Appendix K
Technical Memo 10
Recycled Water Application Rates

TECHNICAL MEMORANDUM – RECYCLED WATER APPLICATION RATES

September, 2008

TECHNICAL MEMORANDUM NO. 10

INTRODUCTION

The rate of application of recycled irrigation water must be accurately determined to protect groundwater and to meet crop nutrition needs. The nitrogen in the recycled water is necessary for plant growth, but any nitrogen that percolates past the root zone will ultimately contaminate groundwater. It is not only necessary to limit the total nitrogen applied during a growing season to that which the crop can assimilate, it is also necessary to match the rate of application of nitrate to that which the plant can absorb.

This technical memorandum will address the irrigation of alfalfa, timothy hay, native pasture and turf grass with recycled water from the South Tahoe Wastewater Treatment Plant. Changes in the rate of application of recycled water as a result of water quality improvements, blending with fresh water and alternating irrigation between recycled and fresh water will be addressed.

SOIL – WATER AND CROP WATER USE

The amount of water held in a volume of soil after gravitational drainage is the Field Capacity (FC) of the soil. Of this capacity, only a percentage is available for use by crops. This is termed the Available Water (AW). The AW, or soil moisture reservoir, is depleted as crops absorb water and replenished by natural precipitation or irrigation. When the AW is depleted to a certain point, different for each crop type, the plants begin to experience water stress. The goal of the irrigator is to irrigate the crop before the plant stress from lack of water causes a reduction in the crop yield. The level of AW depletion that will cause a reduction in crop yield is the Yield Threshold Depletion (YTD). The irrigation manager typically sets an allowable depletion in the AW at some level below the YTD. At the allowable depletion, the crop is irrigated with enough water to replenish the AW. The amount of irrigation should equal the total Evapotranspiration (ET) from the crop, minus any precipitation, since the last irrigation. The ET is essentially identical to the crop's Consumptive Use (CU), and the terms are used interchangeably (Miller and Donahue, 1990).

IRRIGATION WITH RECYCLED WATER

The amount of recycled water that can be applied to any crop will be determined by the smaller of the plant's consumptive use requirement and the plant's nitrogen requirement. A third limit, the soil's permeability limit, is calculated to assist with preventing recycled water from ponding or flowing overland off the intended irrigation site. All three equations are from Metcalf & Eddy (1991).

Plant Consumptive Use

Consumptive use is the amount of water the plant absorbs for vegetative and reproductive growth. These application rates account for evapotranspiration from the plants, precipitation, efficiency of the irrigation system and the leaching requirement. The ET data used in this analysis was obtained from the NCRS Nevada Irrigation Guide and the UNR Agricultural Extension Service, and have been adjusted for the particular crops. Precipitation data was obtained from the National Weather Service for Minden, Nevada. The efficiency is assumed to be 50% for flood irrigation systems. Leaching requirement, discussed below, is the fraction of the irrigation water that will percolate past the root zone, removing salts from the soil. The consumptive use requirements for the four study crops are shown in Table 1.

Table 1

Consumptive Use Requirements

Crop	Consumptive Use Requirement (Ac-Ft/Ac/Year)
Alfalfa	3.89
Native Pasture	3.12
Timothy Hay	3.91
Turf Grasses	4.17

The above numbers represent the amount of water the crop will assimilate from the soil over the growing season. Because the plants transpire essentially all absorbed water, the CU is considered equal to ET.

Total Dissolved Solids

The TDS of the recycled water serves as a measure of its salt concentration. When water is absorbed by the root system of a plant, any dissolved salts are typically left in the soil. Thus, over time salts will build up in the soil to the point that the osmotic gradient prevents any water from being absorbed by the roots (Feigin et.al., 1991). At this point the soil is incapable of supporting vegetative growth. Salts are typically removed from the soil by excessive irrigation with fresh water. The irrigation water in excess of what the field capacity carries the salts from the soil out of the root zone and into the groundwater aquifer. The calculations to determine the consumptive use requirement of the plants, presented above, include a fraction of the irrigation water for leaching salts beyond the root zone, preventing saltification of the soil.

The USDA Office of Water Program Operations classifies water with a TDS < 500 mg/l as water for which no detrimental effects are usually noticed (Rowe and Abdel-Magid, 1995). Effluent from the District's WWTP currently has a TDS of 250 mg/l, placing it well within the highest quality range. For determining crop salt tolerance, the TDS value is converted to an equivalent Electrical Conductivity (EC) using the equation:

$$EC \approx TDS / 640$$

Using this formula, the District's WWTP effluent has an EC of 0.391 mmho/cm (dS/m). The salt tolerances, expressed as EC, for the four study crops are given in Table 2.

Table 2

Plant Salt Tolerances[1]

Crop	Salt Tolerance (mmho/cm)
Alfalfa	3.7
Native Pasture	3.06
Timothy Hay	3.0 (est.)
Turf Grasses	6.25

NOTE

1 Data from USDA Agricultural Research Service Salinity Laboratory

The salt tolerance of each of the four study crops is much higher than the current discharge concentration. These tolerances allow for relatively small leaching fractions to remove salts from the soil, minimizing the amount of recycled water percolating past the root zone.

Nitrogen Limitations

The amount of nitrogen applied to a crop must not exceed the amount the plant can reasonably uptake plus an allowance for percolation past the root zone and an allowance for ammonia volatilization. The majority of the nitrogen in the recycled water is in the form of ammonia, and will be changed to nitrate under natural soil conditions. Nitrate can be further reduced to nitrogen gas, but the conditions necessary for this reaction are not typically present in the soil. Thus nitrate that is not absorbed by the crops will remain as nitrate and will contribute to the nitrification of the groundwater aquifer. Ammonia that percolates past the root zone will likely be converted to nitrate by soil microorganisms and eventually contribute to groundwater contamination.

The effluent from the District's WWTP currently has approximately 20-mg/l total nitrogen. It is estimated that 20% of the ammonia will volatilize prior to the water being absorbed into the soil, and 5-mg/l nitrogen is allowed to percolate past the root zone (NDEP, 1999). Application rates under these conditions for the four study crops are given in Table 3.

Table 3

Application Rates Based on Plant Nitrogen Requirement

Crop	Annual Irrigation Budget as determined by Nitrogen Loading (AF/Ac/Year)
Alfalfa	7.70
Native Pasture	3.02
Timothy Hay	3.62
Turf Grasses	4.11

In all cases these rates are higher than the respective consumptive use rates. Table 4 shows the concentration of nitrogen in the treatment plant effluent that would be required to cause the crop's nitrogen absorption to become the limiting factor in determining the amount of recycled irrigation water that could be applied.

Table 4

Limiting Nitrogen Levels

Crop	Required Nitrogen Concentration (mg/l)
Alfalfa	35
Native Pasture	26.25
Timothy Hay	29
Turf Grasses	22.75

Permeability Limit

The amount of irrigation water that can be applied to any land is subject to the permeability limit of the soil. This limit evaluates the ET, precipitation and percolation rate of the soil to determine the maximum irrigation quantity that can be applied without runoff or ponding. The permeability of the soil is dependant on several geological factors, including particle size, mineral composition and underlying geology. Typically the least permeable fraction of a soil profile will determine the overall permeability. According to the Soil Survey of the Carson Valley Area, Nevada-California (1971), there are 82 different soil types that are irrigated with recycled water, having permeabilities ranging from less than 0.06 inches/hour to greater than 20 inches/hour. Prior analysis by Harding ESE grouped the soils into three permeability classes: 0.06 in/hr, 0.6 in/hr and 2.0 in/hr. These divisions are fairly conservative and will be used in this analysis. In calculating the permeability limit of a soil, the design percolation rate is typically 2-6 % of the minimum permeability for a given soil type. Because the permeability limit is a measure of irrigation water applied in excess of the plants consumptive use requirement, the limit is dependant on the type of crop. Table 5 shows the permeability limits for each study crop for each permeability class, assuming 24 hrs of irrigation per week for a 28 week growing season.

Table 5

Permeability Limits (Ac-Ft/Ac/Year)

	Permeability (inches/hour)		
Crop	**0.06**	**0.6**	**2.0**
Alfalfa	2.01	3.14	6.05
Native Pasture	1.65	2.77	5.68
Timothy	2.03	3.15	6.06
Turf Grass	1.92	3.04	5.96

All of these values for the two lowest permeabilities are below the respective consumptive use requirements. The sole purpose of the permeability limit is to define the quantity of water that can be applied without ponding or runoff. The assumptions made for this calculation are very conservative. Permeability is usually not used as a regulatory control mechanism, only to identify those areas that may require tailwater control measures. Crites and Tchobanoglous (1995) advocate not using the permeability parameter for crop irrigation applications, but determining the required irrigation based on consumptive use. With flood irrigation, the rancher necessarily applies water at a rate greater than the permeability rate of the soil in order to cover the entire field. In this situation, sufficient tailwater control is required to prevent the recycled water from flowing overland to a surface water body.

ADVANCED WASTEWATER TREATMENT

The District's WWTP currently discharges Secondary 23 Recycled Water. The discharge permit requires the effluent to be treated to a BOD_5 of 30 mg/l and a Total Suspended Solids of 30 mg/l. There is currently no nitrogen limit for the WWTP effluent. Further treatment such as filtration or denitrification would not change the amount of recycled water that can be applied to the crops in Alpine County. In no case is the quality of the recycled water the limiting factor in determining the irrigation limits. Advanced wastewater treatment should not be considered by the District in an effort to increase the amount of recycled water that can be utilized through agricultural applications.

BLENDING RECYCLED AND FRESH WATER

Because the amount of irrigation water being applied is limited by the consumptive use of the crop, blending recycled water and fresh water will not increase the amount of recycled water that can be used as irrigation water. It would increase the total amount of recycled water that must be safely disposed of because any fresh water used for blending must be treated as recycled water.

Blending would reduce the TDS, which would tend to reduce the risk of saltification in the soil. However, as discussed, the recycled water from the District's WWTP is already very low and unlikely to cause detrimental soil conditions.

ALTERNATIVELY IRRIGATING WITH RECYCLED AND FRESH WATER

Many of the ranches in Alpine County have surface water rights in addition to contracted rights to recycled water. Alternatively irrigating with fresh and recycled water may be preferable for some ranchers because of logistical concerns. The concern in alternating between recycled and fresh water for irrigation is that the fresh water will flush the nitrogen in the recycled water out of the root zone before the plants can reduce the concentration below the allowed 5 mg/l, causing nitrate to concentrate in the groundwater.

If the crops are irrigated in an efficient manner, the quantity of irrigation water applied will equal ET losses plus a small leaching fraction, returning the soil to its field capacity. No irrigation water will percolate past the root zone, save the leaching fraction. Thus alternating irrigation with fresh and recycled water does not increase the amount of nitrogen reaching the groundwater aquifer. Because most crops uptake a large portion of their required water (40%) in the top 25% of the root zone and an additional 30% in the second 25% of the root zone, a significant water deficit exists at the top of the soil column (USDA 1981). If excess fresh water is applied after irrigation with recycled water, the water deficit at the top of the root zone will slow the movement of the fresh water through the soil, allowing additional time for the lower portion of the root zone to absorb nitrogen from the recycled water. The excess irrigation will still cause percolation past the root zone, but the concentration of nitrogen in the percolating water will be at a minimum. If an effort is made to match irrigation quantity to plant consumptive use, this buffer will serve to reduce the risk of small errors in consumptive use estimation.

It is important to note that the crops under consideration have widely varying nitrogen uptake rates during their life cycle. Active vegetative growth requires the most nitrogen, freshly germinated seeds the least. Irrigation with recycled water should be matched to the portions of the life cycle where nitrogen uptake is at a maximum.

CONCLUSIONS

The amount of recycled water that can be applied to crops in Alpine County is being limited by the consumptive use of the plants. The quality of the recycled water is high enough to not be a restricting factor. Certain portions of the reuse area have soils with low permeabilities, which will restrict the rate of irrigation. Individual site assessments should be made on each application area to determine the actual permeability of the soil to assist in determining the rate of application of irrigation water.

The above analysis assumes the ranchers are applying irrigation water in a manner that closely approximates ET losses. If excess irrigation water is applied, either fresh or recycled, it will percolate past the root zone. Recycled water from the District's WWTP has approximately twice the concentration of nitrogen that is allowable in groundwater, thus irrigation water percolating quickly past the root zone will result in contamination of the groundwater aquifer. Freshwater percolating past the root zone will carry with it salts and excess nutrients from the soil, contributing to groundwater contamination in addition to wasting irrigation water.