Summary and Recommendations of Salinity Related Studies by Denver Water

Research Project	Consultant	Date Complete
Recycled Water for Denver Landscapes	**Aqua Engineering**	**August 2004**
Soil Baseline Study on Landscape Water Reuse Sites	**Colorado State University**	**July 2005**
Reclaimed Water at Select Locations in Denver, CO	**Day and Associates**	**July 2010**
Recycled Water Landscape Management Guidance	**PRZ Sports Turf Consulting**	**December 2010**
Soil Testing Five Years after Irrigation with Recycled Water	**Colorado State University**	**August 2010**
Soil Testing 11 Years After Recycled Water Irrigation	**Colorado State University**	**January 2016**

Recycled Water for Denver Landscapes

(Aqua Engineering, 2004* this report was completed just after the construction of the Recycling Water Plant)

The purpose of this report is to examine water quality issues related to the use of recycled water on urban landscapes. This report aims to examine the water quality parameters in recycled water that tend to impact the effective use of recycled water for landscape irrigation. The primary water quality impacts that are addressed are salinity, sodium induced infiltration problems, ion toxicities, from sodium, boron, and chloride, and miscellaneous impacts from excess nitrogen. Although this report specifically examines the effects of water quality on landscapes, it is recognized and noted throughout the report that an evaluation of water quality values alone cannot provide complete answers about how water quality might affect the health of a landscape both in the short-term and long-term.

Management techniques for salinity impacts can be implemented with chemical amendments, conditioners or fertilizers. But there are also ways to remove salts from the soil profile. The most effective and widely used method for reducing salt from the root zone is leaching. Leaching is achieved by applying sufficient water so that water can percolate through and below the portion of the root zone that contains the accumulated salts. In arid climates, natural precipitation is not abundant enough to sufficiently leach excess salts from the soil. In addition, irrigation methods used on landscapes tend to be quite efficient such that water is not often applied in excess of the crop water requirement for leaching purposes.

The recycled water that Denver Water will deliver to its large landscape customers is suitable for landscape irrigation. However, some changes in management may be required to achieve effective long-term use. Salinity, sodium, and nitrogen levels necessitate a change in management; while boron, chloride, and bicarbonate levels do not require a restriction on use. Recycled water customers should not base the suitability of recycled water for irrigation on an

examination of the water quality levels alone, without further examining the soil conditions, degree of drainage, and level of management at their landscape site.

Recommended practices by water quality parameter

Salinity	Leaching Improve drainage (artificial & soil aeration) Select less sensitive plants
Ion Toxicity	Blend with higher quality water
Sodium	Alter watering schedule: less frequent, low temperature (night), low wind, high humidity Irrigate sensitive plants with methods that minimize overhead spraying
Sodium - Infiltration	Improve aeration physically through cultivation (increase soil aggregation) Leaching Apply calcium based amendments (e.g. gypsum) Acid-injection or sulfur burner if accompanied by high bicarbonates and pH levels
Nitrogen	Monitor levels and adjust fertilizer program Apply growth regulators in problematic areas Remove grass clippings Mixing and selective irrigation with higher quality water Irrigation water aeration

Soil Baseline Study on Landscape Water Reuse Sites (CSU, 2005)

To ensure sustainable and affordable water supplies, Denver Water has completed a wastewater recycling system that treats and delivers recycled wastewater for landscape irrigation and other reuse purposes. Reuse of treated wastewater for irrigating landscapes is one of the approaches to maximize the existing water resources and stretch current urban water supplies. Phase one of the wastewater Recycling System has provided reclaimed wastewater 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 wastewater was also put into the City Ditch, which supplies irrigation water to Washington Park, the Denver Country Club and City Park.

Sponsored by Denver Water, we have conducted a project to collect and test soil samples from the parks, golf courses, and other facilities that use this recycled wastewater for landscape irrigation to establish soil baseline information. The information collected can be used to study changes that may occur in the soils after recycled wastewater is used for many years.

SUMMARY AND RECOMMENDATIONS

The issues surrounding recycled wastewater irrigation are complex and further research is needed to provide more information.

Both problems and opportunities exist in using recycled wastewater for landscape irrigation. 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. Two main concerns over the use of recycled wastewater for irrigation remains. Those are 1) potential problems caused by excessive sodium and salinity, and 2) excessive nutrients or nutrient imbalance. Soil salinity is a function of soil type, management, salinity of water used for irrigation, and the depth of water table. Clay soil is more prone to salt accumulation and sodium deterioration. Shallow water table can reduce leaching and introduce salts to the root zone.

Therefore, the most salinity susceptible sites are sites with shallow water table, high clay content, 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 will reduce the potential sodium problems. 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 the potential problems.

The following are the best management practices that are recommended:

Water and soil quality monitoring:

- Regularly monitor water and soil quality with water quality enforcement guidelines.

Irrigation:

- Adequate leaching and provide sufficient drainage to remove excess Na and salts from the root zone;
- Careful irrigation based on evapotranspiration and leaching requirements;
- Conversion to low angle nozzle to reduce leaf damage on trees and shrubs;
- Select appropriate irrigation frequency to avoid frequent wetting and drying cycles on the tree leaves;
- Blending conventional water with treated RWW or use the two sources in rotation;
- Dual plumbing to irrigation greens with conventional water in cases of excessively high SAR or high salinity, as a last resort.

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 wastewater; fertilize to alleviate nutrient imbalance.

Amendments:

- Additional chemical amendments to displace Na and reduce exchangeable sodium percentage;
- Addition of gypsum to irrigation water to adjust the SAR of irrigation water.

Plant selections:

- Replace with more climate and soil adapted, salt tolerant species and cultivars;
- Maintain healthy plants – healthy plants withstand salinity better.

Evaluation of Trees Subjected to Reclaimed Water at Select Locations in Denver, CO (Day & Associates, 2010)

This report summarized the results of an evaluation of several species of trees growing at sites that utilize recycled water for irrigation. The locations of the sites include Cheeseman Park (control), City Park, Greenway Park, Jackie Robinson Park, Swansea Park, Washington Park, the Denver Zoo, Park Hill Golf Course, and City Park Golf Course. A qualitative assessment based on observations of several tree species was performed and the condition of each tree was listed. Additionally, foliar samples were also collected and submitted for lab analysis. This report indicated that sodium and boron concentrations were a concern across many of the trees tested.

There are other biotic and abiotic stressors that can contribute to tree decline, and many of the symptoms observed in this report are commonly observed and diagnosed at any park of golf course along the Front Range of Colorado. These factors include elevation, sunlight intensity, low relative humidity, winter weather conditions, temperature extremes, drought cycles, soil compaction, people pressures, deleterious insects and diseases, and others. The evaluation of landscaped sites for irrigation using recycled water should consider tactics that minimize potential impacts in addition to best management practices that could help to reduce the negative impacts of recycled water.

RECOMMENDATIONS

Demonstrable improvements in tree color, growth rate and overall condition can occur with any tree species adversely by reclaimed water, primarily from the use of the radial trenching soil replacement, and secondarily from the use of a supplemental watering program. Supplemental watering must include the use of potable water.

Radial trenching involves the removal of the existing soil in several shallow radial trenches emanating from near the trunk outward past the drip line of the crown. Trenches are then backfilled with an amended light soil mix. Sod maybe laid over the newly filled trench. Local studies have shown that radial trenching operations should occur in the spring and can be repeated on the same tree every other year until the tree can sustain an acceptable level foliar color, growth rate and overall condition. Details and specifications for radial trenching soil replacement around trees have been published in the Journal of Arboriculture, through the International Society of Arboriculture, Champaign, IL.

Supplemental watering, with or without the use of radial trenching soil replacement, should occur once per month during the months of October through March, and twice per month during the months of April through September. In most cases only value tree, specimen tree, and trees with significant aesthetic and/or functional value will receive the two treatments or tactics described above.

Tree replacement or planting programs in locations irrigated with reclaimed water, especially on golf courses, should not include any spruce or fir species, or ponderosa pine. Austrian and Scotch pine can be used, provided there is adequate drainage, or the trees are planted in the raised planter beds and/or berms. The use of pinyon pine, Bosnian pine, and Rocky Mountain juniper is acceptable under most planting condition, except poorly drained sites. Deciduous trees generally do not appear to be significantly or permanently affected by reclaimed water.

The adverse effects of reclaimed water on conifer (e.g., pine, spruce, fir) foliage can be mitigated, in part, by reducing or eliminating direct application of irrigation water onto the foliage. Other remedial measures include frequent deep core aeration in turf areas, and over excavation or enlargement of standard planting hole width.

Reducing the amount or concentration of sodium in Denver Water reclaimed water used for irrigation in landscape areas, especially near susceptible conifers, will help mitigate the problems caused by high sodium levels in the foliage and in the soil. Providing irrigation water with sodium level below 75 mb/L (ppm) should be the goal when considering good health and longevity of landscape amenity trees.

Recycled Water Study
(PRZ, 2010)

The purpose of this study was to examine the effects of recycled water for 10 parks and golf courses within the City of Denver. The sites included City Park Golf Course, Park Hill Golf Course, City Park, Washington Park, the Denver Zoo, Dunham Park, Swansea Park, Schafer Park, Bruce Randolph Middle School and the Denver Country Club. This study examined the soils and site conditions to make recommendations on methods and treatments to help alleviate the potential problems by using recycled water for irrigation. In addition to visual observations, several soil samples were collected at each site. This report includes meeting with park superintendents and landscape supervisors. Two types of water delivery systems were identified, the first system is classified as a “closed system” where recycled water was delivered directly to the irrigation system. The second category was an “open system” where recycled water is delivered to a site and stored in an open channel or a pond, then pumped into the irrigation system. At sites that utilized an open system, the recycled water had a more noticeable impact on landscapes and operations.

Due to the number of variables involved, each site should implement soil testing every 4 years. Soil type and soil chemistry play a major role. Testing should be done to evaluate the levels of sodium, chloride, electrical conductivity, pH, sodium adsorption ratio (SAR), and exchangeable sodium percentage (ESP).

Recommendations from this study include additional sampling and developing a site specific strategy to mitigate impacts. The “open systems” can utilize a Sulphur burner and a sodium blocker could be used to minimize sodium accumulation. As new parks are built, thoughtful designs should be implemented to reduce impacts from recycled water.

Soil Testing Five Years after Irrigation with Recycled Water
(CSU, 2010)

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. These sites include Swansea Park, Dunham Park, Bruce Randolph Middle School, Schaefer Park, Park Hill Golf Course, City Park Golf Course, and the Denver Zoo. Recycled water is also delivered into the City Ditch, which supplies irrigation water to Washington Park, the Denver Country Club and City Park. In 2009, five 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. Phase one Denver Water's recycled water system provides recycled water to Swansea Park,

Major findings of this report include:

- 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 exchangeable sodium percentage (ESP) and sodium adsorption ratio (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 2004-2009
- Further studies are needed to determine if these parameters would continue to increase or stabilize.

The issues surrounding recycled water irrigation are complex. Municipalities and communities promote water reuse in landscape irrigation for regional water resource and environment sustainability. Recommendations from this report include regular monitoring of soil, provide adequate leaching and sufficient drainage.

RECOMMENDATIONS

Based on our previous experiments and literature review, the following are some of the best management practices that may be employed when appropriate:

Water and soil quality monitoring:

- 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.

Soil Testing 11 Years After Recycled Water Irrigation
(Colorado State University, 2016)

In 2004, Colorado State University (CSU) collected soil baseline information from 10 parks and golf courses in Denver that had just started to use recycled water for landscape irrigation. CSU collected and tested soils from the original sites five and 11 years after the conversion to determine if any changes had occurred.

In addition, archived soil samples were tested for Arsenic, Chromium, Cobalt, Nickel, Lead, and Cadmium concentrations. Data were subjected to analysis of variance and significant differences in soil properties at baseline, five and 11 years after recycled water irrigation were determined by the general linear model (GLM) procedure using statistical analysis software.

Major findings:

- Average soil salinity was 0.84, 0.88, and 0.98 dS/m in 2004, 2009, and 2015, respectively. Five facilities, including Bruce Randolph Middle School, City Park Golf Course, City Park, Washington Park, and Denver Country Club showed a trend of increasing soil salinity from 2004 to 2015. No clear trend of increasing soil salinity was observed at Swansea Park, Dunham Park, Schaefer Park, Park Hill Golf Course, or the Denver Zoo.

- On average, soil pH was 0.25-0.3 units higher in 2015 and 2009 when compared to 2004. The degree of soil pH increase was greater at deeper depths. Average soil pH level in 2015 was 7.5.

- Soil sodicity was higher in 2009 and 2015 when compared to 2004. However, there was a decrease in ESP in 7 out of 10 sites in 2015 from the 2009 sampling data. All samples collected in 2004, 2009, and 2015 had an average ESP of 2.65%, 5.35%, and 4.43%.

- Results indicated that aerification and calcium addition helped to displace sodium and reduce ESP at the surface depth. Results also indicated it is difficult to manage soil sodium and pH at deeper soil depths, which would impact deeper rooted plants such as trees.

- Soil P content was higher in 2015 than 2009, in aggregate. Bruce Randolph Middle School, Schaefer Park, Denver Zoo, and City Park Golf Course (0-20 cm soil depth) had higher soil P under recycled water use. The impacts of the increased soil P on landscape plants may vary from species to species. In general, P is a plant macronutrient that would improve plant growth.

- Nitrate–N content was lowest in 2015 when compared to 2004 and 2009. Nitrate–N deceased significantly with soil depth, dropping to below 2 mg kg-1 beyond the turfgrass rootzone, well below the EPA standard for potable water quality (10 mg kg-1).

- Soil Nickel content decreased from 2004 to 2015 at Dunham Park, City Park, and Washington Park, but the Nickel reduction was not significant at Schaefer Park and Swansea Park. At all parks, soil Chromium, Lead, Cadmium, and Copper did not show significant change from 2004 to 2015. Therefore, heavy metal accumulation is not a concern on sites irrigated with Denver Water's recycled water.

Recommendations:

- Excess salts should be leached below the root zone so that the EC of the soil solution becomes lower than the crop's critical threshold.

- For soil with high ESP, relatively soluble Ca sources are recommended for regular applications to provide displacement ions for Na on soil CEC sites, allowing sodium to be leached through the soil profile. For soils with poor drainage, it may be necessary to install tile drains to remove salt-laden drainage water and move it below the root zone by rainfall or irrigation water.

- It is possible to amend soil and water with acidifying products including ammonium sulfate and other sulfur-containing products to decrease soil pH; however, it is often necessary to re-apply these substances in order to sustain the effect.