BALANCING BIOSOLIDS, NUTRIENTS, NITRATES AND RECLAIMED WATER – MULTI-TASKING ON NUMEROUS LEVELS

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Introduction

The City of Raleigh Public Utilities Department (CORPUD) operates the Neuse River Wastewater Treatment Plant (NRWWTP) in southeastern Wake County, North Carolina. During 2004, the flows treated by the NRWWTP averaged over 45 mgd. The facility is designed and permitted for 60 mgd with the discharge of treated effluent into the Neuse River. The treatment facility produces a very high quality effluent and, as a result, must manage a fairly large volume of biosolids produced by the advanced wastewater treatment process.

The City maintains Non-Discharge Permit No. WQ0001730 for management of biosolids produced by the NRWWTP. The program includes approximately 1,030 acres of farmland divided into agriculturally managed tracts. Biosolids are land applied at agronomic rates to use the receiving crops and soils to assimilate the biosolids and associated constituents. The site has been operated as a biosolids management farm since 1980.

Monitoring of groundwater at the biosolids farm revealed exceedances of the North Carolina 2L groundwater standards. As a result of the exceedances, the City was required by the NC Division of Water Quality (NC DWQ) to characterize and assess the extent of the groundwater issues. The City suspended land application of the biosolids on the subject lands in September 2002. The City also developed a Corrective Action Plan (CAP) that addresses the actions necessary to remediate the subject groundwater standard exceedances.

The City desires to resume use of the land application sites for the management of biosolids. In order to ensure that future practices do not result in any regulatory compliance issues, the City desires that resumption of land applying biosolids be done with the sensitivity to all potential controls of nutrient loading. In addition to careful analysis, recordkeeping, and application practices, the City wants to optimize the health of the receiving crops to ensure a vigorous uptake of applied nutrients. In order for the receiving crops to be vigorous, they must have water in addition to nutrients. The City's past experience with the sites' farming activities has indicated that during drought conditions, the crops become stressed and no means of irrigation has been available. There is one area of the site, approximately 120 acres in size, that has a solid-set irrigation system and farm personnel have recognized the value of providing water to all crops and fields. This project is to design and install irrigation equipment to irrigate an additional 130 acres of the farm.

Site Characterization and Considerations

Irrigation of treated wastewater from the NRWWTP is being designed at rates necessary to optimize the yield of the receiving crops. The traditional control for an irrigation application rate is the amount of water that can be applied to a site or specific soil series without causing ponding or runoff of the applied water. Transmissive or highly permeable soils in the Piedmont or central part of the State would have irrigation rates exceeding 60 inches per year. The traditional approach gave significant consideration to the underlying soil and its associated loading rate restrictions, but little consideration was given to the hydraulic needs or uptake of the receiving crop (secondary factor). In the current approach, the hydraulic need of the receiving crops is being given the higher priority, with the intent of providing a healthy, vigorous crop to ensure optimization of crop yield.

Wastewater Effluent Versus Reclaimed Water Irrigation
The principle drivers for choosing between reuse quality effluent (reclaimed water) and traditional land application of treated wastewater effluent are primarily:

- Effluent water quality or treatment requirements
- Setbacks or buffers

The North Carolina regulatory requirements for land application of wastewater treatment facility effluents are found in Title 15A of the North Carolina Administrative Code (NCAC) Chapter 2H .0200 – Wastes Not Discharged to Surface Waters. The rules lay out requirements for all types of Non-Discharge Systems but .0219(k) specifically addresses the reclaimed water requirements.

Effluent Water Quality and Treatment Requirements
Typically, the required effluent quality for land application of wastewater on a controlled access site is secondary treatment or better. Typical effluent parameters and their acceptable levels for secondary effluent and for reclaimed water are compared in Table 1.

Table 1. Secondary Effluent and Reclaimed Water Treatment Performance Levels

	Secondary Effluent	**Reclaimed Water**	
Parameter	**Monthly Average Maximum**	**Monthly Average Maximum**	**Daily Maximum**
BOD_5	30 mg/l	10 mg/l	15 mg/l
NH_3	20 mg/l	4 mg/l	8 mg/l
Total Suspended Solids (TSS)	30 mg/l	5 mg/l	10 mg/l
Fecal Coliform	200 colonies per 100 ml	14 colonies per 100 ml	25 colonies per 100 ml
Turbidity	Not Specified or Limited	Not Limited	10 NTU[1]
Total Nitrogen	Not Specified or Limited	Not Specified or Limited	Not Specified or Limited
Total Phosphorous	Not Specified or Limited	Not Specified or Limited	Not Specified or Limited

Note: 1 - Turbidity limit is actually an instantaneous maximum.

Since the NRWWTP produces an effluent that is tertiary in quality as opposed to secondary, the step to produce reclaimed water quality effluent is minimal. A review of existing effluent water quality data indicates that the NRWWTP currently consistently produces effluent that complies with the reclaimed water standards. In the event that turbidity or fecal coliforms are not met, the reuse stream could be diverted to the surface water discharge and still be in compliance with NPDES Permit discharge limitations.

Setbacks or Buffers

Treatment of the effluent to reclaimed water standards provides several attractive incentives from a regulatory perspective. A comparison of the setbacks required for land applied secondarily treated wastewater (non-reclaimed water) versus reclaimed water is shown in Table 2.

Table 2. Secondary Effluent and Reclaimed Water Setbacks

Distance Between Wetted Areas and…	Secondary Treated Wastewater	Reclaimed Water
Property Lines	150 feet	Zero (0) / Not Required
Surface Waters	100 feet	25 feet (Non SA Waters)
Adjacent Residences	400 feet	Zero (0) / Not Required
Public Water Supply Wells	100 feet	100 feet
Public Right-of-Way	50 feet	Zero (0) / Not Required

Other Factors to Consider

Site Access and Control

Wastewater effluent requires a controlled site that prevents access to the land application area. This is usually addressed by barbed wire or chain link fencing along with signage discouraging or preventing access. Reclaimed water utilization sites do not impose any fencing requirements but signage must be posted to ensure that the general public understands that the reclaimed water is not intended for drinking purposes. Inferred in the control of reclaimed water sites are that indirect contact with the reclaimed water is acceptable but long-term contact is not advisable.

Pipe Labeling and Cross Connection Controls

Since wastewater piping is typically color coded differently from potable water piping, no special requirements are imposed to ensure improper cross connections. Since reclaimed water is relatively new to North Carolina and the utility construction industry, reclaimed piping is required to be either color coded (purple pipe) or taped or wrapped in purple plastic labeling to prevent the inadvertent cross-connection between reclaimed systems and potable water systems. The increase in overall cost of the pipe or tape installation is negligible compared to traditional piping costs.

Regulatory Perspective
Management of wastewater effluents by non-discharge means are considered favorable compared to the discharge to surface waters (NPDES Permit). Land application of non-reclaimed effluents is still considered *disposal* whereas land application of reclaimed water is considered *utilization*. Utilization or recycling of water for a beneficial purpose is considered preferable and as such, several regulatory incentives exist. These include buffers or setbacks from irrigation areas and property lines, surface water features, residences; reduction or elimination of groundwater monitoring requirements; and site specific data such as hydrogeological borings and assessments. Overall, the NC DWQ considers reclaimed water utilization to be the *preferred* means of wastewater management and will treat such projects favorably in many cases.

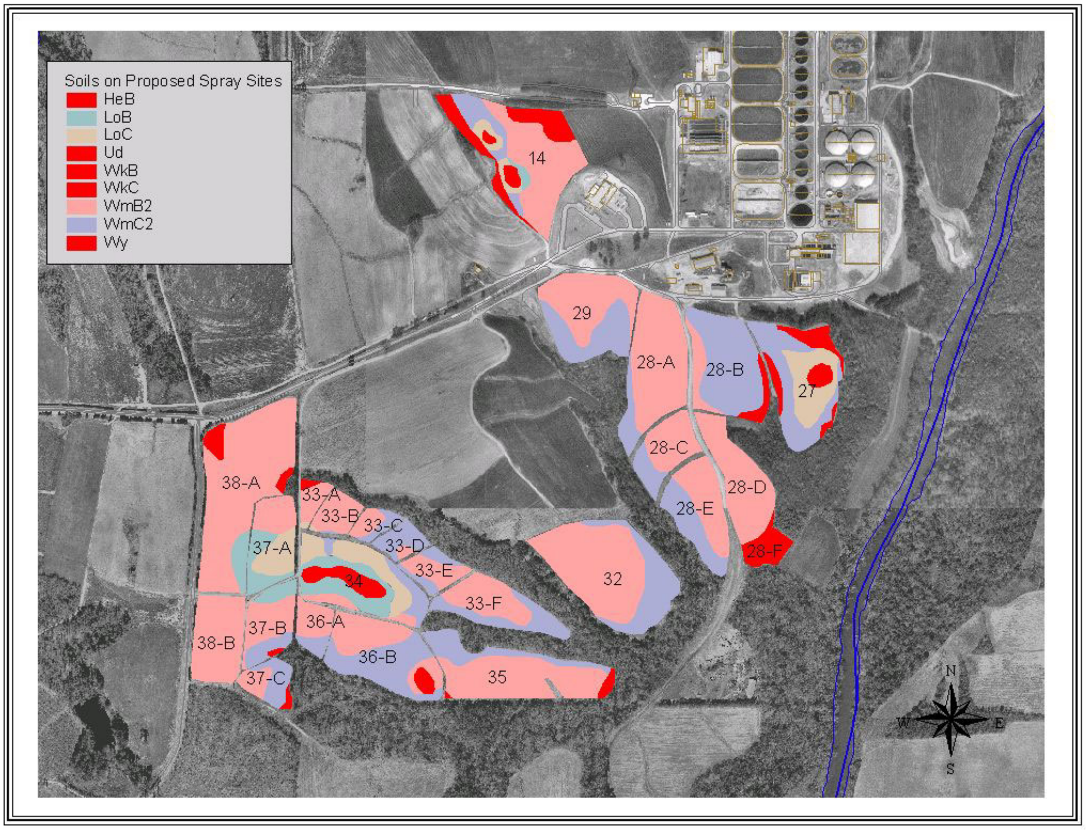
Soil Mapping
Although the site has been utilized for the management of biosolids since 1980, no record could be located of any detailed site assessment of the soils proposed for the irrigation system. Although the Soil Survey for Wake County prepared by the U.S. Department of Agriculture could provide a reasonable survey of the soils, an accurate and site specific soil map was prepared by Synagro Technologies, Inc. A Synagro staff soil scientist evaluated the proposed irrigation sites and developed a soil map and associated soils analysis. A digitized version of the soils map prepared by Synagro is shown in Figure 1. It should be noted that the areas highlighted in red are deemed unsuitable for irrigation due to either wetness (Worsham – Wy and Helena – HeB), shallow soils (Wake – WkB and WkC), or significant soil disturbance (Udorethents – Ud).

Hydrogeological Analysis
The firm of Edwin Andrews and Associates was utilized to prepare the hydrogeological evaluation of the proposed irrigation sites. Hydrology tests were conducted on the most restrictive horizons of the Louisburg, Wake and Wedowee soils. These tests, in addition to the soils mapping and agronomic evaluations prepared by Synagro provided information suitable for development of a water balance for the proposed irrigation sites.

HYDRAULIC AND NUTRIENT MANAGEMENT

Since the project objective is to optimize crop yield and subsequently nutrient uptake, it is very important to ensure that the spray irrigation system is designed and operated to meet these requirements. Historically, most land application systems have focused on the maximum hydraulic loadings of wastewater effluents. This is driven primarily because of the traditional approach of providing the minimum system to dispose of the maximum amount of effluent so that overall costs of the system are minimized. The City has recognized that there is a balance associated with this project between managing biosolids on the farm, attenuating (or at least not exacerbating) the nitrate levels on the site, and the benefits of using the effluent for irrigation.

Crop Schedule and Agronomic Considerations
Discussions with biosolids and farm management staff at the Neuse River Treatment Facility indicate that only three primary crops are utilized for biosolids management. These include corn, soybean and wheat. Synagro was employed by HDR to assist with the agronomic evaluations of the proposed spray irrigation system and to make recommendations as to the appropriate hydraulic loadings to meet the



project objective of optimizing crop yield. The current cropping system is understood to be corn, wheat and soybeans (double-cropped). A summary of Synagro's hydraulic loading recommendations can be found in Table 3.

Figure 1. Soil Map of Proposed Irrigation Area

Table 3. Synagro's Recommended Hydraulic Loadings

Crop	Month	Irrigation (inches / month)
Corn	April	1.1
	May	4.9
	June	7.5
	July	5.4
	August	1.0
	Total	**19.9**
Soybean	July	2.2
	August	4.7
	September	7.5

Crop	Month	Irrigation (inches / month)
	October	4.5
	November	1.0
	Total	**19.9**
Wheat	November	1.0
	December	1.0
	January	1.0
	February	1.0
	March	2.5
	April	5.3
	May	7.5
	June	3.7
	Total	**23.0**

It should be noted that these loading rates do not take into account precipitation or wet conditions and are more reflective of drought conditions. The water balance calculations and loading rate recommendations prepared by Edwin Andrews and Associates will address these matters in later sections.

Hydrogeological Considerations
Extensive hydrogeological evaluations have been conduced by ENSR Consulting and Engineering, Inc., (ENSR) related to the nitrate conditions at the spray site. For the proposed irrigation sites, there are no significant hydrogeological restrictions to irrigation. According to ENSR's Comprehensive Site Assessment Report *(December 2002)*, "Hydrogeology in the area of the application fields consists of a single aquifer system with subunits corresponding to geologic zones. The aquifer units are in descending sequence saprolite, a transition zone primarily of partially weathered rock and fractured bedrock. The fractured bedrock unit is the primary water supply zone for drinking water wells. Groundwater flows from ridge top and side slope recharge areas towards discharge areas along perennial streams such as Beddingfield Creek and the Neuse River.

The objective to only use irrigation as a means to meet the crop water needs is in conformance with the corrective actions recommended by ENSR. By optimizing crop yield in conjunction with the biosolids management program, nutrient migration to the underling aquifers will be minimized, if not eliminated.

Recommended Hydraulic Loadings
The conventional approach to spray irrigation design and operation is to focus on the hydraulic loadings with a given site while ensuring that no ponding or run-off of applied water occurs. Crop nutrient loadings or hydraulic considerations are rarely a factor since soils themselves are primarily the restriction to water adsorption or movement into the aquifer. Since the irrigation project objective is to balance biosolids nutrient management, groundwater nitrate attenuation, and to prevent any further

nitrate issues, the irrigation system will be designed and managed to minimize nitrate migration to the underlying aquifer.

Edwin Andrews & Associates conducted an irrigation analysis for the proposed irrigation sites. The Andrews' Report analyzed the hydrogeology of the site, the soils, and the agronomic considerations and recommendations prepared by ENSR and Synagro, respectively. The Andrews' Report details water balance calculations and analyses to determine the appropriate hydraulic loading rates to meet the project objectives. These analyses take into account the various crops utilized and associated agronomic hydraulic loading recommendations plus expected precipitation and evapotranspiration rates for three general cases – dry, typical and wet years. Actual irrigation system design will not be affected by these seasonal characteristics but operation of the system will be affected. The primary operational constraint will be the length of irrigation (duration) which will have a direct impact on the total hydraulic loadings. A summary of the hydraulic loading recommendations from the Andrews' Report is contained in Table 4.

Table 4. Andrews' Recommended Hydraulic Loadings

Type of Season	Crop	Total Seasonal Irrigation (inches per season)	Maximum Required Irrigation (inches/month)
Dry Year	Corn	7.3	4.5
	Soybean	6.9	4.0
	Wheat	7.7	4.6
	Total	**21.9 inches per year**	**-**
Average Year	Corn	4.7	3.6
	Soybean	4.6	2.9
	Wheat	5.2	3.7
	Total	**14.5 inches per year**	**-**
Wet Year	Corn	3.4	2.9
	Soybean	3.3	2.1
	Wheat	3.9	3.0
	Total	**10.6 inches per year**	**-**

In addition to the seasonal hydraulic loading rates, an application or precipitation rate must be specified. This is the actual rate that water is applied to the ground surface. Too rapid an application can cause ponding or run-off of the irrigated water. Another variation of this application rate is to limit the amount of water applied during a given dose or irrigation event. Short irrigation events allow the soils to effectively drain and promote water uptake by the receiving crops through evapotranspiration. The Andrews' Report recommends that irrigation events be limited to a 0.2 inch dose and at no greater than

0.5 inches per hour. The ideal operating condition would be to irrigate the 0.2 inch dose in a 15 – 30 minute interval and allow the system to rest for several hours before any subsequent irrigation doses. The irrigation system should be designed to accommodate two 0.2 inch doses in a day and on two separate zones simultaneously.

Follow-up conversations with Mr. Andrews *(Safrit personal communications)* have indicated that from a traditional hydraulic perspective, these soils should be able to accommodate a hydraulic loading rate in the vicinity of 30 inches per year. This is important because at some point in the future when it is demonstrated that groundwater issues no longer dictate strictly an agronomic loading rate control, the CORPUD may pursue a hydraulic loading based on the soil characteristics alone.

Crop Nutrient Management

Nutrients applied to the crops will come from two major sources – the biosolids and the reclaimed water. No other sources of nitrogen or phosphorus such as commercial fertilizers are anticipated to be used. Some additional agronomic practices may occur such as pest management, disease control or pH adjustment. It is important that nitrogen and phosphorus be properly managed in order to avoid any over-application of nutrients that may "leak" from the soil profile and exacerbate the current nitrate conditions. For this reason, the nutrients from the irrigation of reclaimed water must be accounted for and included in the overall nutrient budget associated with the biosolids management program.

Surface Water Discharge Nutrient Load Reductions

Based upon effluent data obtained from the Neuse River Wastewater Treatment Facility and the anticipated hydraulic loadings, approximately 2,005 pounds (911 kg) of nitrogen and 16 pounds (7 kg) of phosphorus will be managed on the biosolids farm during a dry year. This also equates to an identical reduction of nutrients discharged to the Neuse River. The potential nutrient load reductions associated with the proposed spray system is summarized in Table 5. Ultimately, as much as 10,200 pounds (4,636 kg) of nitrogen and 3,400 pounds (1,545 kg) of phosphorus could be managed on the farm if all reasonably available sites (690 acres) are utilized for reclaimed water irrigation.

Table 5. Potential Neuse River Nutrient Load Reductions

Dry Year	Corn	590	197
	Soybean	551	184
	Wheat	615	205
	Total	**1,756 lbs per year**	**586 lbs per year**
Average Year	Corn	378	126
	Soybean	370	123
	Wheat	418	139
	Total	**1,166 lbs per year**	**388 lbs per year**
Wet Year	Corn	271	90
	Soybean	267	89
	Wheat	313	104

	Total	851 lbs per year	283 lbs per year

IRRIGATION SYSTEM DESIGN

Irrigation Demand

As reported in Table 4, the Andrew's Report identified a maximum crop irrigation demand of 4.6 inches/month during drought conditions, which is equivalent to an average daily irrigation demand of slightly less than 0.2 inches/day. In addition, the Andrews' Report recommends that irrigation events be limited to a 0.2 inch dose and at no greater than 0.5 inches per hour. Based on these requirements, the irrigation system was sized to provide a maximum dose of 0.2 inch per field at an irrigation rate of less than 0.5 inches per hour on two zones simultaneously. Time associated with irrigation of the existing fields was estimated assuming that CORPUD may irrigate fields up to two times per day at 0.2 inches/dose provided that the seasonal irrigation rates are not exceeded. Figure 2 illustrates the proposed irrigation sites.

Pumping System

The NRWWTP has an existing effluent pump station and 12-inch ductile iron mainline that delivers irrigation water to the existing 120-acre spray irrigation fields. The pump station includes four vertical turbine pumps (40 hp, 75 hp, 125 hp, and 250 hp) with a total flow of 3,400 gpm with all pumps in service. The effluent pump station also provides non-potable water for the NRWWTP.

CORPUD has initiated a project to modify the existing effluent pump station to separate pumps serving the majority of the non-potable plant demands from pumps servicing the spray irrigation fields to eliminate competing pump demands. This project includes addition of approximately 4,800 gpm of pumping capacity to the effluent pumping station which will allow the irrigation of two irrigation zones simultaneously at a rate of 2,000 gpm as well as run one of the water cannons at the equalization basin.

For sizing of the spray irrigation system, it was assumed that average effluent flow of 4,000 gpm would be available for irrigating existing and new irrigation fields. A 4,000 gpm effluent flow is adequate for irrigation of both the existing and proposed fields. However, additional effluent flow would be required to irrigate all of the farm fields in the future, since the total estimated irrigation time is in excess of 24 hours. A 4,000 gpm effluent flow dedicated to irrigation could irrigate a maximum of approximately 354 wetted acres at the maximum dose of 0.2 inches twice daily within a 16 hour timeframe. In order to irrigate the future maximum anticipated quantity of 688 acres of farm land within a 16 hour window, an effluent flow of 7,785 gpm dedicated to irrigation would be required.

Irrigation System Layout and Design Details

A solid-set spray irrigation system will be used to irrigate the proposed spray fields. The existing spray fields use SR100 Nelson Big Gun Sprinklers, which can operate of a pressure range of 40 psi to 110 psi with nozzle sizes ranges from 0.5-inch to 1.0-inch for taper bore nozzles. Proposed irrigation zones were developed for the fields shown in Figure 2 assuming continued use of Nelson Big Gun Sprinklers with an assumed delivery pressure of 70 psi.

NRWWTP effluent will be delivered to each zone through a 12-inch distribution main. Table 6 provides a summary of the identified zones. An automated control valve assembly will be provided for each irrigation zone. The valve assembly will include a gate valve for manual isolation of the zone and an automatically-controlled pressure reducing valve that will maintain a delivery pressure of 70 psi to the irrigation nozzles during irrigation periods. Each irrigation zone will consist of an array of full-circle and part-circle sprinklers aligned to provide irrigation over the spray fields within the zone. Submains (10-inch, 8-inch, 6-inch, and 4-inch, depending on number of sprinklers serviced by the submain) will distribute effluent from the valve assembly to the individual sprinklers located within the zone. Proposed spacing between the sprinklers is based on 60 percent of the manufacturer's published wetted diameter for the nozzle size in use.

Figure 2. Irrigation Sites

Table 6. Irrigation Zones

Zone	Field No.	No. of Sprinklers	Flowrate (gpm)	Wetted Acres
1	28B, 27	25	1,917	7
2	29, 28-A	21	2,034	11.8
3	28C, 28D, 28E	21	1,920	11.5
4	33-F, 35-A, 35-B	21	1,638	12.2
5	33-A, 33-B, 33-C, 33-D,	27	2,478	18.6

Zone	Field No.	No. of Sprinklers	Flowrate (gpm)	Wetted Acres
	33-E, 34, 36-A, 36-B			
6	37-B, 37-C, 38-B	19	1,699	8.3
7	37-A, 38-A, 38-C	24	2,358	13.5
13	32	17	1,611	10.9
25	14	8	710	5.5
Total	-	183	-	103.1

PRELIMINARY COST ESTIMATE

Table 7 provides a summary of the estimated construction cost for the proposed irrigation system. The cost estimate includes the 12-inch distribution main, ten irrigation zones with associated automatically-controlled valve assemblies, irrigation sub-mains within each zone, and a total of 183 sprinklers. The equipment cost for the solid set irrigation system is estimated at approximately $8,000 per wetted acre.

Table 7. Irrigation System Construction Cost Estimate

Item Description	Estimated Cost
11,120-lf of 12-inch DI Forcemain (including fittings / valves)	$509,000
Solid Set Sprinkler System (risers and valve assemblies)	$352,000
PVC Irrigation Sub-mains (includes fittings)	$340,000
General Site Work	$80,000
Electrical / Instrumentation & Control	$40,000
Contingency (10%)	$132,000
Construction Subtotal	**$1,453,000**
Engineering, Legal, and Administration (15%)	$218,000
Total Project Cost	**$1,671,000**

Conclusions and Recommendations

The benefits of the proposed reclaimed water irrigation system are not just for the Neuse River Wastewater Treatment facility but include other valuable benefits that may not be readily apparent as follows:

- The use of reclaimed water is a sustainable approach that meets the needs of the present without compromising the ability of future generations to meet their own needs.

- Each gallon of reclaimed water utilized reduces both nutrients (nitrogen and phosphorus) and oxygen-consuming demands on the receiving stream at a time when the receiving stream is typically at its most critical stage – during hot dry periods when stream flows and associated assimilative capacity are at their lowest point.

- The reclaimed water can provide a vigorous and healthy crop to ensure that applied nutrients are properly assimilated by the plants and those nutrients do not migrate below the root zone.

- Reclaimed water can displace use of potable water, thus off-setting need for new water sources or expansion of existing supplies.

- Reclaimed water can be a dependable, reliable, clean source of water, even in cases of severe drought.

- Reuse is the *preferred* means of wastewater management by regulatory agencies, environmental groups, and the general public.

- Allows a sustainable approach to minimize or avoid inter-basin transfers by reusing water in the basin from which it is derived.
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- Reuse helps avoid dramatic "swings" in water plant operations due to irrigation demands or other peaks – creating an opportunity for a "steady state" mode of operation.

- Reclaimed water can be a source of revenue to offset or cover the cost of additional treatment and distribution.

- It makes sense to use non-potable water for non-potable needs and preserve potable water for its highest and best use – for human consumption, culinary purposes, and bathing.

- The use of reclaimed water from the Neuse River WWTP can help to off-set the groundwater extracted from the Biosolids Farm Corrective Action Plan (CAP) and introduced into the treatment facility.