Purpose

The purpose of this report is to examine water quality issues related to the use of recycled water on urban landscapes. From a water conservation standpoint, the use of recycled wastewater for landscape irrigation is a good practice because less potable water is used for non-potable uses such as irrigation. Future water supply for the Western U.S. will require the use of recycled water to the maximum extent possible. However, there are implications associated with the use of recycled water on landscapes because recycled water is often of a different quality than potable or other non-potable water sources. There is a direct relationship between the quality of irrigation water and the overall health of a landscape so an examination of potential impacts from the use of recycled water should be considered. This report identifies and summarizes impacts, and describes practices to effectively use this water source.

Denver Water (DW) is in the process of implementing a recycled water distribution system for the purpose of supplying recycled water to large landscape irrigation and industrial customers. In 2004, DW began operation of the first phase of its water recycling system. In an effort to better understand and mitigate potential impacts that water quality may have on the landscapes that are and will be receiving recycled water, DW has requested that this report examine recycled water more closely and detail possible operational procedures to minimize any negative impacts to the landscape.

This report specifically examines 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[1], and miscellaneous impacts from excess nitrogen. Each water quality parameter will be defined in detail and will include a discussion on management practices that can be used to mitigate impacts.

This report is organized into the following sections:

1. The Landscape System
2. Recycled Water for Landscape Irrigation
3. Salinity
4. Sodium – Impacts on Infiltration
5. Sodium
6. Boron
7. Chloride
8. Nitrogen
9. Successfully Using Recycled Water for Landscape Irrigation

[1] A toxicity problem occurs when high levels of ions are taken up by plants from the soil water. The ions can accumulate in the leaves to concentrations that may physically damage plants.

1. The Landscape System

The health of an urban landscape depends on the quality of the water, air (climate/weather), plant, and soil, all of which make up the landscape system. In addition to these physical factors, the management and design of the landscape may also greatly influence the overall landscape health. Although this report specifically examines the effects of water quality on landscapes, it is recognized and noted throughout that an evaluation of water quality values alone can not provide complete answers about how water quality might affect the health of a landscape both in the short-term and long-term. There is a complex interaction between all aspects of the landscape system. For example, in a landscape with poorly drained soils, poor water quality will have a more detrimental impact on the landscape than a landscape that has ideal drainage conditions. In well drained soils, constituents are less likely to accumulate and be taken up by plants because they are easily leached.

A complete understanding of a landscape system is needed to fully evaluate the suitability of recycled water for irrigation. However, because the quality of water is a crucial component to a healthy landscape, we believe it is meaningful to look at water quality parameters without direct knowledge of the landscape system. Examination of water quality values will provide insight as to what mitigation practices, if any are necessary for the successful use of recycled water.

2. Recycled Water for Landscape Irrigation

This section briefly defines recycled water quality parameters important to landscape irrigation. This section also reports the quality of the recycled water that DW customers can expect to receive, which will then be discussed in the context of generally accepted water quality guidelines for irrigation.

Water Quality Parameters for Irrigation

When evaluating the suitability of recycled water for irrigation, salinity, Sodium Adsorption Ratio (SAR), sodium, boron, chloride, and nitrogen are all important water quality parameters to consider. These parameters are simply defined as follows:

Salinity – The total soluble salt content in water, measured as electrical conductivity (EC_w) or total dissolved solids (TDS). When salt content in irrigation water is too high, the ability of plants to use water is impacted.

Sodium Adsorption Ratio (SAR) – A measure of the proportion of sodium ions to calcium and magnesium ions in a water solution. A high SAR value indicates that sodium ions are high relative to calcium and magnesium ions. High SAR water applied to soils tends to disperse soil, which can create water infiltration problems. The adjusted SAR (SARadj) is also used to measure the additional influence that bicarbonates in irrigation water have on infiltration. The salinity and SAR should be considered together when evaluating sodium impacts on infiltration.

Sodium – Excess sodium ions in irrigation water may also be toxic to plants when taken up through the roots or when absorbed through the leaves from sprinkler irrigation. Sodium toxicity can physically damage the appearance of plants.

Boron – Excess boron ions in irrigation water can accumulate in the soil to levels that are toxic to plants. Although boron is needed to some degree to maintain plant health, high levels can physically damage plants.

Chloride – Excess chloride ions in irrigation water are toxic to plants. Chloride ions can be taken up through the soil or be absorbed through the leaves of the plant.

Nitrogen – Excess nitrogen in irrigation water can over-stimulate growth, delay plant maturity, and contribute to poor plant quality. When this report refers to nitrogen, it is referring to nitrogen in the form of nitrate (NO_3-N), because nitrate-nitrogen (NO_3-N) is the form of nitrogen that occurs most frequently in irrigation water[2].

The Quality of Recycled Water at DW

Denver Water's recycling plant began operation in the spring of 2004. Table 1 includes water quality data from this new facility for water quality parameters of interest to landscape irrigation. The water quality levels reported in this table were obtained by analysis of the direct discharge from the plant under conditions believed representative of future plant operation. The quality of water delivered to customers that are serviced by this recycled water may differ significantly if the recycled water is mixed with other water sources.

Table 1. DW's recycled water quality

Water Quality Parameter	Value
Electrical Conductivity EC_w (dS/m)	0.89
Total Dissolved Solids TDS (mg/L)	570
pH	6.92
Sodium Adsorption Ratio adjusted (SARadj)	3.7
Sodium - Na (mg/L)	130
Chloride - Cl (mg/L)	99.3
Boron - B (mg/L)	0.28
Bicarbonate - HCO_3 (mg/L)	66
Nitrogen - NO_3 - N (mg/L)	14.1

Note: Measurements were taken on 6/29/04 and 7/7/04

[2] There are many ways to report nitrogen because it exists in many forms. Forms of nitrogen that are commonly found in irrigation water include nitrate (NO_3) and ammonium (NH_4), but nitrate occurs most frequently. Total nitrogen (N), regardless of its form, is the most important factor for plants. By reporting the various forms of nitrogen as nitrogen (N) (for example NO_3-N is reported as nitrogen in the form of nitrate), comparisons between total nitrogen levels can be made. When this report refers to nitrogen, it is referring to nitrogen in the form of nitrate (NO_3-N). Ammonium nitrogen is seldom significant in irrigation water. (Ayers and Westcot, 1985).

Water Quality Guidelines for Irrigation

The most widely referenced water quality guidelines for irrigation are presented by Ayers and Westcot (1985). Table 2 summarizes these guidelines. While these guidelines are based on field studies, research trials, and observations, they are also highly dependent on the characteristics of the landscape, including the design and management of the system (Pettygrove and Asano, 1986, pg. 3-10). The assumptions used to determine these guidelines should be examined thoroughly before these guidelines are applied (Appendix).

The potential for restrictions in water use presented in Table 2 are divided into three categories: no restriction, slight to moderate, and severe. A "restriction on use" indicates that there may be a limitation such as the choice of crop or the need for special management in order to maintain full production capability. A restriction on use does not indicate that the water is unsuitable for irrigation (Ayers and Westcot, 1985). In other words, no restriction on use means that in most cases full production of a crop is possible without the use of special practices or changes in management. For landscape plants, the "full production of the crop" can be equated with a healthy landscape.

Figure 1 relates the quality of recycled water that will be provided by DW to the water quality guidelines for irrigation. The expected recycled water quality value for salinity (electrical conductivity), sodium, nitrogen and SARadj are higher than the recommended water quality guidelines for irrigation without any restriction on water use[3]. These parameters do fall within the slight to moderate restriction on use, which indicates that the water quality is suitable for use, but changes in management are necessary to maintain a healthy landscape.

3. Salinity

Salinity Impacts

Salinity is the single most important parameter for evaluating the quality of water for irrigation (Pettygrove and Asano, 1986, pg. 3-16). All irrigation water includes some degree of soluble salts, but when the total soluble salt content (salinity) in the irrigation water is high, landscapes may be negatively impacted. Some of the more typical soluble salts include sodium, potassium, calcium, magnesium, chloride, bicarbonate, sulfate, nitrate, and boron (USGA, 1997, pg. 107). The salinity of water can be measured as electrical conductivity (EC_w) or total dissolved solids (TDS)[4], both of which quantify the amount of dissolved salts or ions in a water solution.

It is important to distinguish between the soluble salt content in irrigation water and the salt content in soil because the latter can often be two to ten times higher than that of the irrigation water applied to the soil (USGA, 1997, pg. 215)[5]. When irrigation water is applied to a

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[3] DW's SARadj value for recycled water is compared to the water quality guidelines for irrigation in Figure 2, which is on page 10.

[4] An approximate relationship between EC_w and TDS is: EC_w (in dS/m) x 640 = TDS (mg/L).

[5] Salt levels in irrigation water (EC_w) and soil salinity levels (EC_e) should not be directly compared. Salt content in the root zone various with depth. At the soil surface, salt levels may be equal to that of the irrigation water but may be many times saltier at the bottom of the root zone.

Table 2. Guidelines for interpretation of water quality for irrigation

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Salinity				
EC_w	dS/m	< 0.7	0.7 - 3.0	> 3.0
TDS	mg/L	< 450	450 - 2000	> 2000
Infiltration				
SAR =		EC_w =		
0 - 3		> 0.7	0.2 - 0.7	< 0.2
3 - 6		> 1.2	0.3 - 1.2	< 0.3
6 - 12		> 1.9	0.5 - 1.9	< 0.5
12 - 20		> 2.9	1.3 - 2.9	< 1.3
20 - 40		> 5.0	2.9 - 5.0	< 2.9
Specific Ion Toxicity				
Sodium (Na)				
Surface Irrigation	SAR	< 3	3 - 9	> 9
Sprinkler Irrigation	mg/L	< 70	> 70	
Chloride (Cl)				
Surface Irrigation	mg/L	< 140	140 - 350	> 350
Sprinkler Irrigation	mg/L	< 100	> 100	-
Boron (B)	mg/L	< 0.7	0.7 - 3.0	> 3.0
Bicarbonate (HCO_3)				
Sprinkler Irrigation	mg/L	< 90	90 - 500	> 500
Miscellaneous Effects				
Nitrogen (NO_3 - N)	mg/L	< 5	5 - 30	> 30
pH			Normal range 6.5 - 8.4	

Summary of assumptions used to develop guidelines, see Appendix for complete list:

- 1 mg/L = 1 ppm
- EC_w = electrical conductivity of water; SAR = sodium adsorption ratio. SAR can be compared directly with adjusted SAR (SARadj).
- TDS = Total Dissolved Solids = EC_w x 640, expressed in mg/L (approximate).
- Soil textures range from sandy-loam to clay, with good internal drainage. Rainfall is low and does not play a significant role in meeting crop water demand or leaching requirements. Drainage is assumed to be good, with no uncontrolled shallow water table present.
- Normal sprinkler irrigation methods are used. Water is applied infrequently as needed, and the crop utilizes a considerable portion of the available stored soil water (50% or more) before the next irrigation. At least 15% of the applied water percolates below the root zone.
- Salinity increases with depth and is greatest in the lower part of the root zone. The average salinity of the soil solution is about three times that of the applied water.
- These guidelines are intended to apply to traditional agricultural crops but also apply to turf grass and landscape ornamentals.

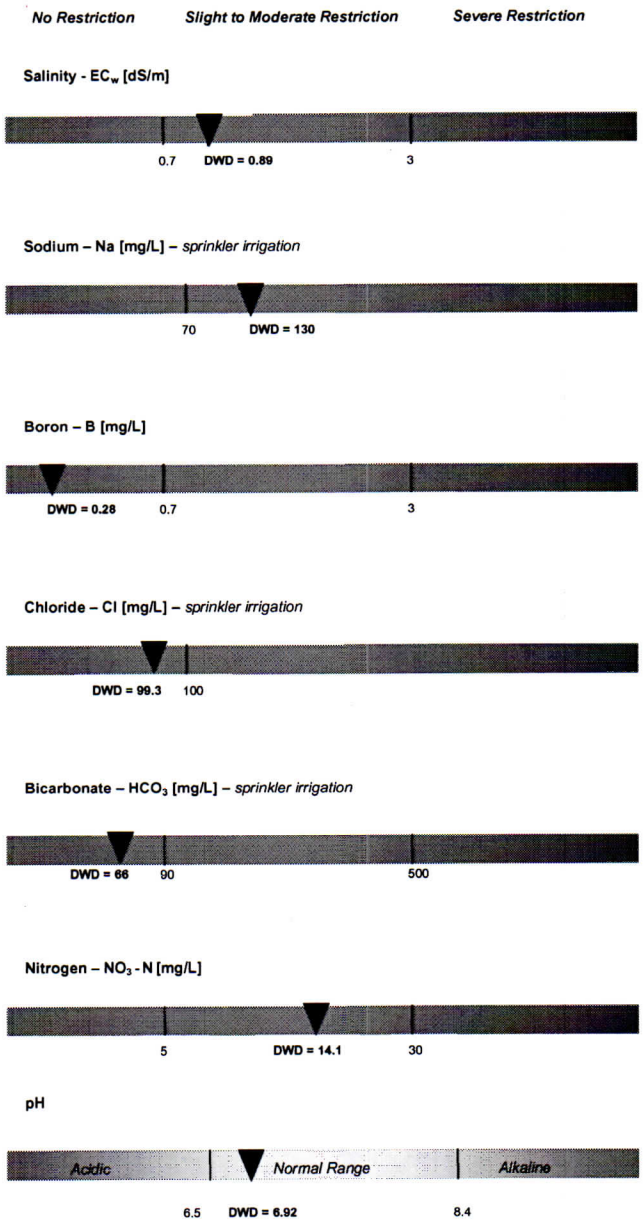

Figure 1. Water quality comparison between DW's recycled water and irrigation guidelines

landscape, salts tend to accumulate in the soil profile because plants use the irrigation water and leave the salts behind. Over time, salts will build up in the soil profile to concentrations that are higher than that of the irrigation water applied. If salts are not removed from the root zone, soil salt concentrations will become detrimental to landscapes. High soil salt levels inhibit a plant's ability to effectively uptake water through osmosis (this process is often referred to as a physiological drought). High salts can cause plants to die, retard plant growth, inhibit seed germination, cause nutritional imbalances, accumulate toxic ions, compete with less desirable but more salt tolerant plants, and add stress during adverse climate conditions (USGA, 1997, pg. 112).

The quality of irrigation water applied to the root zone is the most influential factor determining the accumulation of salt in the soil; however, soil type, field characteristics and drainage, irrigation system design and management, degree of leaching, distance to water table, and climate conditions will also affect the accumulation of salts in the soil over time (Bauder et al., 2004). A better understanding of these factors, particularly the soil type and drainage capability, will provide insight as to how the salt level in irrigation water may impact a landscape.

Salinity Levels in Recycled Water

If irrigation water has EC_w levels much greater than 0.7 dS/m, changes in the management of the landscape system will be necessary. Salt water levels that are greater than 0.7 dS/m can be used successfully for landscape irrigation; however, if levels approach 3.0 dS/m it is likely that irrigation will be unsuccessful. The expected water quality of DW's recycled water is 0.89 dS/m, which is slightly above the no restriction in use category (Figure 1). Table 3 further classifies salinity levels in irrigation water.

Although salinity levels in DW's recycled water are slightly elevated above the recommended guidelines, the water is still suitable for landscape irrigation. Some important observations regarding the use of recycled water that has higher salt levels include:

- There are several golf courses in Colorado that have used recycled water for many years. Their experience has shown that the negative impacts from elevated salt levels have primarily occurred after several years of accumulation in the soil. Special consideration should be given to impacts over the long-term and such changes in the salt content of the soil should be regularly monitored.

- Characteristics of a landscape play a large role in the impact of salinity. Landscapes that have salt sensitive plants[6], tighter soils, or inadequate drainage will tend to experience salinity impacts more quickly.

[6] Annual and Kentucky bluegrass are more sensitive to high soil salt levels than perennial rye grass and fescue (Swift and Koski, 2003). Trees, shrubs, and ornamental plantings are typically more sensitive than turf grass (Ayers and Westcot, 1985). Investigations into the use of recycled water at golf courses in Colorado have shown that pine trees are particularly sensitive to long-term accumulation. DW has published a guide to using recycled water on trees and shrubs called "Recycled Water for Trees & Shrubs."

Table 3. Classification of salinity limits for irrigation water

Classes of Water	Electrical Conductivity (EC_w)
	dS/m
Class 1, Excellent	< 0.25
Class 2, Good	0.25 to 0.75
Class 3, Permissible[1]	0.76 to 2.00
Class 4, Doubtful[2]	2.01 to 3.00
Class 5, Unsuitable[2]	> 3.00

(1) Leaching or special management needed.

(2) Good drainage needed. Sensitive species may be impacted.

Management of Salinity Impacts

Soils high in salts cannot be reclaimed with chemical amendments, conditioners, or fertilizers (Cardon et al., 2004). An existing landscape impacted by salinity can only be reclaimed if the salts are removed from the soil. There are several ways to remove salts from the soil profile.

The most effective and widely used method for reducing salts in the root zone is leaching. Leaching is achieved by applying sufficient water so that water percolates through and below the portion of the root zone that contains the accumulated salts (Ayers and Westcot, 1985). 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. Therefore if leaching is to be used, it will be necessary to develop a specific leaching program as well as a program for meeting crop water requirements. Salts are most effectively leached from the soil under higher frequency irrigation events. Keeping the soil moisture high between events has shown to help dilute the overall salt concentration in the soil (Cardon et al., 2004). The amount of water that is needed to leach salts will depend on the amount of accumulation and the quality of the irrigation water applied for leaching purposes (see Ayers and Westcot, 1985). If higher quality water is available during certain times of the year, this water should be used to improve the leaching program and reduce the degree of leaching required.

Most landscapes have artificial and/or natural drainage systems. Good drainage systems can help alleviate salinity problems because they more efficiently remove salts from the root zone. In locations where the groundwater table is high, drainage can channel water away from the soil surface where the evaporation of water may further contribute to the accumulation of salts. If feasible, landscapes without adequate drainage should be improved. However, special consideration must be given to the disposal of any drainage water collected in the landscape. Because there are restrictions governing the discharge of drainage water, a leaching program and improvements to drainage systems should be investigated through the Colorado Department of Public Health and Environment (CDPHE) prior to implementation[7].

[7] See Regulation No. 84, *Reclaimed Domestic Wastewater Control Regulation*, CDPHE and the Water Quality Control Commission.

The preferred method for reducing salinity impacts on landscapes is to mix recycled water with water that is less salty prior to irrigation. Unfortunately, for many landscapes, it may not be feasible to obtain additional water sources for mixing or to develop facilities necessary for mixing.

One rather expensive method for mitigating salinity impacts on landscapes is to replace salt sensitive plant species with those that are more salt tolerant. DW has published a guide to using Recycled Water for Trees & Shrubs (DW, 2003), which examines those trees and shrubs that are more tolerant of high salt levels. The Colorado State University Cooperative Extension has also published a guide that examines the salt tolerances of several turf grasses (Swift and Koski, 2003).

Regardless of the mitigation practices used for salinity, the water and soil quality should be regularly monitored. A monitoring program will help to better understand salinity impacts over time and will more importantly help evaluate the effectiveness of mitigation practices used. A monitoring program is recommended for all water quality parameters of concern.

4. Sodium – Impacts on Infiltration

Sodium Impacts

Excess sodium levels in irrigation water can impact the quality of a landscape both directly through toxicity and indirectly through reduced soil infiltration. This section will discuss sodium induced infiltration problems, while the next section will specifically address sodium toxicity issues.

Decreased soil infiltration is a common symptom of excess sodium in irrigation water. A sodium induced infiltration problem occurs when the level of sodium is high relative to the amount of calcium and magnesium in the irrigation water[8]. Excess sodium displaces calcium, thus reducing the stabilizing effects in the soil structure. Without soil stability, finer soil particles tend to fill in soil pores, seal the soil surface, and reduce infiltration (Ayers and Westcot, 1985)[9]. Reduced soil infiltration not only has the potential to limit the amount of water that is available for crop use, but it also can cause soil crusting, weed growth, nutrient deficiencies and imbalances, oxygen deficiencies, and ion toxicities from water logging (Pettygrove and Asano, 1986, pg. 3-24).

The Sodium Adsorption Ratio (SAR) is used to quantify the proportion of sodium ions to calcium and magnesium ions in irrigation water. The adjusted Sodium Adsorption Ratio (SARadj) is another method of calculating SAR, which adjusts the calcium level to include the effects of carbon dioxide, bicarbonate, and salinity (Ayers and Westcot, 1985).

A soil sodium hazard cannot be assessed independent of salinity (USGA, 1997, pg. 115). Low salinity levels in irrigation water may dissolve and leach calcium, which may cause excess

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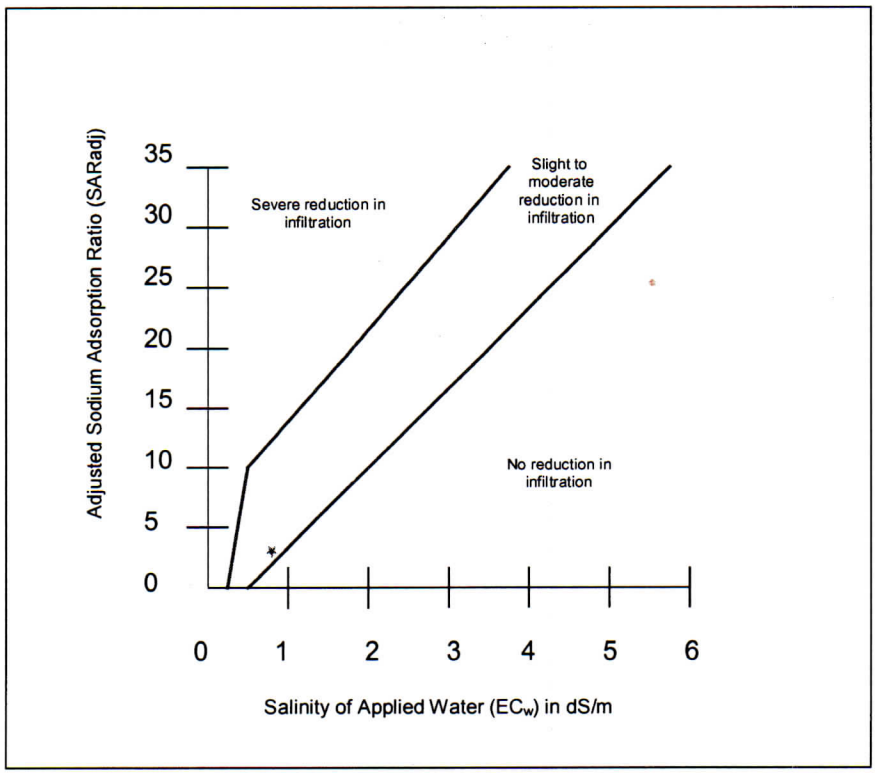
[8] Infiltration problems typically occur when sodium exceeds calcium by a ratio of 3 to 1 (Ayers and Westcot, 1985). Sodium tends to disperse soil, while calcium and magnesium tend to flocculate soil.

[9] Because clay soils have more surface area for sodium to bind to, they tend to be more susceptible to excess sodium dispersion and associated infiltration problems. Soil textures with less surface area (large particles) such as sand are not as prone to infiltration impacts.

amounts of sodium relative to calcium (increasing SAR). Because recycled water is typically rich in salt, low salinity induced infiltration problems are usually not of concern. More often than not, an infiltration problem associated with recycled water is caused by excess sodium in the recycled water, not low salinity (Pettygrove and Asano, 1986, pg. 3-26). It should be noted that soil texture, organic matter, crop type, climate, irrigation system design and management all impact how sodium in irrigation water impacts landscape (Bauder et al., 2004).

Sodium Levels in Recycled Water

Figure 2 shows that the proposed SARadj value for recycled water (SARadj = 3.7) is nearly adequate if the EC_w is 0.89 dS/m. In general, when SAR is high relative to EC_w, water infiltration problems are likely to occur (Hayes, 1995). Because the level of sodium in the recycled water is slightly higher relative to calcium and magnesium (slight to moderate restriction on use), special consideration should be given to any increases in and accumulation of sodium over the long-term. This may especially be the case under conditions where sodium accumulation is more significant (tight soils and poor drainage).



★ Indicates DW recycled water: SARadj = 3.7 and EC_w = 0.89 dS/m
Notes: Adapted from Qian (2004); Ayers and Westcot (1985)

Figure 2. Relative rate of infiltration as influenced by salinity and SARadj

Management of Sodium Impacts

The most commonly used practice for managing sodium induced infiltration problems is to apply a soluble source of calcium. Calcium can be added in the form of limestone, dolomite, calcium chloride and lime among others, but gypsum is typically used because it is moderately water soluble, does not impact the pH of the soil, and is inexpensive (Mitra, 2001). Calcium chloride is more water soluble, but is typically more expensive than gypsum (Davis et al., 2004). The application of gypsum will not help improve soil infiltration if that infiltration is a function of poor soil texture and compaction. It should be noted that adding a calcium source such as gypsum tends to increase the salinity in the soil, so application should be used with caution in soils with high salt levels.

The rate and amount of calcium application typically depends on the quality of the irrigation water and soil, the soil types and drainage, degree of traffic on the landscape, and the management level. It is recommended that enough calcium amendment be added to remove most of the sodium in the top 6 to 12 inches of the soil profile (Davis et al., 2004). Other practices used to mitigate negative impacts include a frequent and well managed cultivation plan including aerification, spiking, and deep tining. These cultivation practices help to improve infiltration and incorporate amendments into the top portion of the soil where sodium problems are most severe.

Acid-injection or sulfur burner systems can also be used to mitigate sodium induced infiltration problems. These systems are primarily used to lower soil pH for purposes of increasing the calcium in the soil relative to sodium (USGA, 1997, pg. 123). If sodium induced soil infiltration problems are not accompanied by high pH levels in the soil, sulfur burners and acid injection systems are not recommended. If pH levels in the soil are adequate, direct application of calcium amendments are preferred because they do not impact soil pH levels and they provide a source of calcium needed to effectively replace sodium in the soil. These amendments can also be used to remove excess bicarbonates in soils, but because bicarbonate and pH levels in DW's recycled water are adequate, the systems are most likely not needed.

5. Sodium

Sodium Toxicity Impacts

Sodium toxicity occurs when a plant absorbs sodium through its roots and accumulates excess levels in its leaves. This can cause leaf burn, scorch, and dead tissue along the outside of the plant leaves (Ayers and Westcot, 1985). As toxicity increases, the dead tissue may propagate to the center of the leaves. Toxicity can also occur when water is applied directly to the leaves of the plant through sprinkler irrigation. Plants that are sensitive to sodium are more sensitive to foliar absorption (through sprinkler irrigation) than they are through soil uptake. Sodium toxicity effects may be due to or complicated by soil infiltration impacts of excess sodium (Ayers and Westcot, 1985).

Not all landscape plants are susceptible to sodium toxicities. The guidelines presented in Table 2 are not specific to plant species and therefore may be significantly different between plant types. Trees and shrubs are more sensitive to the physical damage caused by high

sodium levels[10]. Turf grass is less sensitive to sodium and rarely experiences physical damage because it is regularly mowed. However, in the case of golf courses where grass is mowed relatively short, sodium accumulations in leaves may exist on a significant percentage of the remaining leaf area (Harivandi and Beard, 1998).

Sodium Levels in Recycled Water

Ayers and Westcot (1985) and Harivandi and Beard (1998) state that a majority of landscape plants that are sprinkler irrigated can tolerate sodium water levels up to 70 mg/L without a toxicity impact or restriction on use (Table 2). However, hot and dry climatic conditions may exacerbate these problems (Ayers and Westcot, 1985). The sodium levels for DW's recycled water are expected to be 130 mg/L, which indicates a slight to moderate restriction on use. Although the sodium level is higher than the recommended guideline, it is likely that turf grass can be irrigated with this water without significant physical damage. More sodium sensitive species such as trees, shrubs, and flowering plants may experience toxicity impacts from the use of this water. Caution should be used to minimize the frequency of this water being applied to the leaves or needles. For landscape plants that are not sprinkler irrigated (surface irrigation), the recommended SAR of the water is less than 3.0 for no restriction on use. DW'S recycled water is slightly higher than this recommendation at 3.7, indicating slight to moderate restriction on use.

Management of Sodium Toxicity

Directly improving water quality is the most effective way to improve a sodium toxicity problem; however this may not be feasible. Because irrigating with sprinklers during windy, hot, and low humidity periods increases the likelihood of toxicity, it may be possible to decrease negative impacts by watering at night when temperatures are lower and humidity is higher. Lower frequency irrigation periods may also decrease the likelihood for sodium toxicity. Another option may be to replace sodium sensitive plants with those that are more tolerant. Because plants that are sensitive to sodium are more sensitive to foliar absorption than uptake through the roots, it may be possible to mitigate negative impacts by irrigating with surface methods rather than overhead sprinkling, such as:

- irrigating with low-angle heads to decrease water spray on to plant leaves or needles
- bubble or drip irrigating when possible
- irrigating with subsurface methods

In some instances sodium toxicities are caused by sodium induced infiltration problems. In instances such as these, toxicity problems may be solved by first mitigating the infiltration problem.

[10] Ayers and Westcot (1985) classify most deciduous and fruit trees as sensitive to sodium, while most turf grasses fall into the tolerant classification.

6. Boron

Boron Toxicity Impacts

Similar to sodium, boron can damage landscapes through toxicity. Although boron can be toxic at low concentrations for many plants, some level of boron is needed to maintain plant health. Unlike sodium and chloride, boron is not absorbed through leaves when applied via sprinkler irrigation; rather it accumulates in the soil to levels that may be toxic. Plants may uptake and accumulate excess boron in leaves, which causes yellowing, spotting, and drying of primarily leaf tips and leaf edges (Ayers and Westcot, 1985).

Boron toxicity can occur in ornamental landscape plants when irrigation water concentration is less than 0.7 mg/L. Turf grasses tend to be more tolerant of boron levels than ornamental plants, although they are more sensitive to boron than to either sodium or chloride (Harivandi and Beard, 1998). When boron toxicity occurs in turf grass, it is often not a concern because turf is regularly mowed and accumulated boron in grass blades is frequently removed (USGA, 1997, pg. 117). Boron accumulation in the soil is not only a function of the concentration in the irrigation water, but also soil and climate characteristics.

Boron Levels in Recycled Water

Ayers and Westcot (1985) state that boron levels in irrigation water should not be greater than 0.7 mg/L unless special management practices are used to mitigate boron accumulation in soils. DW's recycled water quality is expected to be 0.28 mg/L, which does not pose a water quality problem for landscapes that irrigate with recycled water. Nonetheless, because boron can accumulate in soils and is not readily leached in tighter soils, boron levels in soils should be monitored over the long-term to insure accumulation does not reach toxic levels, especially for plants that are more sensitive to boron[11]. Some golf courses in Colorado have experienced problems with long-term boron accumulation (Qian, 2004).

7. Chloride

Chloride Toxicity Impacts

Like sodium, chloride toxicity can occur directly to plant surfaces through sprinkler irrigation or can cause toxicity through uptake from accumulation in the soil. Most plants tend to be more susceptible to toxicity through sprinkler irrigation rather than toxicity caused by uptake through the soil. Chloride is essential to plant production and health, but high concentration (greater than 100 mg/L) can be toxic to plants when applied via sprinkler irrigation. Direct absorption of chloride occurs through the surface of moistened leaves and can cause leaf burn or drying of leaf tissue (Westcot and Ayers, 1985). Landscape ornamentals such as shrubs, trees, and ground covers are generally believed to be more sensitive to high chloride levels than are turf grasses, and as such should be monitored more closely for chloride impacts (Harivandi and Beard, 1998).

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[11] Many deciduous and fruit trees are classified as sensitive to boron (0.5 – 0.75 mg/L); while Kentucky bluegrass is classified as moderately tolerate of boron (2.0 – 4.0 mg/L) (Ayers and Westcot, 1985).

Chloride Levels in Recycled Water

Ayers and Westcot (1985) state that chloride levels in irrigation water should not be greater than 100 mg/L for sprinkler irrigation if the use of recycled water is not to be restricted. For surface irrigation, chloride levels in irrigation water should not be greater than 140 mg/L. DW's recycled water quality is expected to be just under 100 mg/L and can therefore be used for landscape irrigation without a restriction on use. Because chloride is highly soluble and therefore readily leached, it is likely that accumulation in the soil will not occur over the long-term.

8. Nitrogen

Nitrogen Impacts

Nitrogen used by plants for growth is found in the soil and in irrigation water, and is often applied through fertilizer application. The most readily available forms of nitrogen are ammonium and nitrate (NO_3–N)[12], the latter of which occurs most frequently in irrigation water. Excess nitrogen in irrigation water has much the same effect as applying excess nitrogen to the soil; too much nitrogen can cause over-stimulation of growth, delayed plant maturity, and poor plant quality (Ayers and Westcot, 1985).

The nitrogen that occurs in irrigation water is essentially the same as nitrogen applied through fertilizers. However, it cannot be as easily regulated as a fertilizer program and therefore can be problematic if levels are high in the irrigation water (Pettygrove and Asano, pg. 3-30). Plant sensitivity to nitrogen varies by crop type and growth stage. For example, excess nitrogen levels in irrigation water may be beneficial during early growth stages but may cause plant quality to decline as it matures to full growth.

A good understanding of the nitrogen that is taken up by landscape plants from nitrogen rich irrigation water is needed in order: (1) to adjust the regular fertilization program, and (2) to determine the likelihood that excess nitrogen will be transported below the root zone and into groundwater (Pettygrove and Asano, pg. 6-5).

When nitrogen rich irrigation water is added to the root zone, the inorganic form of nitrogen is immediately available for uptake by plants. Nitrogen that is not taken up by plants or soil microbials will readily leach below the root zone. Organic nitrogen is typically converted to ammonium by microorganisms in a process called mineralization. During times when microbial activity is low, organic nitrogen may build up in the soil, but be released during the warmest times of the year when microbial activity is high. The inconsistent rate of mineralization and the variability by which plants take up inorganic nitrogen makes it difficult to control nitrogen levels in the soil (USGA, pg. 213). Managing the use of irrigation water that is rich in nitrogen represents a challenge because it is difficult: (1) to control the nitrogen added and utilized by plants, and (2) to regulate the movement of nitrogen into and out of the root zone.

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[12] In this report, nitrogen values are reported as nitrogen in the form of nitrate (NO_3–N).

Nitrogen Levels in Recycled Water

Ayers and Westcot (1985) state that irrigation water should not have nitrate-nitrogen concentrations greater than 5 mg/L for sensitive plants if no restriction on use is desirable. Most landscape plants, including turf grass are not considered nitrogen sensitive and can therefore withstand levels well above 5 mg/L. Figure 1 shows that nitrogen levels for DW's recycled water fall within the slight to moderate restriction on use category. This implies that changes in management may be necessary for the successful use of the irrigation water.

Management of Nitrogen

The primary impact to turf grass from high nitrogen levels in irrigation water is the over-stimulation of plant growth. Areas impacted by over-stimulation may require more frequent mowing, application of growth regulators, and removal of grass clippings that contribute to the nitrogen load. Nitrogen accumulation in the soil not only depends on the quality of the irrigation water, but also the plant type, depth and distribution of roots, frequency and amount of water application, and the soil type. As such, it is important to recognize that areas within a landscape may experience different impacts from excess nitrogen.

Directly improving the nitrogen content in the irrigation water is the best method for managing nitrogen impacts to landscapes. If recycled water is pumped out of ponds for irrigation, one means of improving water quality is to install aeration systems to help reduce nitrogen levels in the water. If lower-nitrogen water is available, mixing or selective irrigation may also help mitigate negative impacts. For example, because plants tend to use less nitrogen as they mature, the selective use of higher quality water for irrigation during maturity may reduce negative impacts.

If it is not possible to directly reduce nitrogen levels in the irrigation water, the best solution is to frequently monitor nitrogen levels in the irrigation water and the soil so that necessary adjustments can be made to the fertilizer program. Adjustments to the fertilizer program that consider the excess nitrogen added from the recycled water will help to eliminate over application of nitrogen and leaching to groundwater. Additional changes to landscape operation and management that may be necessary include increasing the frequency of mowing, collecting and removing grass clippings, and/or applying growth regulators.

9. Successfully Using Recycled Water for Landscape Irrigation

The recycled water that DW 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. The purpose of presenting and discussing recycled water quality in this report was: (1) to better understand potential impacts of recycled irrigation water on landscape, and (2) to determine what management practices are available to mitigate impacts on landscapes.

It is difficult to fully understand how a particular level of water quality may impact the health of a landscape. Those who maintain landscapes know that the health is a function of the physical and environmental aspects (water, soil, plants, climate, irrigation design), in addition to the degree of management and level of use. For these reasons among others, the importance of monitoring water quality and soil quality over time cannot be overemphasized. The results obtained from monitoring will determine if management changes are needed and if the management practices employed are successful. The more specific management practices for mitigating recycled water impacts that were discussed in this report are summarized in Table 4.

General recommendations for landscapes that use recycled water for irrigation include:

- Collect and test soil samples from a wide variety of test locations in the landscape, and at an adequate frequency, so subsequent test results can be monitored and actual trends measured.
- Establish soil quality and water quality baselines.
- Document and measure all management changes made to deal with water quality induced problems.
- Improve and increase drainage capabilities in selected areas that exhibit drainage concerns.
- Continually improve irrigation management and irrigation scheduling.
- Over time, select less sensitive ornamental plants when possible.

Table 4. Recommended practices by water quality parameter

Water Quality Concern	Mangement Practices for Mitigating Negative Impacts
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

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Appendix

Assumptions in the Irrigation Guidelines – From Ayers and Westcot (1985)

The water quality guidelines in Table 2 of this report are intended to cover the wide range of conditions encountered in irrigated agriculture. Several basic assumptions have been used to define their range of usability. If the water is used under greatly different conditions, the guidelines may need to be adjusted. Wide deviations from the assumptions might result in wrong judgments on the usability of a particular water supply, especially if it is a border line case. Where sufficient experience, field trials, research or observations are available, the guidelines may be modified to fit local conditions more closely.

The basic assumptions in the guidelines are:

Yield Potential: Full production capability of all crops, without the use of special practices, is assumed when the guidelines indicate no restrictions on use. A "restriction on use" indicates that there may be a limitation in choice of crop, or special management may be needed to maintain fully production capability. A "restriction on use" does not indicate that the water is unsuitable for use.

Site Conditions: Soil texture ranges from sandy-loam to clay-loam with good internal drainage. The climate is semi-arid to arid and rainfall is low. Rainfall does not play a significant role in meeting crop water demand or leaching requirement. (In a monsoon climate or areas where precipitation is high for part or all of the year, the guidelines restrictions are too severe. Under the higher rainfall situations, infiltrated water from rainfall is effective in meeting all or part of the leaching requirement). Drainage is assumed to be good, with no uncontrolled shallow water table present within 2 meters of the surface.

Methods and Timing of Irrigations: Normal surface or sprinkler irrigation methods are used. Water is applied infrequently, as needed, and the crop utilizes a considerable portion of the available stored soil-water (50 percent or more) before the next irrigation. At least 15 percent of the applied water percolates below the root zone (leaching fraction >/= 15 percent). The guidelines are too restrictive for specialized irrigation methods, such as localized drip irrigation, which results in near daily or frequent irrigations, but are applicable for subsurface irrigation if surface applied leaching satisfies the leaching requirements.

Water Uptake by Crops: Different crops have different water uptake patterns, but all take water from wherever it is most readily available within the rooting depth. On average about 40 percent is assumed to be taken from the upper quarter of the rooting depth, 30 percent from the second quarter, 20 percent from the third quarter, and 10 percent from the lowest quarter. Each irrigation leaches the upper root zone and maintains it at a relatively low salinity. Salinity increases with depth and is greatest in the lower part of the root zone. The average salinity of the soil-water is three times that of the applied water and is representative of the average root zone salinity to which the crop responds. These conditions result from a leaching fraction of 15-20 percent and irrigations that are timed to keep the crop adequately watered at all times.

Salts leached from the upper root zone accumulate to some extent in the lower part but a salt balance is achieved as salts are moved below the root zone by sufficient leaching. The higher

salinity in the lower root zone becomes less important if adequate moisture is maintained in the upper, "more active" part of the root zone and long-term leaching is accomplished.

Restriction on Use: The "Restriction on Use" shown in Table 1 is divided into three degrees of severity: none, slight to moderate, and severe. The divisions are somewhat arbitrary since change occurs gradually and there is no clear-cut breaking point. A change of 10 to 20 percent above or below a guideline value has little significance if considered in proper perspective with other factors affecting yield. Field studies, research trials and observations have led to these divisions, but management skill of the water users can alter them. Values shown are applicable under normal field conditions prevailing in most irrigated areas in the arid and semi-arid regions of the world.