over time.

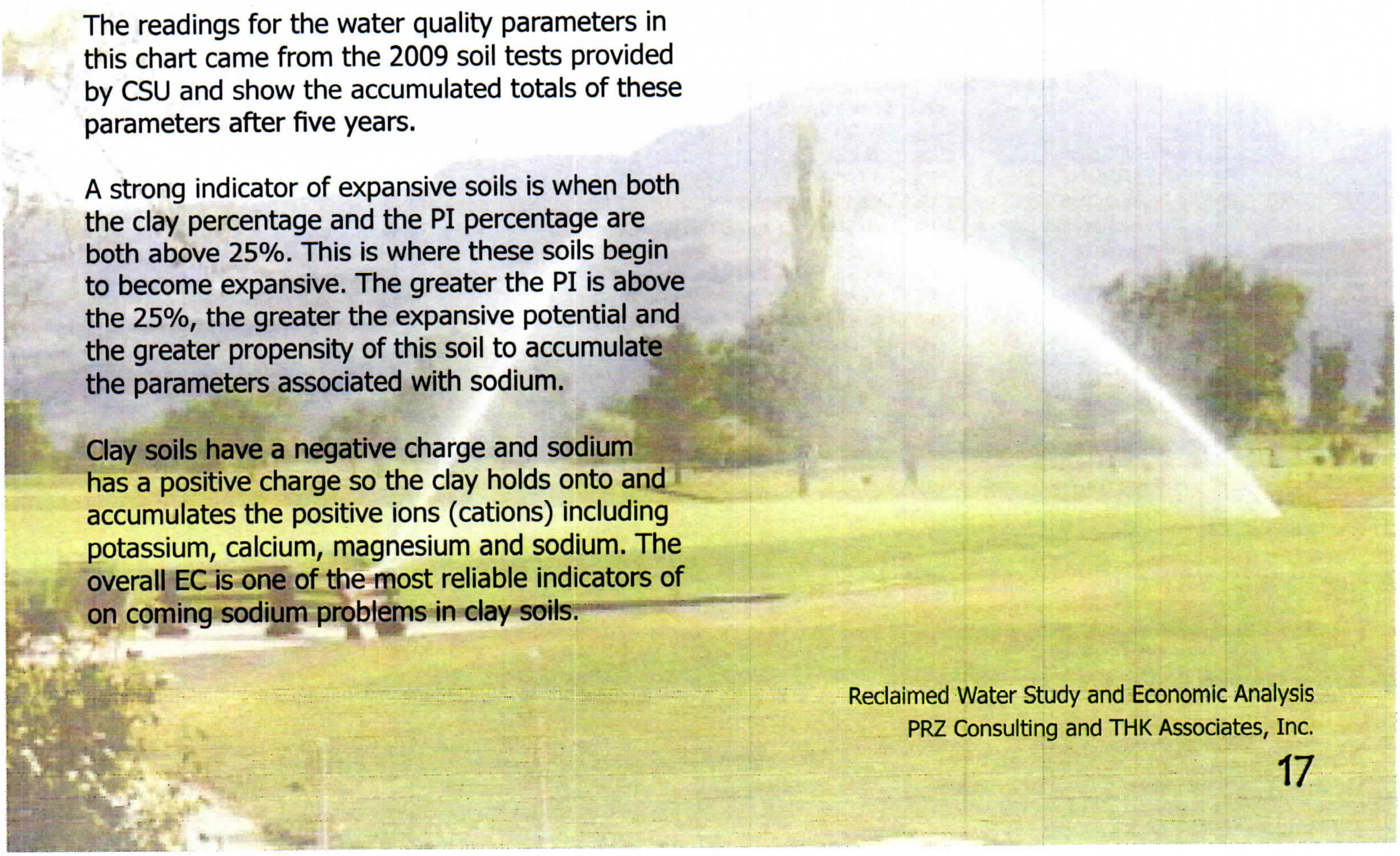
The readings for the chart on the next page came from the 2009 soil tests provided by CSU and show the accumulated totals of these parameters after 5 years.

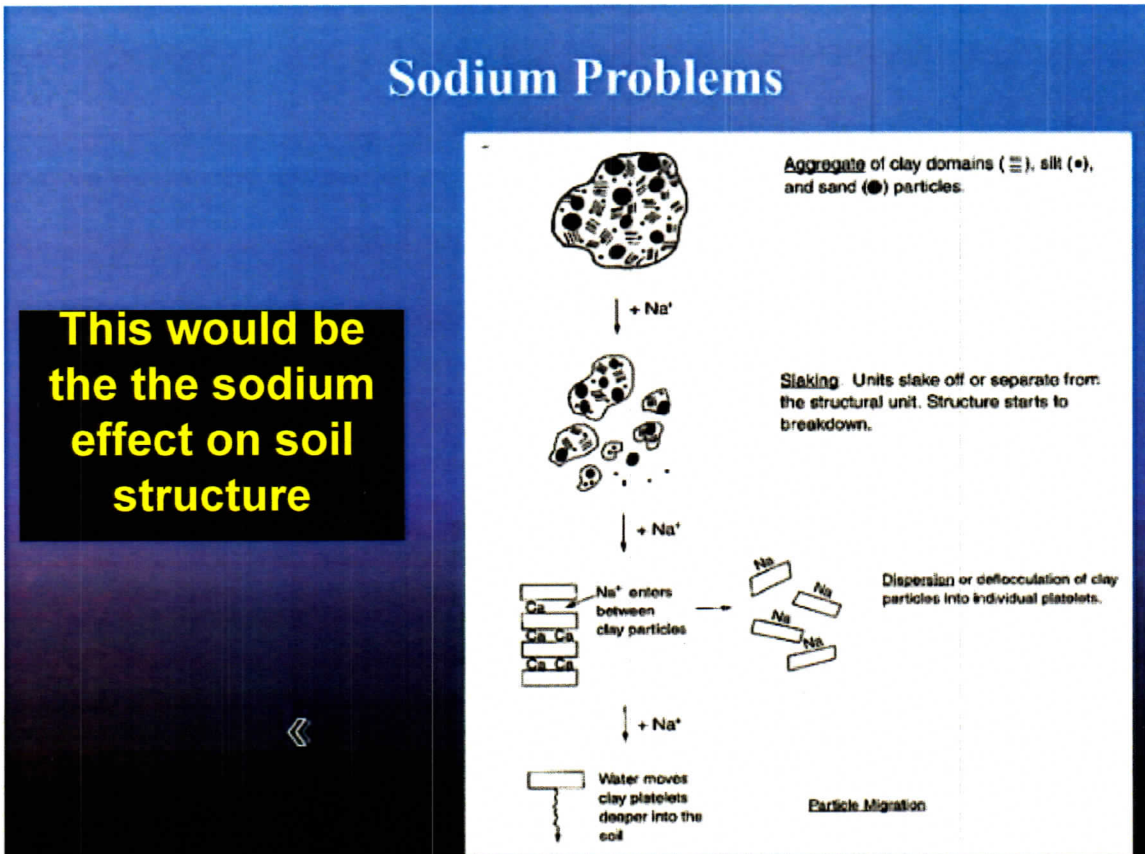
The slide on the next page prepared by CSU, shows how the sodium accumulation in the root zone over time breaks down the soil structure. This also has a dramatic affect on the plants growing in these conditions.

The readings for the water quality parameters in this chart came from the 2009 soil tests provided by CSU and show the accumulated totals of these parameters after five years.

A strong indicator of expansive soils is when both the clay percentage and the PI percentage are both above 25%. This is where these soils begin to become expansive. The greater the PI is above the 25%, the greater the expansive potential and the greater propensity of this soil to accumulate the parameters associated with sodium.

Clay soils have a negative charge and sodium has a positive charge so the clay holds onto and accumulates the positive ions (cations) including potassium, calcium, magnesium and sodium. The overall EC is one of the most reliable indicators of on coming sodium problems in clay soils.





*** Slide excerpt from CSU power point presentation (Dr. Yaling Qian, 2005)*

Future tests for these parameters should be conducted to monitor new recycled water users that begin using recycled water as an irrigation source.

Soil Analysis % of Change by Site Between 2004-2009								These don't change		Plasticity
	pH	Salts EC	ESP	Na	Cl	CEC	SAR	Texture	Clay%	Index
City Park	4.8%	32.3%	52.1%	58.5%	16.0%	-52.5%	50.0%	Clay Loam	30%	29
City Park Golf Course	2.2%	33.0%	62.4%	61.2%	6.8%	21.6%	60.4%	Loam	27%	23
Park Hill Golf Course	2.5%	-37.5%	5.5%	-19.0%	-76.1%	-44.6%	0.0%	Loam	13%	10
Denver Country Club	4.1%	-57.1%	52.9%	18.4%	-33.8%	-12.5%	49.6%	Silty Sand	9%	17
Bruce Randolph Middle School	4.1%	-76.9%	46.1%	13.7%	-89.6%	9.7%	46.2%	Sandy Loam	17%	6
Denver Zoo	2.4%	37.5%	68.1%	72.3%	35.1%	-48.7%	65.7%	Sandy Loam	17%	12
Dunham Park	7.1%	43.3%	60.8%	64.4%	26.2%	9.9%	59.5%	SiltySand	8%	11
Schafer Park	5.4%	18.2%	66.2%	60.2%	-7.7%	-1.8%	64.1%	Sandy Loam	15%	11
Washington Park	2.9%	30.0%	62.7%	59.0%	48.5%	45.9%	58.6%	SiltySand	13%	13
Swansea Park	8.5%	11.1%	62.5%	50.6%	-10.3%	-9.7%	61.5%	Sandy Loam	17%	12

Potential Solutions
Improve Drainage

Slit Drain System for turf

This surface and subsurface drainage system is used extensively on golf course fairways, greens and sports fields to increase percolation into the soil and move salts out. It will provide 4" per hour initial percolation rate in heavy clay soils. This system has collector sand channels 8" deep and 1.75" wide every 20" on centers. It also has 3" sand channels with 2" slotted pipe in them and are spaced at 16-20' centers to carry water to the perimeter. This system works well for leaching sodium from the root zone with flushing and also for preventing subsurface water with high sodium levels from leaching up into the root zone of turf.

Aeration Equipment

KWIK Drain Surface & Subsurface Drain System - $1.10 per square foot

Site	Irr. Acres	Acre Ft	Annual $ Savings	Annual $ Costs	Annual $ Cost Per Acre	Initial $ Cost	Years to Payback
Park Hill Golf Course (1/2 site)	150	302	$0	$0	$0.00	$3,593,700	NA
City Park Golf Course (1/2 site)	150	255	$0	$0	$0.00	$3,593,700	NA
City Park (1/2 site)	185	900	$0	$0	$0.00	$4,432,230	NA
Denver Zoo	2	4	$0	$0	$0.00	$0	NA
Bruce Randolph Middle School	8	22	$0	$0	$0.00	$191,664	NA
Swansea Park (1/2 site)	8	24	$0	$0	$0.00	$191,664	NA
Schafer Park	9	17	$0	$0	$0.00	$215,622	NA
Dunham Park (1/2 site)	5	5	$0	$0	$0.00	$119,790	NA
Washington Park (1/2 site)	106	500	$0	$0	$0.00	$2,539,548	NA
Denver Country Club (1/2 site)	100	307	$0	$0	$0.00	$2,395,800	NA

** This KWIK Drain System is a drainage system and there is no pay back when using this system

On "high use" fields, compaction can be a primary cause of turf damage. Higher clay content and plasticity index result in more compaction. Sodium accumulation slows down percolation and also contributes to the compaction.

Deep roots are critical to giving high use sports fields maximum wear-ability. Since roots only go as deep as oxygen exists and oxygen is carried by percolating water, compaction of the soil results in turf that can be damaged more quickly.

Aeration on a monthly basis in the wear areas can help prevent the compaction and associated sodium accumulation. The aerator below is an example of a machine that has both slicing tines (6" depth) for monthly use and fracturing tines (7" depth that fracture as deep as 10") for annual renovation or late fall or summer rest time before the leach and flush periods described above.

Sulfur Burner

A sulfur burner lowers pH and converts bicarbonate in recycled water to CO_2 and H_2O. The low pH (approximately 6.5) mimics rainwater, but the sulfurous gas it produces causes the negatively charged sulfates to attract, hold and move the positively charged sodium out of the root zone. This system gradually produces a healthier environment for all vegetation that is affected by sodium and also reverses damage initiated by the sodium through percolation and soil stability.

For any site that incorporates a sulfur burner, the benefit would equal the site receiving 20"- 30" of rainfall in a year. The sulphur burner is a very effective cost solution.

Skid Mounted

Sulfur Burners on Trailer for Scale

Trailer Mounted

Site	Irr. Acres	Acre Ft	Annual $ Savings Recycled	Annual $ Costs Sulfur	Annual $Cost Per Acre Sulfur	Initial $ Cost of Sulfur Burner	Months to Payback Sulfur Burner
Park Hill Golf Course	150	302	$241,379	$2,012	$13	$17,810	1.0
City Park Golf Course	150	255	$257,849	$1,699	$11	$17,810	0.9
City Park	185	900	$0	$5,990	$32	$17,810	
Denver Zoo	2	4	$4,041	$27	$13	$17,810	53.0
Bruce Randolf Middle	8	22	$17,939	$150	$19	$17,810	12.0
Swansea Park	8	14	$14,310	$94	$13	$17,810	15.0
Schaffer Park	9	17	$16,923	$112	$13	$17,810	12.7
Dunham Park	5	5	$4,765	$31	$6	$17,810	44.9
Washington Park	106	500	$0	$3,328	$31	$17,810	
Denver Country Club	100	307	$245,000	$2,043	$20	$17,810	1.0
Lowry Sports Complex	36	105	$105,949	$698	$19	$17,810	2.1

Calcium Application

CSU has conducted some treatment studies to evaluate the application of gypsum, calcium chloride, humates, mycorrhizae VAM, and humate & gypsum to soil in a controlled environment. Initial results indicated that calcium chloride was the only element that seemed to lower the sodium content of the soil and increase the quality of the overall turf stand. However, performance improvements were not sustained and the results were inconclusive.

Sodium Blocker

"Sodium Blocker" has been used on other sites irrigated with recycled water that resulted in significant improvements in little over one year.

When the EC levels rise above 1.25, Kentucky Blue Grass starts to slow down its spreading and mending rate. When the EC level reaches 2.0, Kentucky Blue Grass may not even require mowing and starts to yellow even though fertilizer applications are still being applied.

Although the Sodium Blocker product can be applied monthly through a sprayer, it is more effective if it is applied through fertigation where it can tie up the sodium in the water before it can get into the soil. This product is an essential combination of a concentrated liquid calcium and a concentrated wetting agent. The combination of these two products make this system successful. When applied at the rate of 1 gallon per acre per month, it produces noticeable results for a reasonable price.

Liquid Sodium Blocker 1 Gallon Per Acre for 7 Month Growing Season			Annual	Annual	Annual $ Cost	Initial	Months to
Site	Irr. Acres	Acre Ft	$ Savings	$ Costs	Per Acre	$ Cost	Payback
Park Hill Golf Course	150	302	$216,748	$18,900	$126	$14,040	1.82
City Park Golf Course	150	255	$234,559	$18,900	$126	$14,040	1.69
City Park	185	900	$0	$23,323	$126	$14,040	
Denver Zoo	2	4	$3,676	$252	$126	$3,185	11.22
Bruce Randolph Middle School	8	22	$16,035	$1,000	$125	$4,349	4.00
Swansea Park	8	24	$13,017	$945	$118	$4,349	4.88
Schafer Park	9	17	$15,394	$1,071	$119	$5,175	4.87
Dunham Park	5	5	$4,334	$683	$137	$4,249	13.66
Washington Park	106	500	$0	$13,394	$126	$7,020	
Denver Country Club	100	307	$220,000	$12,600	$126	$7,020	1.07

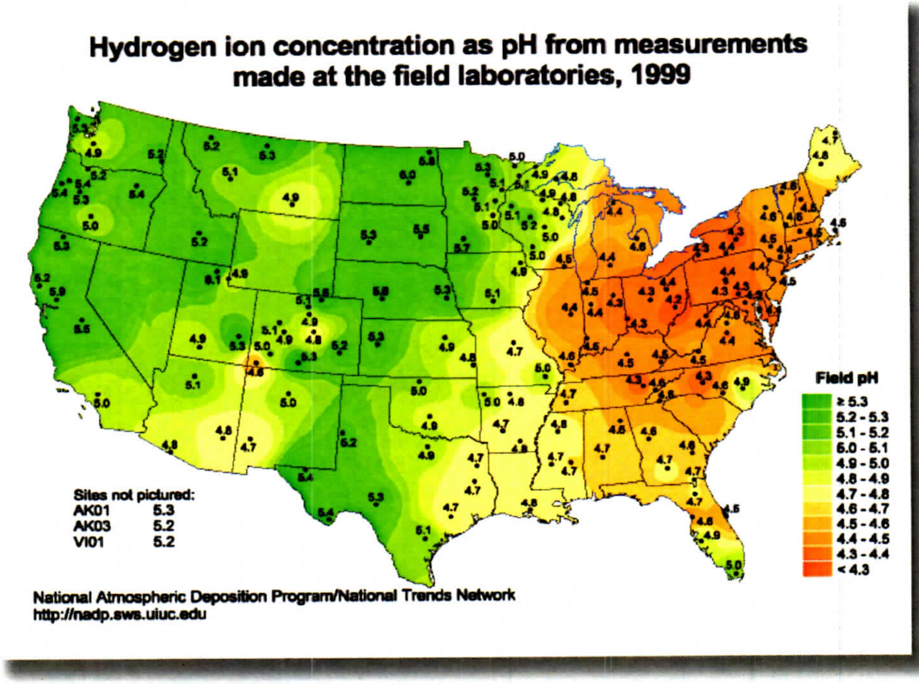
Leach and flush periodically

"Natural"

Snowfalls and rain help achieve this leaching process. The chart on the next page shows the pH of rainfall and snow fall of the continental United States. The testing stations in Colorado have recorded pH readings from 4.9-5.3 which helps to move lime and salts from the soil. If aeration is performed in late fall to allow these snowfalls and rains to move through the soils, the soil can take advantage of this leaching. With an annual precipitation of 15.5 inches, Colorado does not receive enough snowfall, and especially rainfall, to leach and flush sodium from clay-soil root zones.

"Potable"

In heavy clay soils that accumulate sodium faster, it may be necessary to leach and flush with potable water, if possible, for a short period after heavy aeration during the summer as well. If it is not feasible to use potable water for this, there is still value in doing this with recycled water. Although less sodium will be flushed, spraying the site with a wetting agent alone or sodium blocker first will help to move the water/salt out of the root zone. The flush should be done with a minimum of 2 inches of potable water without runoff after heavy aeration with a plug puller and deep tine or fracture tine aeration with 6-7" tines.



Leach and Flush Once Annually - 2" Potable Water Per Acre

Site	Irr. Acres	Acre Ft	Annual $ Savings	Annual Labor & Water $ Costs	Annual $ Cost Per Acre	Initial Potable Wate $ Cost	Months to Payback
Park Hill Golf Course	150	302	$216,748	$29,534	$197	$27,534	1.6
City Park Golf Course	150	255	$234,559	$29,534	$197	$27,534	1.5
City Park	185	900	$0	$2,467	$13	$0	0.0
Denver Zoo	2	4	$3,676	$0	$0	$367	0.0
Bruce Randolph Middle School	8	22	$16,035	$1,564	$195	$1,457	1.2
Swansea Park	8	24	$13,017	$1,484	$185	$1,377	1.4
Schafer Park	9	17	$15,394	$1,680	$187	$1,560	1.3
Dunham Park	5	5	$4,334	$1,062	$212	$995	2.9
Washington Park	106	500	$0	$1,413	$13	$0	0.0
Denver Country Club	100	307	$220,000	$19,689	$197	$18,356	1.1

Low Trajectory Spray Heads

Plants are more susceptible to salt and chemical damage from direct contact of sprayed irrigation on the leaves of the plant. Trees and landscape plants that are already growing in soil that is being impacted by recycled water are more susceptible to damage via direct spray of water that contains salts. This is not so prevalent with turf species because they are mowed frequently and lose some of the plant tissue that absorbs the additional salts and elemental compounds. Trees and shrubs do not have this ability. Concentrations build over time as they absorbed through the leaves. As mentioned earlier, chlorides above 100 Mg/Liter, (Denver Water -106 Mg/Liter) can cause leaf burn when sprayed on plants in the heat of the day. During the highest temperatures, irrigation should be avoided and should occur during cooler hours to prevent this leaf burning. A logical solution would be to irrigate at night to prevent leaf burn.

One solution is to use low trajectory spray heads and rotors to keep irrigation spray off of sensitive leaves. Low trajectory heads are available in spray and rotor configurations. They can be retrofitted with existing irrigation systems or may require a complete new irrigation system because of reduced "throw distances" of low trajectory heads.

Conventional Park Spray Pattern

Low Trajectory Spray Pattern

*** Slide excerpt from CSU power point presentation (Dr. Yaling Qian, 2005)*

Low Trajectory Irrigation Retrofit - $0.50 per sf 50% Replacement							
Site	Irr. Acres	Acre Ft	Annual $ Savings	Annual $ Costs	Annual $ Cost Per Acre	Initial $ Cost	Years to Payback
Park Hill Golf Course	150	302	$216,748	$0	$0	$3,267,000	15
City Park Golf Course	150	255	$234,559	$0	$0	$3,267,000	14
City Park	185	900	$0	$0	$0	$4,029,300	
Denver Zoo	2	4	$3,676	$0	$0	$43,560	12
Bruce Randolph Middle School	8	22	$16,035	$0	$0	$174,240	11
Swansea Park	8	24	$13,017	$0	$0	$174,240	13
Schafer Park	9	17	$15,394	$0	$0	$196,020	13
Dunham Park	5	5	$4,334	$0	$0	$108,900	25
Washington Park	106	500	$0	$0	$0	$2,308,680	
Denver Country Club	100	307	$220,000	$0	$0	$2,178,000	10

Low Trajectory Irrigation-New System (Abandon old in place - $1.00 per sf 100% Replacement							
Site	Irr. Acres	Acre Ft	Annual $ Savings	Annual $ Costs	Annual $ Cost Per Acre	Initial $ Cost	Years to Payback
Park Hill Golf Course	150	302	$216,748	$0	$0	$6,534,000	30
City Park Golf Course	150	255	$234,559	$0	$0	$6,534,000	28
City Park	185	900	$0	$0	$0	$8,058,600	
Denver Zoo	2	4	$3,676	$0	$0	$87,120	24
Bruce Randolph Middle School	8	22	$16,035	$0	$0	$348,480	22
Swansea Park	8	24	$13,017	$0	$0	$348,480	27
Schafer Park	9	17	$15,394	$0	$0	$392,040	25
Dunham Park	5	5	$4,334	$0	$0	$217,800	50
Washington Park	106	500	$0	$0	$0	$4,617,360	
Denver Country Club	100	307	$220,000	$0	$0	$4,356,000	20

Site Recommendations

Each of the sites has its unique attributes and site conditions. To ensure the viablility of these sites, it is recommended that the soil at each site should be tested every 4 years. Soils should be tested for all sodium related parameters including pH, soil EC, ESP, Na, Cl, CEC, and SAR. In addition, soil texture, clay content and plasticity index should also be tested.

1. Park Hill Golf Course

This site had the lowest increase of the sodium related parameters of the 10 sites.

Annual Water Usage: 24.19 acre inches

Actions Recommended: Reduce direct spray onto the conifers. A sulfur burner could be used to replace both the acid and the calcium at an annual cost of approximately $2,000 and provide the equivalent of 24 inches of low pH rainwater.

2. Bruce Randolph Middle School

This site had the second lowest increase of sodium related parameters of the 10 sites.

Actions Recommended: None now for sodium reduction. Soil tests should be done every 4 years at this site.

3. Denver Country Club

This site had a 3% overall increase of the sodium related parameters over the 5 year period.

Annual Water Usage: 36.83 acre inches

Actions Needed: Install low trajectory near conifers. A sulfur burner at this site would replace both the acid and the calcium at a great annual savings in chemical and manpower. This site should be tested at least every 4 years but they probably already doing this more frequently than this.

4. City Park

This site had a 23% increase of the sodium related parameters over a five year period.

Annual Water Usage: 58.35 acre inches

Actions Recommended: A sulfur burner is recommended to provide the equivalent of 58 inches of low pH rain-water. Soil tests should be done every 2 years at this site. (See Park Hill Golf Course for testing recommendations).

5. Swansea Park

Actions Recommended: None now for sodium reduction. The soil tests should be done every 4 years at this site. (See Park Hill Golf Course for testing recommendations).

6. Schafer Park

Annual Water Usage: 23.65 acre inches

Actions Recommended: Perform a natural flush each fall by deep-tinning or fracture-tinning in two directions just before winter to allow the rain and snow to help flush sodium from the root zone. Soil testing should be done every 4 years at this site. (See Park Hill Golf Course for testing recommendations).

7. Denver Zoo

Annual Water Usage: 24.0 acre inches

Actions Recommended: No action required

8. City Park Golf Course

Annual Water Usage: 20.42 acre inches

Actions Recommended: A sulfur burner is recommended to provide the equivalent of approximately 20 inches more of low pH rain water. This site should be retested every 2 years. (See Park Hill Golf Course for testing recommendations).

9. Dunham Park

Annual Water Usage: 10.44 acre inches

Actions Recommended: Begin doing a natural flushing each fall by deep-tinning or fracture-tinning in two directions just before winter to allow the rain and snow to help flush sodium from the root zone. Soil testing should be done every 4 years at this site. (See Park Hill Golf Course for testing recommendations).

10. Washington Park

Annual Water Usage: 56.44 acre inches

Actions Recommended: A sulfur burner is recommended to provide the equivalent of 56 inches of low pH rain-water. The soil tests should be done every 4 years at this site. (See Park Hill Golf Course for testing recommendations).

11. Vegetation

Trees and shrubs should be removed when they appear have severe browning. Generally, for evergreen trees, if needle death appears on more than 1/3 of the tree canopy, the tree should be removed. For deciduous trees and shrubs, the most notable symptom is browning and curling of the leaves. No hard and fast rule applies to this situation. Plants with these characteristics should be monitored and the park/golf or school maintenance superintendent should make the determination for removal of that plant. When new plants are needed, replacements should be made with salt tolerant species

Another option is to replace vegetation with more salt tolerant varieties before the current ones die. It is recommended to collect water samples from various points in open systems to determine if the water quality changes in these systems.

Conclusions

Soil salinity can injure and/or kill salt sensitive plants at fairly low levels of EC. Kentucky Blue Grass is the least salt tolerant turf grass but is found at all 10 of these sites and will be the dominant grass in probably 95% of all future sites. Rye and fescue grasses are both much more salt tolerant than Kentucky Blue Grass and can be over-seeded into the Kentucky Blue Grass as the sodium levels rise. This is not recommended for sports fields.

The ESP and SAR values doubling over five years suggests that sodicity needs to be carefully managed. The CSU Study indicates that continued increases of ESP and SAR could potentially cause reductions in soil hydraulic conductivity, soil sealing and reduced infiltration in soils with high clay content and some of these sites fit that category. A soil with an ESP value of 12 or greater is classified as a sodic soil. However for clay soils and compacted areas, an ESP greater than 6-9 will start to impose the sodic affects discussed earlier.

SAR levels above 12 would indicate a serious problem. The average SAR for these sites is 5.74 with the highest being 7.9. Based on the 5 year study and our 20 years of experience with soils from all over the US, the soils in this area are expected to continue accumulating salts over time. The costs to recover will be substantial if preventative steps aren't taken on a continuous basis.

Soil Monitoring Frequency

For sites with a clay content above 25% soil sampling is recommended every two years. For soils with clay content below 25% soil sampling is recommended every 4 years. Tests should include Sodium, Chlorides, Salts EC, pH, SAR, ESP, and CEC.

Soil Chemistry Targets for Parameters of Concern

For turf areas, an EC reading of 1.25 or more in the soil should be a trigger to begin steps to reduce the sodium levels in these soils. Highly compacted areas need to be tested separately because this is where sodium accumulates the fastest and should trigger remediation measures for the entire site.

For other plants and trees, a soil SAR above 9 or an ESP reading above 6 for soils with clay content above 25% or a soil SAR above 12 for soils with less than 25% clay should be the trigger for immediate remediation.

Based on observations and interviews, it appeared that much of the tree and plant kill was from direct spray of recycled water spraying onto trees and plants from an open system. Evergreens appeared to be the most vulnerable Most of these trees were dying even though the sodium levels in the soil were not high enough to cause tree kill. Also we saw the greatest number of tree deaths at the sites where the water comes through a ditch, is pumped into a pond and then pumped through the irrigation heads.

We have proposed further studies to be done on this water in the summer to evaluate what chemical or water characteristic changes may be taking place from the time this water is de-chlorinated as it leaves Denver Water's pipe until it is sprayed on the plants. We think that there could be outside factors such as bio growth or algae that may be contributing to this problem and testing the water characteristics at each of these distribution points along this distribution system may give us further evidence for solving this problem.

Final Conclusions - General

Each of the 10 sites with the exception of the Zoo should select the strategy that would best fit them. Some of these sites could possibly go another 5 years before plant damage is observed. However, there the possibility that delaying salt-management programs could ultimately result in more expensive management or remediation programs.

In general, it is recommended to amend the water with either the sulfur burner or the sodium blocker to minimize sodium accumulation. Steps should be taken to reduce the irrigation spray on trees and plants or replace salt intolerant varieties.

As landscape architects and parks planners begin to design new parks or redesign existing park and golf course areas, careful planning and research should be included as it pertains to salts and plant species that can tolerate salt conditions. Testing for salt content and to engineer soils to allow for salt migration.

Plant Salt Tolerances
Appendix H: Salt Tolerances of Various Plants

(Source: Swift, C. 1997. Salt Tolerance of Various Temperate Zone Ornamental Plants, Colorado State University Extension, Tri-River Area.)
Several BMPs in this Manual discuss salt-related impacts to plants. These include; Irrigation Using Nonpotable Water, Turf Management, and Soil Amendment, among others. While a variety of measures may be implemented to reduce salt related impacts originating from soil or irrigation water conditions, in some cases, selection of salt tolerant plants may be a key part of the solution. The plant list below identifies the salt tolerances of some common Colorado plants based on a literature review and personal experiences of nurserymen in Western Colorado's Tri River Area and is suggested as a guide when recommending trees, shrubs, vines and herbaceous plants for salty sites. The tolerance values below are based on soil tests reported as electrical conductivity in millimhos/centimeter (mmhos/cm), which is equivalent to deciSiemens/meter (dS/m). Check your local Colorado State University Extension Office for the most up-to-date or regionally specific plant lists. This plant list was developed by Curt Swift, CSU Extension and is subject to periodic revision. Comments on this list may be submitted to cswift@coop.ext.colostate.edu.

Deciduous Trees

High Tolerance; up to 8 mmhos/cm

Acer plantanoides; Norway Maple Aesculus hippocastanum Common Horsechestnut Ailanthus altissima; Tree of Heaven Amelanchier canadensis; Shadblow Crataegus crus-galli; Cockspur Hawthorn Elaeagnus angustifolia; Russian Olive; possibly up to 10 mmhos Gleditsia triacanthos; Honeylocust Quercus alba; White Oak Quercus robur; English Oak Quercus rubra; Red oak Robinia pseudoacacia; Black Locust Ptelea trifoliata; Wafer Ash

Moderately High Tolerance; up to 6 mmhos/cm

Acer negundo; Box-elder
Acer ginnala; Amur maple
Betula lenta; Sweet Birch
Betula populifolia; Grey Birch
Betula alleghaniensis; Yellow Birch Betula papyrifera; Paper Birch
Fraxinus americana; White Ash
Populus alba; White Poplar
Populus deltoides; Eastern Cottonwood   Populus grandidentata; Large-toothed Aspen
Populus nigra; Lombardy Poplar
Populus tremuloides; Trembling (Quaking) Aspen
Prunus padus; European Bird Cherry Prunus serotina; Black Cherry
Prunus virginiana; Choke Cherry
Salix alba `Tristis'; Golden Weeping Willow Salix alba `Vitellina'; Golden Willow Salix nigra; Black Willow
Sophora japonica; Japanese Pagoda Tree Ulmus pumila; Siberian Elm

Moderate Tolerance; up to 4 mmhos/cm

Catalpa speciosa; Northern Catalpa Celtis occidentalis; Hackberry
Celtis reticulata; Netleaf hackberry Cercis occidentalis; Western Redbud Fraxinus anomala; Singleleaf Ash Fraxinus excelsior; European Ash Fraxinus pennsylvanica; Green Ash Ginkgo biloba; Maindenhair Tree Koelreuteria paniculata; Goldenrain Tree Maclura pomifera; Osage-Orange Pyrus species; Pear
Ulmus americana; American Elm

Slight Tolerance; up to 2 mmhos/cm

Quercus palustris; Pin Oak Malus species and cultivars; Apple and Crabapple

Sensitive or Intolerant (less tha 2mmhos/cm

Acer rubrum; Red Maple Acer saccharinum; Silver Maple Acer saccharum; Sugar Maple Cercis canadensis; Eastern Redbud Juglans nigra; Black Walnut Plantanus acerifolia; London Plane Sorbus aucuparia; European Mountain-Ash Tilia americana; American linden Tilia cordata; Littleleaf Linden

Coniferous Trees

High Tolerance; up to 8 mmhos/cm

Juniperus chinensis; Pfitzer juniper Picea glauca ` densata'; Black Hills Spruce Pinus mugo; Mugho Pine Pinus nigra; Austrian Pine
Moderately High Tolerance; up to 6 mmhos/cm Pinus ponderosa; Ponderosa Pine Pinus thunbergiana; Japanese Black Pine Thuja occidentalis; American Arborvitae
Slight Tolerance; up to 2 mmhos/cm Picea albies; Norway Spruce Pinus strobus; Eastern White Pine Pinus sylvestris; Scot's Pine Pseudotsuga menziesii; Douglas Fir Taxus cuspidata; Japanese Yew
Sensitive or Intolerant Abies balsamea; Balsam Fir Pinus resinosa; Red or Norway Pine Tsuga canadensis; Canadian Hemlock Shrubs

Very High Tolerance; Up to 10 mmhos/cm

A triplex canescens; Fourwing Saltbush
A triplex convertifolia; Shadscale Saltbush A triplex corrugata; Mat Saltbush A triplex nuttalli; Nuttall Saltbush A triplex nuttalli cuneata; Castle Valley Clover
A triplex nuttalli gardneri; Gardner Saltbush Baccharis emoryi; Emory Baccharis Baccharis glutinosa; Seep-Willow Ceratoides lanata; Common Winterfat Chrysothamnus greenei; Greene Rabbitbrush
Chrysothamnus linifolius; Flaxleaf Rabbitbrush
Ephedra species; Mormon Teas
Ephedra torreyana; Torrey Ephedra Kochia americana; Greenmolly Summercypruss
Sarcobatus vermiculatus; Black Greasewood

Deciduouas Shrubs

High Tolerance; up to 8 mmhos/cm

Caragana arborescens; Siberian Peashrub Chrysothamnus albidus; Alkali Rabbitbrush Cytisus scoparius; Scotch Broom Elaeagnus commutata; Silverberry Elaeagnus multiflora; Cherry Elae-

agnus Euonymous japonica; Spindle Tree Halimodendron halodendron; Salt-tree Hippophae rhamnoides; Sea Buckthorn Juniperus chinensis; Pfitzer Juniper Lonicera tatarica; Tararian honeysuckel Rhamnus cathartica; Common Buckthorn Rhus trilobata; Squawbush
Rhus typhina; Staghorn Sumac; Rhamnus frangula; Glossy Buckthorn Shepherdia canadensia; Buffaloberry Spiraea vanhouttei; Van Houtte Spirea Symphoricarpuos albus; Snowberry Syringa amurensis japonica; Japanese Tree Lilac
Syringa vulgaris; Common Lilac Potentilla fruiticosa `Jackmanii'; Jackman's potentilla

Moderately High Tolerance; up to 6 mmhos/cm

Artemisia frigida; Fringed Sagewort Artemisia spinescens; Bud Sagebrush Artemisia tridentata; Basin Big Sagebrush Buxus microphylla; Japanese Boxwood Chrysothamnus nauseosus; Rubber Rabbitbrush Chrysothamnus visci diflorus; Douglas Rabbitbrush Ephedra nevadensis; Nevada Mormontea Forsythia x intermedia; Showy Border Forsythia Juniperus communis; Common Juniper Philadelphus coronarius; Sweet Mockorange Purshia glandulsa; Desert Bitterbrush Pyracantha fortuneana; Pyracantha Rhus glabra; Smooth Sumac Rhus trilobata; Skunkbush Sumac; Three-leaf Sumac Shepherdia rotundifolia; Roundleaf Buffaloberry Spirea `Froebel's'; Froebel's spirea
Slight to Moderate; up to 4 mmhos/cm Artemisia cana; Silver Sagebrush Berberis fremontii; Fremont Barberry Robinia neo-mexicana; New Mexican Locust Rosa woodsii; Wood's Rose Salix exigua; Coyote Willow

Slight Tolerance; up to 2 mmhos/cm

Chaenomeles speciosa; Flowering Quince Ligustrum vulgare; Common Privet Rosa rugosa; Rugosa Rose; may be slightly tolerant Viburnum opulus; High Bush Cranberry

Vines

High Tolerance; up to 8 mmhos/cm

Lonicera tataricum `Zabelii'; Zabel's Honeysuckle Parthenocissus quinquefolia; Virginia Creeper; Woodbine

Slight Tolerance; up to 4 mmhos/cm

Lonicera japonica; Japanese Hall's Honeysuckle

Flowers

High to Moderate; 6 to 8 mmhos/cm

Aquilegia micrantha; Cliff Columbine Machaeranthera xylorrhiza; Common Woody Aster Psilostrophe bakerii; Paperflower Stanley pinnata; Prince's Plume; a good indication that the soil is high in selenium

Moderate Tolerance; 4 to 6 mmhos/cm

Fallugia paradoxa; Common Apache Oenothera caespitosa; Tufted Evening Primrose Sphaeralcea coccinea; Scarlet Globemallow Yucca elata Soaptree; Yucca Yucca glauca; Small Soapweed

Slightly Tolerant; 2 to 4 mmhos/cm

Argemone species; Prickly Poppies Calochorutus species; Mariposa Lilly Chyrsopsis villosa; Hairy

Goldenaster Gallardia pennatifida; Cutleaf Blanketflower Mentzelia species; Blazing Stars Physaria australus; Twinpod

Grasses and Other Ground Covers

Sensitive or Intolerant; 2 to 4 mmhos/cm)

Cornus racemosa; Grey Dogwood Cornus stolonifera; Red-osier dogwood Rosa; Rose

High tolerance; 14 to 18 mmhos/cm

Agropyron elongatum; Tall Wheatgrass Agropyron smithii; Western Wheatgrass Distichlis; Saltgrass
Elymus triticoides; Beardless wildrye Lotus corniculatus; Birdsfoot trefoil
Puccinellia; alkaligrass
Sporobolus airoides; Alkali sacaton

Moderately High; 8 to 12 mmhos/cm

Bromus marginatus; Mountain brome Lolium perenne; Perennial ryegrass Melilotus alba; White sweet clover Melilotus oficinalis; Yellow sweet clover Trifolium fragiferum; Strawberry clover

Moderate; 4 to 8 mmhos/cm

Agropyron cristatum; Crested Wheatgrass Agropyron riparium; Streambank Wheatgrass
Agropyron trachycaulum; Slender Wheatgrass Arrhenatherum elatium; Tall meadow oatgrass
Bromus inermis; Smooth brome Buchloe dactyloides; Buffalograss Dactylis glomerata; Orchardgrass
Elymus giganteus; Mammoth wildrye Elymus junceus; Russian wildrye Festuca arundinacea; Tall Fescue Medicago sativa; Alfalfa
Phalaris arundinacea; Reed Canarygrass Low Salt Tolerance
Alopecurus pratensis; Meadow foxtail Festuca rubra; Red fescue
Festuca elatior; Meadow fescue Poa pratensis; Kentucky Bluegrass Trifolium pratense; Red clover
Trifolium repens; White clover

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Relevant Team Resumes

PRZ Resume

Larry Musser

Qualifications:

Larry Musser, President of PRZ (Prescription Root Zone) Consulting, has been involved in soil, water and wastewater chemistry for 35 years. In 1988 he began concentrating his efforts on soil analysis and accumulating a database of soil analysis from all over the US. Since then, he has used the results from this database of analyses to amend or repair badly damaged athletic fields and to properly engineer the root zone of new fields. Today this program is being used for ongoing soil consulting on over 500 athletic fields at any one time in 15 states. This data base has become instrumental in the assessment of and the corrective specification for parks and athletic fields on reclaimed water!

Larry has 18 years of experience in teaching the techniques of proper turf maintenance via PRZ Seminar's Sports Turf Maintenance and Design for Sustainability Seminars. He has been teaching his findings by providing approximately 35-50 PRZ Athletic Field Maintenance Seminars per year.

Experience: 35 years

Professional and Private Affiliations:
California Annual Park & Recreation Society (Speaker twice)
Texas Annual Recreation And Park Society (Speaker)
National Sports Turf Manager's Association (Member)
Florida Annual Recreation & Park (Speaker twice)
Colorado Sports Turf Managers Association (Speaker)

THK Resume

Kevin Shanks, RLA

Qualifications:

Kevin Shanks has over 27 year's experience as a Landscape Architect. For the last twenty-one years, Mr. Shanks has been a Senior Landscape Architect and Project Manager for THK Associates, Inc., responsible for projects requiring a full range of landscape architectural services. He is experienced in land use planning, project master planning, preliminary and detailed site design, graphic presentation, construction documentation, specification writing, irrigation design and construction administration. In addition to Mr. Shanks' project responsibilities, he is Vice President and Principal of THK, managing the Landscape Architectural and Planning Departments and overseeing all design and planning projects undertaken by the firm.

Professional/Registration

Registered Landscape Architect by the State of Iowa, 1984; Colorado, 2008

THK Resume
Mark S. Wilson, RLA

Qualifications:
Mark Wilson has over 26 year's experience as a Landscape Architect. Mr. Wilson is creative visionary that provides design input from conceptualization to implementation. He is well educated and articulate with a strong background in landscape architecture, planning, marketing, and communication skills. He is people oriented and a proven leader. Exceptional ability to manage staff and coordinate large design teams in a clear and efficient manner.

He is well versed in all aspects of landscape architecture including proposal preparation, client interaction and public workshop/presentations and all phases of design development, construction document/specification preparation, project management and coordination, construction supervision and project/contract administration for a wide variety of projects in both the public and private sectors. His work efforts include parks, trails, urban design corridors, streetscapes, residential projects, mixed-use developments and planning projects.

Professional/Registration

Registered Landscape Architect by the State of Colorado, 2008

References

1. Qian, Y. *Soil Baseline Study on Landscape Water Reuse Sites,* Department of Horticulture and Landscape Architecture, Colorado State University, July 1, 2005

2. Aqua Engineering, *Recycled Water for Denver Landscapes,* September, 2004

3. Lin Wu, Xun Guo and Jerry Brown, Studies of Recycled Water Irrigation and Performance of Landscape Plants under Urban Landscape Conditions, Slosson Report 1999-2000

4. Colorado Analytical Laboratories, Inc., Tissue Cultures for Denver Sites, 2009

5. Mills, H/Jones, J, Plant Analysis Handbook II, MicroMacro Publishing, Inc., 1991