WATER SYSTEMS COUNCIL

October 25,2024

VIA ELECTRONIC MAIL
OWP_rulemaking@FloridaDEP.gov

Comments submitted with respect to the Recovery Strategy for the Lower Santa Fe and Ichetucknee Rivers and Associated Priority Springs (LSFIR) minimum flows (MFLs) Rulemaking

Thank you for the opportunity to submit comments. Water Systems Council submits the following comments with respect to the Recovery Strategy for the Lower Santa Fe and Ichetucknee Rivers and Associated Priority Springs (LSFIR) minimum flows (MFLs) Rulemaking. These comments mainly address proposed Rule 6.0 Private Residential Irrigation, which prohibits the construction of any "new private residential irrigation wells used solely for irrigation" in the Floridian aquifer after the effective date of the rules "where a lower quality water source is available or public supply or reclaimed water is available at or immediately adjacent to the property boundary at the time of the well construction.

Water Systems Council submits that lower quality water sources will generally not be practical or reliable for private residential irrigation. Private residential irrigation wells offer many advantages over public water supply and impose little or no harm to the water resources. States using similar water allocation systems as Florida uniformly exempt private residential irrigation from permitting requirements, recognizing the economic and environmental benefits of private residential irrigation wells. Water Systems Council urges the Florida Department of Environmental Protection to consider the environmental and economic benefits of private residential irrigation wells in the rulemaking process.

Founded in 1932, the Water Systems Council (WSC) is the only national nonprofit organization with programs solely focused on private water wells and small, shared wells serving an estimated 23 million households nationwide (according to the U.S. EPA). Approximately 12% of Floridians, or 2.5 million people, rely on private water wells for drinking water.[1]

The members of WSC include water well contractors, manufacturers and distributors of water well components, and state groundwater associations. WSC is committed to ensuring that Americans who depend on wells have safe, reliable drinking water and works to educate well owners, consumers, and policymakers at the local, state, and federal levels about water wells and the importance of protecting America's groundwater resources. The core values of WSC include preservation of important groundwater resources.

[1] Florida Department of Health, 2020.

The Florida Department of Environmental Protection (DEP) regulates the construction, permitting, and contracting of water wells. DEP rules regulating water well contracting, and construction are contained in Chapters 62-531 and 62-532 of the Florida Administrative Code.

Proposed Rule 6.0 forces landowners to consider unreliable and impractical options for private residential irrigation. Shallow wells, rainwater barrels, and reclaimed water are not available in a meaningful way for the vast majority of these homeowners. Public supply proves harmful to the water resources. These comments focus on the public water option and the benefits of private residential irrigation wells.

Private residential irrigation wells fall into the broad category of decentralized water systems. Decentralized water systems provide a host of environmental benefits.[2] These benefits include reduced energy use, increased efficiency, minimization of water loss, preservation of natural ecosystems, safeguarding of water quality, and building of climate resilience.[3]

Small, decentralized wells create smaller cones of depression than a large public water supply well, reducing the potential impact of the pumping on the water resources. If the private irrigation needs are met with public supply, the amount of water removed from the aquifer is not reduced, but the impact is increased. In addition, water removed from the aquifer by private domestic irrigation wells is returned to the system, less losses from intake by the vegetation and evaporation. Water used from public water systems is often returned to distant water basins or aquifers. Leaking water pipes lose an estimated 6 billion gallons of treated water.[4] In addition, use of public water supply or treated wastewater for private irrigation poses dangers to the vegetation, trees, and the environment in some circumstances.[5]

Recognizing these benefits, western states have permit systems that exempt domestic water wells and private irrigation from most restrictions. Although not a prior appropriation system, Florida has a unique system of water rights like no other state in the east. However, western prior appropriation systems resemble the Florida regulatory regime in many ways. Priority in the west is documented through a permitting system. In all but one state (Utah) that uses prior appropriation, and in some states that use eastern regimes, the western states provide "exempt well" status for domestic water

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[2] Illuminem, The environmental benefits of decentralized water systems (2023). *Available at* https://illuminem.com/illuminemvoices/the-environmental-benefits-of-decentralized-water-systems
[3] Ibid.
[4] American Society of Civil Engineers. *Available at* https://infrastructurereportcard.org/ .
[5] See, e.g., Kelly T. Morgan, T. Adair Wheaton, Larry R. Parsons, and William S. Castle, Effects of Reclaimed Municipal Waste Water on Horticultural Characteristics, Fruit Quality and Soil and Leaf Mineral Concentration of Citrus, HortScience 43(2):459-464 (2008) (attached to these comments).

wells.[6] Each state includes within the domestic well use a certain amount of private domestic irrigation.[7]

Not only are these wells the most practical and efficient source of water available to rural citizens, in many cases, they are the only viable option for obtaining potable water for households.[8] Connecting to public water often proves to be cost-prohibitive in rural areas where homes are widely dispersed. Private water wells provide safe and affordable drinking water options to many rural and suburban residences, often proving much more cost effective. Using data provided by Water Systems Council and Water Well Trust, the National Ground Water Association (NGWA) used seven case studies to illustrate the significant cost savings of private water wells over extension of public water lines.[9] Domestic wells are also critical for rural development.[10] A moratorium on domestic wells in a portion of Kittitas County, Washington several years ago resulted in "lost jobs, reduced property value, investments wiped out, shifting tax burdens, significant local economic damages, and significant opportunity costs." [11]

In conclusion, Water Systems Council supports reasonable and effective regulations to protect groundwater and springs. However, private residential irrigation wells form part of the solution, not the problem, in Florida. To promote the recovery of the Lower Santa Fe and Ichetucknee Rivers and Associated Priority Springs minimum flows (MFLs), the rule should encourage, not make almost impossible, the use of private residential irrigation wells.

Thank you for your consideration. Please contact me if I can answer any questions or provide further information.

Margaret Martens, Executive Director
Water Systems Council

[6] Jesse J. Richardson, Jr., Existing Regulation of Exempt Wells in the United States, J. Contemporary Water Research & Education, Issue 148, pp. 3-9, 3-4 (August 2012).
[7] Ibid, pp. 5-6.
[8] *See* Western States Water Council, *Water Laws and Policies for a Sustainable Future: A Western States Perspective* (June 2008) *Available at* http://www.westernstateswater.org/wp-content/uploads/2012/10/laws-policies-report-final-with-cover-1.pdf; Washington State Groundwater Ass'n, *White Paper Focusing On Instream Flows and Exempt Wells, Available at* http://robinson-noble.com/publications/white-papers/instream-flows-and-exempt.
[9] NGWA, Cost Comparisons of Local Groundwater Sources to Regional Water Lines, 2021.
[10] *See, e.g.,* Resolution and Recommendation of the Umatilla County, Oregon Critical Groundwater Task Force (Jan. 6, 2005) (attached to these comments).
[11] Paul Jewell, Kittitas County Board of Commissioners, Presentation to Conference, *Exempt Wells: Problems and Approaches in the Northwest* (Walla Walla, WA, May 2011) summarized in *Conference White Paper* at p. 7. *Available at* https://www.eiseverywhere.com/file_uploads/c0eea58c3d987fa399d191a1d5bf287a_Summary_2.pdf .

THE BOARD OF COMMISSIONERS OF UMATILLA COUNTY

STATE OF OREGON

In the Matter of Adoption)
of Exempt Well Resolution) Order No. BCC2005-15

WHEREAS on January 5, 2004, the Board of Commissioners adopted Order No. BCC2004-01 creating and appointing the Umatilla County Critical Groundwater Task Force to identify and implement technically and economically feasible measures to enhance and protect groundwater quantity and quality, as an essential natural resource necessary to assure continued economic development in Umatilla County, especially in designated Critical Groundwater Areas;

WHEREAS on January 6, 2005, the Umatilla County Critical Groundwater Task Force adopted a resolution and recommendation to deal with the immediate domestic water use issue and to provide security and clear and objective standards for Umatilla County citizens to develop domestic water supplies as allowed by law; a copy of which is attached to this order as Exhibit A;

WHEREAS on February 24, 2005, the Board of Commissioners held a public meeting to consider the resolution and recommendation of the Umatilla County Critical Groundwater Task Force, and voted to adopt the resolution with revised language for the 11th paragraph on page 2 of the resolution, further set out in Exhibit B attached to this order;

NOW THEREFORE, the Board of Commissioners orders that the Exempt Well Resolution is adopted as the policy of Umatilla County, as set out in Exhibit A, further amended by Exhibit B, attached to this order and incorporated by this reference. The Exempt Well Resolution will remain the policy of Umatilla County until further order of the Board of Commissioners.

DATED this 24th day of February, 2005.

UMATILLA COUNTY BOARD OF COMMISSIONERS

Emile M. Holeman

Emile M. Holeman, Chair

BOARD OF COMMISSIONERS UMATILLA COUNTY STATE OF OREGON

William S. Hansell, Commissioner

Dennis D. Doherty, Commissioner

ATTEST:
OFFICE OF COUNTY RECORDS

Records Officer

EXHIBIT A

January 6, 2005
UMATILLA COUNTY
CRITICAL GROUNDWATER TASK FORCE
Rural Residential Water Use
Resolution and Recommendation

WHEREAS the Umatilla County Critical Groundwater Task Force was created by order of the Umatilla County Board of Commissioners on January 5, 2004.

WHEREAS groundwater is an essential natural resource necessary to meet current and long-term water needs for domestic, municipal, agricultural, environmental, and other water uses in Umatilla County. The Umatilla County Critical Groundwater Task Force is created to identify and make recommendations on steps that Umatilla County should take to protect, sustain, and enhance groundwater quantity and quality in order to address future water supply needs in the County including the entire Umatilla Basin, but especially within designated Critical Groundwater Areas (critical areas).

WHEREAS one of the objectives of the Task Force, as specified by the Board of Commissioners, is to prepare a sustainable plan for groundwater development in Umatilla County through 2050.

WHEREAS the Task Force has met for ten months and has been presented with scientific and factual data from private parties, irrigation related entities, the Oregon Water Resources Department (OWRD) and other state agencies, and federal agencies. The Task Force has further been presented with scientific and technical information by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) representatives and experts. The CTUIR information provides knowledge of the interconnections of overall water uses and inventories in the Umatilla Basin. This information provides the Task Force with the foundation to understand the general makeup of the Umatilla Basin groundwater area as well as the reasons behind the creation of the various designated critical areas.

WHEREAS groundwater is the sole source of water supply to the residences outside the municipal water systems in the critical areas.

WHEREAS the development of the basalt groundwater reservoir in the lower Umatilla Basin, beginning mid-1960's and largely for irrigation, has resulted in regional water level declines in basalt wells.[1] The declines are continuing despite the administrative actions by the Oregon Water Resources Department to declare critical groundwater areas for the basalt aquifer in Stage Gulch, Ordnance and Butter Creek areas and restrictively classifying the basalt aquifer in the Ella Butte area. These administrative actions affect approximately 800

[1] Zwart, M.J., 1990, Groundwater conditions in the Stage Gulch area, Umatilla County, Oregon: OWRD, Salem, 44 p.

square miles (most of which is in Umatilla County) and severely limit future groundwater development and reduce groundwater use in much of these areas.[2]

WHEREAS the Ordnance gravel aquifer, separate from the basalt aquifer and overlying much of the Ordnance basalt aquifer in Umatilla County, is also a critical groundwater area designated by the Oregon Water Resources Department. Through the actions of several well owners in the Ordnance area to artificially recharge the gravel aquifer, groundwater levels in this critical area have responded favorably as a result of the recharge project and are relatively stable[3]**. Despite these improvements in the gravel aquifer, Oregon Water Resources Department is no longer issuing water right permits for non-exempt uses of groundwater in any of the critical areas.**

WHEREAS the Task Force has been presented with information by OWRD that the total available groundwater for use for irrigation and other non-exempt uses in the 800-square miles of critical areas is approximately 54,600 acre-feet per year, which is less than 40% of the 145,400 acre-feet per year of water rights issued for groundwater in the critical areas for non-exempt use.

WHEREAS the Task Force has been presented information demonstrating that domestic and residential uses of water are insignificant in volume compared to non-exempt uses of groundwater, such as irrigation and municipal, in the critical areas but are of critical importance to the citizens and the growth and vitality of Umatilla County.

WHEREAS the Task Force has received information that the volume of water for domestic purposes on 330 undeveloped rural residential lots within the designated critical areas is estimated to be less than 1-acre foot per year[4] **(af/yr) per resident having a family of four. To put this quantity into context, the amount of water that would be used annually by all 330 domestic users is less than 330 af/yr, which is less than 0.6 percent of the active groundwater rights in the critical areas.**

WHEREAS the Task Force is aware that the impetus for its creation was the threat of limiting or restricting the ability of county citizens to develop property that utilizes exempt domestic wells for residential purposes on lands presently designated for rural residential development in the critical areas. Behind the impetus to the threat to Umatilla County citizens was sustaining pressure by OWRD and the Department of Land Conservation and Development (DLCD) on Umatilla County, during the County's comprehensive plan periodic review process. This process by OWRD and DLCD encouraged the adoption of an overlay zone to "help enhance" groundwater supply by restricting rural residential growth.

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[2] OWRD, 2003, Ground water supplies in the Umatilla Basin: OWRD, unpublished, 30 p.

[3] OWRD, 2003, Ground water supplies in the Umatilla Basin: OWRD, unpublished, 30 p.

[4] Domestic water consumption (water for normal household purposes including watering lawns and garden) in Oregon is reported as 109 gallons per day per capita (van der Leeden, F., etal, 1990, The water encyclopedia, second edition: CRC Press LLC, Lewis Publishers, Florida, p.335).

WHEREAS the Task Force finds it necessary to provide an interim recommendation to the Board of Commissioners to establish a policy in order to preserve to county citizens the existing right to develop a water source for domestic and residential purposes as allowed by law.

WHEREAS the Task Force is aware, in making this Resolution and Recommendation, of state law ORS Chapter 197 taking effect December 2, 2004. This law would require Umatilla County to compensate landowners for a reduction in land value, or provide a waiver for any new regulation.

WHEREAS the Task Force is aware that a majority of the rural residential properties available for development within and outside of urban growth boundaries are within the boundaries of one of the four large irrigation districts, i.e., Stanfield Irrigation District, Westland Irrigation District, Hermiston Irrigation District, and West Extension Irrigation District. A majority of the rural residential properties, developed and undeveloped use water from the irrigation districts for irrigation purposes. These delivery systems provide surface water for lawn, garden, pasture, and small crop irrigation and serves as a distribution system for alluvial groundwater recharge by the residential properties.

WHEREAS the Task Force is aware that a "standard" rural residential on-site septic system is designed to accommodate domestic uses in the home (not garden or lawn) of 450 gallons per day. The Task Force is aware that most of the water use within the home is not consumed; rather, it is discharged to the septic system and into a drain field. Most drain fields are designed primarily for peculation of water. Because of drain field design, domestic water use in the home provides replenishment to the alluvial groundwater resource by virtue of the self contained on-site septic system.

WHEREAS, groundwater is a public resource and its development and use are regulated by the State of Oregon. The Task Force is aware that residential, domestic, and municipal uses are high priority uses under State of Oregon water policy, even in critical areas. Domestic use from groundwater sources is classified as an exempt use under Oregon law but can be regulated by priority date by the OWRD.

WHEREAS the Umatilla County Planning Department has provided the Task Force with information that at present there are approximately 330 undeveloped rural residential lots within the critical areas. Under current zoning regulations, each of the lots could be developed with a single home.

WHEREAS the Task Force has been presented with facts demonstrating that domestic and other exempt uses of water are insignificant in volume compared to groundwater availability and to irrigation and municipal uses in critical areas but are of importance to the citizens and the growth of Umatilla County.

WHEREAS domestic and other exempt water uses account for very little of alluvial and basalt aquifer waters used in the Umatilla Basin and the designated critical areas. The Task Force believes there are immediate and reasonable solutions to the issue of providing domestic water supplies to the rural residential parcels now or hereafter established in the critical areas. The Task Force wishes to resolve this matter so it can focus its efforts on exploring ideas, water supply needs, enhancement opportunities, and potential projects necessary to complete a 2050 plan, which will address long-term groundwater supply problems that affect economic development, the environment, and the quality of life in the Umatilla Basin.

WHEREAS the Task Force is aware that there are active exempt wells in the critical areas and that the continued growth of exempt wells, scattered throughout the critical areas, may have an impact to the existing water-right holders in the critical areas. Inasmuch the cumulative impact of groundwater withdrawals by all exempt wells in the critical areas may be significant, groundwater withdrawal by a single resident or 330 residences is insignificant compared to current withdrawals for both exempt and non-exempt uses.

WHEREAS the Task Force recognizes that the current groundwater conditions of decline and overdraft are widespread and affect all groundwater users in the critical areas, and that limiting or restricting withdrawals for domestic use will not solve the problem of groundwater decline and overdraft. Moreover, because a relatively small amount of groundwater is needed to supply 330 residential lots, as compared to existing exempt and non-exempt withdrawals, development of groundwater for use on these residential lots is unlikely to exacerbate the problem significantly.

NOW THEREFORE, the Task Force presents the following findings and recommendation to the Umatilla County Board of Commissioners as a means to deal with the immediate domestic water use issue and to provide security and clear and objective standards for Umatilla County citizens to develop domestic water supplies as allowed by law:

1. The Task Force finds the comfort and economic security of the citizens of Umatilla County, and the county's ability to provide an appropriate balance of rural residential housing, is dependant upon a citizen's ability to construct a water well for domestic purposes. The citizens of Umatilla County are aware that neither the state nor the county has ever guaranteed (or will ever guarantee) a supply of water for domestic, irrigation, or other uses, but the county must recognize a citizen's right to install a well for lawfully allowed uses.

2. The Task Force finds domestic and other exempt uses of water consume relatively very little of the alluvial and basalt aquifer waters in the Critical Groundwater Areas as compared to non-exempt uses such as that used for municipal, industrial, and agricultural purposes.

3. The Task Force finds, at present, there is the potential for approximately 330 additional domestic wells in the one hundred square mile area surrounding Hermiston. These

wells would serve new rural residences in the critical areas. The Task Force finds that some wells will be installed in the alluvial aquifer and some will be installed in the basalt aquifer.

4. The Task Force finds that domestic uses currently allowed by Oregon law are consistent with existing uses by Umatilla County citizens. The Task Force further finds that while such uses and quantities are measurable overall, they make up an insignificant quantity of water use within the Umatilla Basin and the critical areas compared to other existing commercial, industrial, agricultural, and municipal uses. The domestic and residential uses, however, are of the highest priority to Umatilla County and are paramount to preserve for the benefit of Umatilla County citizens.

5. The Task Force finds that the addition of approximately 330 new residential and domestic users will have an insignificant impact on the overall groundwater supply in the critical areas. The Task Force finds that it would be both unfair and economically unwise to impose non-proportional burdens on domestic and residential water users when such users will have an insignificant effect on current water-supply problems. This is based on the fact that the domestic and other exempt usage is relatively insignificant, and is spread over a one hundred square-mile area.

6. The Task Force is aware that certain wells may need to be deepened or relocated due to age, water quality, or declining water levels. The Task Force finds that one isolated area or areas exists near Hermiston (e.g. the Dickenson Addition) where a high concentration of residential and domestic wells has created well interference and consequent deepening of domestic wells. The Task Force finds that an isolated area, or areas, containing a high density of residential and domestic wells is not a reasonable basis to impose restrictions or limitations on the development of domestic wells on rural residential properties in the critical areas in Umatilla County.

7. The Task Force finds that state law provides a means to deal with domestic well interference. The Task Force finds that neither the state nor the county can guarantee any well owner an adequate water supply to meet the water demands of the owner, and the OWRD has the authority under state law to regulate well use, including domestic well use. Owners of existing and new domestic wells must accept the risk of having the use of their domestic wells regulated, including restrictions on pumping, by OWRD.

8. The Task Force finds that facts, ideas, projects (such as rural water systems), and proposals brought before the Task Force for the last ten months have provided tremendous opportunities to help enhance and preserve the Umatilla Basin's alluvial and basalt aquifer water supplies. Such projects impact larger areas in many ways and are likely to be disbursed throughout the Umatilla Basin and primarily in the Critical Groundwater Areas. These projects require a collective element of private, semipublic, city, county, tribal, and state cooperation, oversight, and implementation. Such projects cannot be implemented,

nor their costs borne by individual county citizens. Individuals, like all others, may bear their proportional share upon properly enacted county or state legislation.

9. The Task Force finds that no meaningful solution to the widespread problem of groundwater level declines and overdraft can be achieved through the restricted development of 330 residential lots, and that other actions are needed to address meaningful recovery of groundwater levels, or at the very least, prevent further declines of groundwater levels in the critical areas.

10. The Task Force finds that it is important to employ the most environmentally sound and cost-effective method of providing safe water supplies to its rural residents. Unless and until municipal or quasi-municipal systems are created, individual domestic water wells are presently the most environmentally sound and cost effective method of providing safe and reliable residential and domestic water supplies.

11. The Task Force finds that for purposes of demonstrating compliance with development standards for land use permits, water is "available" for rural domestic and other exempt uses of groundwater in the critical areas in Umatilla County.

12. The Task Force recognizes that existing houses and development are allowed to expand and rely on exempt wells, provided the wells are utilized within the parameters of Oregon Water Law.

13. The Task Force, in order to fulfill a portion of its mission, makes the following recommendation with regards to existing and future domestic and other exempt water uses in the critical areas.

RECOMMENDATION

The Umatilla County Critical Groundwater Task Force hereby recommends to the Umatilla County Board of Commissioners to confirm the following interim policy in partial fulfillment of its objectives and mission:

Until a 2050 plan is developed to direct development, allocation, and management of groundwater in the Umatilla River Basin in Umatilla County, the citizens within the critical areas may continue to install domestic wells, as authorized by state statute, and as they have been historically allowed to do. In the interim, applicants to Umatilla County for zoning permits, land partitions, or rural subdivisions, existing as of the date of this Resolution, will not be required to pay impact fees, conduct water availability studies, provide mitigation measures, or have any other domestic water supply condition imposed on them by the county until a 2050 plan is developed, or as duly authorized by County Ordinance.

Insofar as the county is required to adopt findings to approve land use permits, the county will rely on this document to defend the assumption that new exempt wells do not make a significant adverse impact on the groundwater resource. The county will assume exempt wells are appropriate and permissible.

In the event adjoining property owners or other interested parties raise concerns about a potential negative impact to groundwater supply of a proposed development, the county will continue to defer to OWRD. The county will rely on the findings in this document to allow development of exempt wells. Until such time as the county is granted authority to manage or regulate water use, claims about well interference, inadequate water supply, etc., shall not be treated as a land use matter and shall be deferred to the OWRD for regulation under Oregon water law.

Dated this 15th day of January, 2005.

Kent Madison, Chair
Harmon Springer, Vice-Chair
Umatilla County Critical Groundwater Task Force

EXHIBIT B

Adopted Alternative Language for 11th paragraph, page 2 of recommended resolution, supersedes and replaces the paragraph in the recommended resolution.

WHEREAS the impetus for creation of the Task Force was:

Statewide Planning Goal 5, which requires protections for essential natural resources (e.g. groundwater);

The reality of the long-term groundwater declines in the critical areas;

The interests, concerns, and objectives by some homeowners who believe that their domestic water supplies are placed at risk by groundwater uses on neighboring properties;

Encouragement by various state bodies for the county to address these issues in the land use context during the periodic review process;

Periodic review, which impelled the county to consider a temporary moratorium on new housing on rural residential zoned lands in the critical areas pending development of a plan which complies with state Goal 5;

Subsequent support by the general public to, instead move ahead immediately with the development of the plan.

HORTSCIENCE 43(2):459–464. 2008.

Effects of Reclaimed Municipal Waste Water on Horticultural Characteristics, Fruit Quality, and Soil and Leaf Mineral Concentration of Citrus

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Additional index words. oranges, *Citrus sinensis* L., Entisols, reclaimed water, Florida, nutrition, irrigation

***Abstract.* Water Conserv II is a municipal reclaimed water project operated by the city of Orlando and Orange county, FL. The Water Conserv II project has been supplying high-quality reclaimed water for irrigation of citrus orchards, nurseries, greenhouse operations, golf courses, and residential landscapes in Orange and Lake counties since 1986. Selected commercial citrus orchards in the Water Conserv II service area receiving either groundwater or reclaimed water have been monitored quarterly since the project began. This yearly monitoring was undertaken to determine any adverse long-term effects on citrus tree growth or production associated with irrigation using this reclaimed water. Citrus blocks were rated for horticultural condition quarterly, fruit quality was determined before harvest, and soil and leaf samples were analyzed yearly from 1994 to 2004. Citrus growers irrigating with reclaimed water were encouraged to use higher-than-recommended amounts of water as a means of disposal of this reclaimed water resulting in increased weed growth and dilution of juice solids per box of fruit. Leaf boron and magnesium were significantly higher after irrigation with reclaimed water. Calcium and boron from the reclaimed water have eliminated the need in orchards receiving reclaimed water for liming of the soil and applying annual foliar sprays containing boron.**

Florida has experienced rapid growth in population during the last 50 years with a 5.5-fold population increase from 1950 to 2000 (Perry and Mackum, 2001; Smith, 2005; U.S. Census Bureau, 1997). Groundwater withdrawal for domestic and irrigation use has increased by 15.5 and 20.7 times, respectively, during the same period (Marella and Berndt, 2005). Likewise, the amount of wastewater generated by cities in Florida has increased more than fivefold since 1950. Environmental concerns about degradation of surface waters by treated effluent water have caused many communities to consider advanced secondary-treated wastewater (reclaimed water) reuse. Currently, there are 440 reclaimed water reuse systems in Florida irrigating 92,345 ha with 2385 million liters of reclaimed water per day (Florida Department of Environmental Protection, 2005). The majority of these systems irrigate golf courses, public right-of-ways, and home landscapes. However, 6144 ha of production agriculture is currently irrigated with reclaimed water with citrus (*Citrus* spp. L.) orchards accounting for all but 364 ha.

Florida citrus production benefits from irrigation because the average annual rainfall of more than 1200 mm is unevenly distributed throughout the year with ≈75% of annual rainfall occurring from June to September (Koo, 1963). Furthermore, Florida citrus trees are grown on sandy soils with very low water-holding capacity, particularly orchards in the central "ridge" portion of the state. Typical available water content values for central Florida ridge citrus soils range from 0.05 to 0.08 $cm^3 \cdot cm^{-3}$ (Obreza and Collins, 2003). Increased water use by the growing population and localized water shortages during low rainfall years have resulted in the development of water use restrictions and decreases in permitted water use for agriculture. Increased use of reclaimed water for agricultural irrigation would not only reduce the wastewater disposal problem for urban areas, but could also reduce the amount of water withdrawn from surficial and Floridan aquifers for irrigation.

Before 1986, the city of Orlando and Orange county were discharging treated effluent into Shingle Creek that leads into Lake Tohopekaliga in central Florida. As a result of concerns that nutrient loading from this effluent would reduce lake water quality, Orlando and Orange county, along with the U.S. Environmental Protection Agency, developed a plan to use the wastewater normally disposed of in Shingle Creek for agricultural irrigation instead. Initial funding of $180,000,000 established the project, which is called Water Conserv II (Parsons et al., 2001a). The project currently delivers ≈133,000 m^3 of reclaimed water per day (cmd) (275,000 cmd maximum flow) to ≈1750 ha of citrus (Phil Cross, pers. comm., 2006). Other users of reclaimed water from the Water Conserv II project are eight foliage greenhouse operations, four tree farms, two ferneries, and three golf courses. The reclaimed water is distributed though 80 km of pipelines maintained by the project. Excess reclaimed water is disposed of in 71 ha of rapid infiltration basins that recharge surficial and Floridan aquifers. Water Conserv II is the largest reclaimed water agricultural irrigation project of its type in the world and was the first project in Florida to be permitted to irrigate crops for human consumption with reclaimed water (McMahon et al., 1989).

The reclaimed water distributed by the Water Conserv II project and used for irrigation of orchards in this study was treated with advanced secondary treatment with high-level disinfection, coagulation, filtration, and chlorination (Parsons et al., 2001b). Water quality standards were negotiated among Water Conserv II, Univ. of Florida researchers, and local growers.

To receive reclaimed water for irrigation at no cost, citrus growers were required to sign a contract with the city of Orlando and Orange county to accept 1270 mm of water per year for a period of at least 20 years. Initially, there was grower resistance because of concerns that use of the reclaimed water might damage citrus trees or make the fruit unmarketable. As part of the contract, the growers requested that the Univ. of Florida study the long-term effects of reclaimed water on citrus tree health and fruit quality. Dr. R.C.J. Koo of the Univ. of Florida (IFAS) Citrus Research and Education Center initiated a study to determine tree appearance (i.e., foliage density and color), weed growth, leaf nutrient status, and soil nutrient retention in citrus orchards irrigated with either groundwater or reclaimed water in 1987. No adverse affects of reclaimed water use on tree health and productivity were noted in the initial phase of the orchard survey; however, continued monitoring was suggested to determine long-term effects (i.e., metal accumulation in soil, leaves, or fruit). Orchards are not now required to accept the full 1270 mm of water per year under the contract because

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rapid infiltration basins (RIBs) were installed in the early 1990s. As a result of the highly porous nature of the soils, the RIBs function as alternate disposal sites (particularly during the normally wet summer rainy season) where the reclaimed water is applied at high rates and allowed to percolate to the groundwater. Still questions persisted regarding the effect of long-term use of wastewater on tree productivity.

This orchard monitoring project continued through the 1990s and was ended in 2004. This article reports data collected since the preliminary reporting of results in 1993 (Zekri and Koo, 1993) to the conclusion of the study in 2004. The monitoring of citrus orchards was continued to determine if adverse effects on citrus tree health and production were associated with irrigation using reclaimed water. Therefore, the objective of this project was to determine whether long-term irrigation with treated municipal wastewater 1) reduces tree health (i.e., canopy appearance and leaf nutrient content), 2) decreases visual fruit loads, 3) impacts internal fruit quality (i.e., Brix, titratable acid, Brix:acid ratio), or 4) increases in soil contaminant concentrations.

Materials and Methods

The Water Conserv II project distributes reclaimed water to users in western Orange and eastern Lake counties in central Florida (lat. 28°28′20″N, long. 81°38′50″W, elevation 64 m). The reclaimed water meets drinking water standards for nitrate-N (Table 1), is low in heavy metal concentrations (i.e., cadmium, chromium, lead, and mercury), and has no odor or color. Grower benefits include a free source of high-quality irrigation water maintained below established maximum mineral and metal concentration levels (Table 1) delivered at a minimum pressure of 276 kPa. The predominant soil order in this area is Entisol, with Candler fine sand (hyperthermic, uncoated, Typic Quartzipsamment) being the dominant soil series (Obreza and Collins, 2003). The Candler series consists of excessively drained, very rapidly permeable soils formed from marine deposits. These soils are located in upland areas and typically have slopes of 0% to 12%. The A and E horizons consist of single-grained fine sand, have a loose texture, and are strongly acidic (pH = 4.0 to 5.5). A Bt horizon is located at a soil depth of 2 m and includes loamy lamellae of 0.1 to 3.5 cm thick and 5 to 15 cm long.

Before 1994, unequal numbers of sampled commercial orchards were irrigated with the two water sources but did not have the same citrus scion cultivars. In 1994, 10 orchards irrigated with one of the two water sources were selected for a total of 20 orchards. These 20 orchards were paired so that trees of the same scion and relative age were irrigated with either water sources. The scions used were 'Hamlin' and 'Valencia' oranges (*C. sinensis* L.), 'Sunburst' tangerine (*C. reticulata* Blanco), and 'Orlando' tangelo (*C. reticulata* Blanco × *C. paradisi* Macfadyn); however, the root stocks were not always consistent among the two water sources. Random trees over a 4-ha plot in each orchard were evaluated quarterly for canopy appearance, leaf color, fruit crop, and weed cover. Each orchard received a separate visual rating for each category on a 1 to 5 scale. A rating of 1 indicates a less dense canopy compared with visual inspection of orchards in the area at the same time period, leaf color would be chlorotic or have visual deficiency symptoms, the fruit crop would be low enough to be unharvestable, and the weed population would be very low indicating insufficient nutrition, soil water content, or excess herbicide application. Ratings of 5 would indicate a thick dense canopy with excessive vegetative growth, dark green leaves with nitrogen concentrations above that considered optimum, a fruit crop considered to be well above the average for trees of comparable age and size in the area, and a dense weed population in the herbicide zone well in excess of standard grower practices. Fruit samples (20 fruit) were taken from five trees in each orchard just before harvest and analyzed for percent juice content, Brix, acid, and weight. Degrees Brix and total titratable acidity were determined according to methods approved for Florida citrus quality tests (Wardowski et al., 1995).

Samples of spring growth leaves (20 leaves from five trees) and soil (two cores from each of five trees) were taken from each orchard in August or September of each year from 1994 to 2004. Leaf samples were analyzed for N, P, K, Ca, Mg, Na, Zn, Mn, Fe, and B. Soil samples were taken at the same time to a depth of 60 cm and were analyzed for P, K, Ca, Mg, Zn, Mn, Al, Cu, Fe, Na, and Cl. Leaf samples were dried at 70 °C to a constant weight and ground using a Cyclotec mill (Tecator Manufacturing, Tecator, Sweden). Ground tissue was analyzed for N by Kjeldahl methods (U.S. EPA, method 351.2) using steam distillation (Buchi Analytical, New Castle, DE). Other leaf elemental concentrations were determined using nitric acid/hydrogen peroxide digestion and determination with inductively coupled plasma (ICP) spectroscopy (Hanlon and DeVore, 1989). Soil samples were extracted using Mehlich 1 (5 g of dry soil in 20 mL of extractant) and analyzed by ICP spectroscopy.

Because the orchards were paired by age and scion, horticultural ratings, fruit quality, and leaf and soil sample analysis data were analyzed by irrigation water source using analysis of variance using SAS Proc GLM (SAS, 1989). However, because only two scions (Hamlin and Valencia) of similar ages were in only two orchards each, no comparison of the effect of irrigation water source by scion was possible.

Results and Discussion

Citrus orchards in this project were irrigated with either groundwater or reclaimed water. Orchards irrigated with groundwater were managed using recommended practices receiving 30 to 60 cm of irrigation per year. However, orchards irrigated with reclaimed

Table 1. Maximum allowable contaminate limit (MACL) for Florida drinking water and Conserv II reclaimed water and typical Water Conserv II reclaimed water concentrations.[z]

	Drinking water MACL	Well water typical concentrations[y]	Conserv II reclaimed water MACL	Typical Conserv II reclaimed water concentrations[y]
	mg·L^{-1}			
Arsenic	0.05	—	0.10	<0.005
Barium	2	—	1	<0.01
Beryllium	0.004	—	0.10	<0.003
Bicarbonate	—	—	200	105
Boron	—	0.02	1.0	<0.25
Cadmium	0.005	—	0.01	<0.002
Calcium	—	39	200	42
Chloride	250	15	100	75–81
Chromium	0.1	—	0.01	<0.005
Copper	1	0.03	0.20	<0.05
Electrical conductivity (μmhos)	781	360	1100	720
Iron	0.3	0.02	5	<0.4
Lead	0.015	—	0.1	<0.003
Magnesium	—	16	25	8.5
Manganese	0.05	0.01	0.20	<0.04
Mercury	0.002	—	0.01	<0.0002
Nickel	0.1	—	0.20	0.01
Nitrate-N	10	3	10	6.1–7.0
pH	6.5—8.5	7.8	6.5–8.4	7.1–7.2
Phosphorus	—	0.01	10	1.1
Potassium	—	6	30	11.5
Selenium	0.05	—	0.02	<0.002
Silver	0.1	—	0.05	<0.003
Sodium	160	18	70	50–70
Sulfate	250	23	100	29–55
Zinc	5	0.02	1	<0.06

[z]All values are in mg·L^{-1} except for pH and electrical conductivity.
[y]As reported in Parsons et al., 2001b.

water had higher soil water content (Zekri and Koo, 1993), presumably because of more frequent irrigation. Orchards irrigated with reclaimed water had soil moisture content of 0.06 $cm^3 \cdot cm^{-3}$ compared with 0.05 $cm^3 \cdot cm^{-3}$ for orchards irrigated with groundwater. Field capacity was estimated to be 0.65 $cm^3 \cdot cm^{-3}$ for these soils, indicating that orchards irrigated with reclaimed water were near or above field capacity a higher proportion of the time compared with orchards irrigated with groundwater. The quality of the reclaimed water used for irrigation was monitored monthly, and a report of average water constituent concentrations was provided to the growers (Table 1). Reclaimed water provided to citrus orchards by the Water Conserv II project is of very good quality and consistently within drinking water standards for all constituents, including heavy metals. Fertilizer macroelements (N, P, K, and Mg) are two to more times greater in the reclaimed water than well water, particularly for phosphorus, which is 10 times greater. The level of constituent concentrations in the reclaimed water is not considered to be toxic (Burton and Hook, 1979; Feigin et al., 1984). However, if soil or tissue accumulation were to occur, concentrations of heavy metals (i.e., cadmium, lead, and zinc) may approach toxic levels (Campbell et al., 1983; Feigin et al., 1984; Neilsen et al., 1991).

Horticultural ratings. Before 1994, Zekri and Koo (1993) reported that soil to a depth of 0.5 m beneath trees irrigated with reclaimed water was usually 14.7 mm higher in water content and the trees had 6% higher canopy, leaf color, and fruit crop ratings than trees irrigated with groundwater. The higher ratings were attributed to consistently higher soil water content in the orchards irrigated with reclaimed water. For the period 1994 to 2004, mean quarterly canopy appearance, leaf color, and fruit crop were significantly higher in orchards irrigated with reclaimed water compared with orchards irrigated with groundwater (Table 2). Weed growth in orchards irrigated with reclaimed water was consistently higher, but not significantly different, than orchards irrigated with well water. The difference in mean rating for the four categories was 12.3%, possibly indicating greater water use in reclaimed water blocks compared with orchards irrigated with well water.

Horticultural ratings for canopy appearance, leaf color, and fruit crop had significant year*water source interactions (Table 2). Mean canopy, leaf color, and fruit crop ratings for trees irrigated with groundwater were significantly greater than ratings from 2000 to 2004 compared with trees irrigated with the same water source from 1996 to 1999, whereas canopy, leaf color, and fruit crop ratings for the orchards irrigated with reclaimed water did not have a similar pattern. Reduced canopy appearance, leaf color, and fruit set in orchards irrigated with groundwater can be attributed to reduced rainfall from 1994 to 1999 (390 mm, 1998) compared with average rainfall from 2000 to 2004 (1191 mm). Significantly lower tree appearance in a drought year agrees with conclusions of Zekri and Koo (1993) that commercial citrus orchards irrigated with reclaimed water were commonly irrigated more frequently or with a greater volume than those irrigated with groundwater.

Weed growth as measured by weed cover ratings was higher in reclaimed water-irrigated orchards for most years compared with those irrigated with groundwater (Table 2). Higher weed growth ratings have been correlated with high irrigation rates of reclaimed water (Parsons and Wheaton, 1992; Zekri and Koo, 1993). Like with tree appearance and fruit crop, weed cover ratings only were significantly lower for orchards irrigated with groundwater in 1998 compared with other years, presumably as a result of lower rainfall. Growers have adjusted their herbicide practices to reduce the negative impact of increased weed growth resulting from higher irrigation use with reclaimed water by reducing reclaimed water use or increasing herbicide applications (John Jackson, personal communication, 2006).

Fruit quality. In 5 of 11 years (1994, 1995, 1998, 2000, and 2001), mean fruit juice content or the percent of fruit weight in juice was significantly higher among trees in orchards irrigated with reclaimed water rather than groundwater (Table 3). These years with significant juice content differences among irrigation water sources lead to a significant year*water source interaction for juice content. Juice soluble solids or Brix was not significantly different among water sources. However, Brix was significantly different among water sources in 1994, 1997, and 1998 contributing to a significant year*water source interaction. Two of these years were considered dry years with below-normal rainfall. Fruit weight was significantly higher for orchards irrigated with reclaimed water compared with fruit from orchards irrigated with groundwater; however, no year*water source interaction was noted. Therefore, higher fruit crop ratings, fruit weights, and similar solids per fruit (during normal rainfall years) in orchards irrigated with reclaimed water would suggest similar or greater yields in terms of soluble solids per hectare compared with orchards irrigated with groundwater. The previous study by Koo and Zekri (1989) found that reduced soluble solids and acid concentration in the juice was correlated with higher soil water content in the orchards receiving reclaimed water. Likewise, significant differences in fruit Brix and acid were seen in this study from 1994 to 1998, but not after 1998. This change in fruit Brix and acid may indicate a change in irrigation practices with orchards being irrigated with similar amounts some time after 1998. This shift in irrigation practice would correspond with construction of RIBs and reduced requirement for the use of reclaimed water. Because fruit yield was greater from orchards irrigated with reclaimed water, total soluble solids

Table 2. Mean horticultural rating of citrus orchards taken in January, April, July, and October of each year from orchards irrigated with reclaimed or groundwater between 1994 and 2004.

	Canopy			Leaf color			Fruit crop			Weed cover		
	Reclaimed water	Ground water	Mean	Reclaimed water	Ground water	Mean	Reclaimed water	Ground water	Mean	Reclaimed water	Ground water	Mean
Yr	1–5 rating											
1994	3.7	3.2	3.5	3.3	3.4	3.3	3.4	3.4	3.4	3.6	3.2	3.4
1995	3.7	3.1	3.4	3.5	3.1	3.3	3.9	3.7	3.8	4.0	3.7	3.8
1996	3.7	3.2	3.4	3.4	3.2	3.3	3.8	3.3	3.6	3.4	3.6	3.0
1997	3.8	3.1	3.4	3.4	2.8	3.1	3.7	3.4	3.5	3.8	3.5	3.6
1998	3.9	3.0	3.4	3.8	3.1	3.4	3.9	3.3	3.5	3.2	2.7	3.0
1999	3.8	2.9	3.4	3.7	3.5	3.6	3.4	3.4	3.4	3.5	3.6	3.5
2000	4.2	3.7	4.0	4.1	3.7	3.9	2.9	3.2	3.0	3.4	3.1	3.2
2001	4.0	3.4	3.7	3.9	3.5	3.7	3.6	3.3	3.4	3.2	3.1	3.1
2002	4.0	3.6	3.8	3.8	3.2	3.5	2.9	3.4	3.1	3.1	3.2	3.1
2003	4.2	3.7	3.9	4.1	3.7	3.9	3.8	3.5	3.6	3.2	3.0	3.1
2004	4.1	3.4	3.7	3.8	3.5	3.6	3.6	3.4	3.5	3.1	3.1	3.3
Mean	3.9	3.3	3.6	3.7	3.3	3.5	3.6	3.3	3.5	3.4	3.1	3.3
Significance[z]												
Year			NS			NS			NS			NS
Water source			*			*			*			NS
Year*water source			*			*			*			NS

[z]NS and * = nonsignificant or significant at $P = 0.05$, respectively.

produced per hectare were higher in the reclaimed water orchards than the groundwater-irrigated orchards.

Soil and leaf nutrient content. Irrigation with reclaimed water has increased soil concentrations of P, K, Mg, B, Na, and Cl when reclaimed water was used as an irrigation water source (Burton and Hook, 1979; Campbell et al., 1983; Feigin et al., 1984; Neilsen et al., 1991). Elemental concentrations in soil samples taken in August or September of each year from orchards irrigated with either reclaimed or groundwater varied from year to year but were not significant by years (Table 4). Calcium was the only element significantly different by soil sample depth with higher concentrations found near the surface. This result was expected because calcium was applied as lime applied for pH adjustments in orchards irrigated with either groundwater or reclaimed water and calcium in the reclaimed water would be incorporated into this layer with little leaching over time. With the exception of increased P, Ca, and Al, no elements were found to be significantly different when comparing water sources. Soil in orchards irrigated with reclaimed water was significantly higher for P, Ca, and Al compared with soils in orchards irrigated with groundwater. However, no elements were found to be excessive (Maurer and Davies, 1993; Tucker et al., 1995). Lower extractable soil potassium was found in orchards receiving higher rates of reclaimed water despite the higher potassium concentration of reclaimed water. These data are consistent with findings of Zekri and Koo (1993) who reported P, Ca, and Mg were significantly higher and potassium significantly lower in soil samples from orchards irrigated with reclaimed water compared with orchards irrigated with groundwater.

Calcium was the only element with years*water source and depth*water source interactions (Table 4). Soil calcium concentrations were significantly lower (1034.7 $kg \cdot ha^{-1}$) in years with normal rainfall (2000 to 2004) compared with drier years (1338.5, 1996 to 1999). Differences in soil calcium concentration among the two irrigation water sources followed the same pattern during these years with soil from orchards irrigated with reclaimed water having higher concentrations than soil from orchards with

Table 3. Mean citrus fruit quality parameters from mature fruit samples taken in before harvest of each year from orchards irrigated with reclaimed or groundwater between 1994 and 2004.

	Juice content (%)			Brix (deg)			Acid[z] (%)			Fruit wt (g)		
Yr	Reclaimed water	Ground water	Mean	Reclaimed water	Ground water	Mean	Reclaimed water	Ground water	Mean	Reclaimed water	Ground water	Mean
1994	58	53	55	12.9	13.9	13.3	0.72	0.75	0.74	221	204	212
1995	57	56	57	13.5	13.8	13.6	0.69	0.93	0.82	161	155	155
1996	60	45	52	12.9	12.1	12.4	0.77	0.73	0.76	172	156	159
1997	63	60	61	11.5	14.8	13.1	0.78	0.91	0.85	181	141	160
1998	62	54	58	12.8	15.6	14.1	0.69	0.60	0.65	189	167	173
1999	61	50	55	11.5	14.3	12.8	0.71	0.75	0.74	180	154	166
2000	69	66	67	12.6	11.4	11.9	0.63	0.75	0.70	179	169	173
2001	66	61	63	12.8	13.8	13.2	0.65	0.62	0.64	191	181	185
2002	63	50	58	11.8	14.5	13.1	0.68	0.73	0.71	196	189	192
2003	67	52	59	11.3	13.6	12.4	0.69	0.66	0.68	179	188	183
2004	72	55	63	10.4	12.1	11.2	0.70	0.79	0.75	176	179	177
Mean	64	55	59	12.4	13.9	12.8	0.70	0.75	0.73	185	172	176
Significance[y]												
Water source			*			NS			NS			*
Year*water source			*			*			NS			NS

[z]Total titratable acidity,
[y]NS and * = nonsignificant or significant at $P = 0.05$, respectively.

Table 4. Soil Mehlich 1 extractable elemental concentrations in samples taken in August or September of each year at three depths from orchards irrigated with reclaimed or groundwater between 1994 and 2004.

	P	K	Ca	Mg	Zn	Cu	Mn	Al	Fe	Na	Cl
Yr	$kg \cdot ha^{-1}$										
1994	80.7	52.4	463.0	117.1	30.4	18.4	6.4	46.4	13.4	5.9	8.5
1995	63.1	40.3	945.7	97.8	54.7	15.5	10.6	63.7	10.1	5.2	5.5
1996	101.7	50.5	1454.8	153.3	43.2	31.3	18.5	170.1	22.1	9.4	9.6
1997	114.9	42.9	1458.8	127.6	25.4	20.2	12.4	131.2	17.4	7.2	9.1
1998	113.5	44.7	1410.0	137.5	77.5	21.5	15.5	149.7	17.6	7.0	9.3
1999	48.8	44.2	1030.4	72.6	44.0	17.8	5.4	58.2	9.6	5.0	8.6
2000	69.7	24.4	983.9	86.0	29.1	22.1	7.9	39.1	10.8	3.7	8.1
2001	71.8	31.1	1261.6	86.7	38.1	29.8	13.3	66.0	5.8	4.0	6.4
2002	50.8	29.5	945.0	83.3	59.2	16.6	10.0	114.9	15.1	7.6	6.5
2003	73.4	25.8	757.3	81.6	29.2	21.8	9.0	76.1	8.8	6.5	6.1
2004	69.1	29.6	1225.7	81.7	40.0	23.7	12.5	51.3	8.2	4.9	5.0
Significance[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depth (cm)											
0–15	87.0	43.4	1438.8	138.3	51.9	20.1	13.1	84.3	11.1	7.7	7.6
15–30	73.6	28.1	837.2	76.9	34.0	18.6	9.1	68.8	10.7	5.1	5.2
30–60	84.1	41.8	979.3	91.7	42.5	26.4	10.9	110.6	16.0	5.4	9.8
Significance	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
Water source											
Reclaimed	97.1	27.8	1209.2	107.3	40.4	22.6	11.4	100.2	15.1	5.6	8.8
Groundwater	66.1	47.7	961.0	97.3	45.2	20.8	10.7	75.6	10.1	6.5	6.3
Significance	*	*	*	NS	NS	NS	NS	*	NS	NS	NS
Interactions											
Year*depth	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year*water source	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
Depth*water source	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS

[z]NS and * = nonsignificant or significant at $P = 0.05$, respectively.

Table 5. Mature spring growth leaf elemental concentrations in samples taken in August or September of each year from orchards irrigated with reclaimed or groundwater between 1994 and 2004.

Yr	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg·kg^{-1})	Zn (mg·kg^{-1})	Mn (mg·kg^{-1})	B (mg·kg^{-1})	Fe (mg·kg^{-1})
1994	2.6	0.14	1.4	2.2	0.38	403.6	40.2	22.1	78.8	31.4
1995	2.8	0.06	0.9	3.6	0.25	359.1	39.4	35.0	39.2	22.1
1996	3.0	0.18	1.8	3.6	0.51	441.3	53.8	49.8	86.2	59.4
1997	2.9	0.18	1.5	3.9	0.47	983.4	40.3	39.8	117.0	64.4
1998	2.7	0.13	1.4	2.8	0.30	376.1	23.4	64.8	61.7	30.5
1999	3.0	0.12	1.5	1.6	0.57	337.3	64.9	38.6	53.8	39.1
2000	3.0	0.11	1.5	1.9	0.24	422.3	62.2	32.5	58.5	74.8
2001	2.9	0.08	0.9	1.5	0.17	219.7	24.7	32.6	82.7	59.0
2002	2.7	0.13	1.3	2.6	0.53	462.6	61.2	36.4	82.4	52.1
2003	2.7	0.15	1.3	2.8	0.25	463.7	53.5	39.6	48.4	55.9
2004	2.8	0.07	1.4	3.7	0.18	378.4	64.6	35.7	49.8	67.0
Significance[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Water source										
Reclaimed	2.8	0.14	1.6	3.0	0.47	476.3	58.1	30.1	78.0	51.1
Groundwater	2.8	0.10	1.1	2.5	0.24	405.1	37.9	47.5	59.9	49.9
Significance	NS	NS	NS	NS	*	NS	NS	NS	*	NS
Interaction										
Year*water source	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]NS and * = nonsignificant or significant at $P = 0.05$, respectively.

groundwater (data not shown). Likewise, soil calcium concentrations followed the same pattern with depth regardless of irrigation water source resulting in higher concentrations in soil irrigated with reclaimed water at the selected depths compared with soil from orchards irrigated with groundwater.

Like with soil samples, elements in mature spring flush leaves taken at the same time as the soil samples from orchards irrigated with either reclaimed or groundwater were not significantly different by year as indicated by the lack of year*water source interaction (Table 5). Leaf sample elemental concentrations were generally higher from orchards irrigated with reclaimed water compared with orchards irrigated with groundwater. Although higher, significantly higher phosphorus and calcium concentrations in soils irrigated with reclaimed water did not lead to significantly higher leaf concentrations. These results can be explained by dilution of leaf concentration by increased biomass production of trees irrigated with reclaimed water, reduced nutrient uptake efficiency, or a combination of the two. Unfortunately, differences in biomass accumulation were not determined in this study. However, only magnesium and boron were significantly higher in leaf samples from orchards irrigated with reclaimed water compared with samples from orchards irrigated with groundwater. Zekri and Koo (1993) found significantly higher iron and boron concentrations in more than half the years between 1987 and 1993. Based on this information, it is now recommended that orchards irrigated with reclaimed water not add boron to micronutrients sprays. Zekri and Koo (1993) found significantly higher sodium and chlorine concentrations in leaf samples from orchards irrigated with reclaimed water, presumably from higher irrigation applications. However, sodium and chlorine were not significantly different from 1994 to 2004, further indicating a change in irrigation practice among orchards irrigated with reclaimed water.

Conclusion

Few detrimental effects on citrus orchards have been associated with irrigation using the reclaimed water provided by Water Conserv II because the soils on which most citrus is grown in the Water Conserv II service area are very porous and drain rapidly. However, the impact of using reclaimed water on groundwater contamination were beyond the scope of this project. Appearance of trees irrigated with reclaimed water was usually better with higher canopy, leaf color, and fruit crop ratings than orchards irrigated with groundwater. These higher ratings are similar to results reported earlier. Higher weed growth in reclaimed water-irrigated orchards was associated with higher soil water content. However, growers apparently have made adequate adjustments to their herbicide practices. Higher soil water content in the orchards receiving reclaimed water resulted in reduced fruit soluble solids. However, because fruit crop ratings and larger fruit size indicated greater fruit yield, total soluble solids produced per hectare were similar to or higher in the reclaimed water irrigated orchards than in the groundwater-irrigated orchards. Like in the previous commercial orchard study, irrigation with reclaimed water increased soil phosphorus and calcium and reduced soil potassium. Reduction of phosphorus and calcium and increases in potassium applied to citrus orchards irrigated with reclaimed water may be required adjustments in fertilizer applications to citrus orchards irrigated with reclaimed water.

Likewise, leaf boron concentration was also increased, requiring an adjustment in foliar application practices. However, because nitrate-N concentration in the reclaimed water was less than 7 mg/L, nitrogen uptake by citrus roots was probably limited and did not result in higher leaf nitrogen. Other work in the Vero Beach area in Florida showed that reclaimed water alone did not provide adequate nitrogen nutrition for young grapefruit trees (Maurer and Davies, 1993), so current nitrogen fertilization practices will need to be continued. Therefore, long-term citrus irrigation with high-quality reclaimed water on well-drained sandy soils did not significantly reduce tree viability or yield and requires relatively little adjustment in production practices.

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