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Introduction

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Prepared by Arizona Water Resources Research Center, The University of Arizona, Tucson, Arizona 85721

Research Program

Measurement of Hormonal Activity and Volume Contribution of Treated Wastewater in Water from Wells Along the Santa Cruz

Basic Information

Title:	Measurement of Hormonal Activity and Volume Contribution of Treated Wastewater in Water from Wells Along the Santa Cruz
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Principal Investigators:	Martin Karpiscak, Robert Arnold, Kevin Lansey, Charles Gerba

Publication

A. Problem and Research Objectives

Even full utilization of the Tucson regional allotment of Central Arizona Project water (approximately 140,000 acre-feet per year for the City of Tucson) will not indefinitely satisfy area water requirements, without resorting to groundwater mining. Consequently, water reuse will become an increasingly important part of regional water supply planning in decades to come. Only the designation of permissible uses for reclaimed water and regulatory issues remain in doubt. Currently, about 10,000 acre-feet (AF) of reclaimed water is infiltrated and recovered for reuse each year at the Sweetwater Recharge Facilities (SRF) in west Tucson. The facility is operated by the City of Tucson, but receives chlorinated secondary effluent from Pima County's Roger Road Wastewater Treatment Plant (RRWTP). Recovered water is used for landscape irrigation. RRWTP effluent above the 10,000 AFY that is infiltrated and recovered is discharged to the Santa Cruz River (Figure 1) where, during perhaps 11 months of the year, it percolates into the (otherwise) dry streambed or is lost due to evapotranspiration. Effluent from Pima County's Ina Road Wastewater Treatment Plant is also discharged into the Santa Cruz, about 5 miles downstream from the RRWTP outfall. Together, the plants provide an average of 50,000 AFY to the river, much of which recharges the Tucson aquifer. Gaylean (1996) estimated that about 90% of the effluent discharged to the Santa Cruz infiltrates in the 23-mi reach between the Roger Road treatment facility and Trico Road. Estimates of infiltration values for effluent releases on the Santa Cruz River (compiled in Lacher, 1996) vary from 5.0 to 8.7 ac-ft/mi/day. The degree to which reclaimed waters contribute to local well waters and affect quality characteristics in potable wells along the Santa Cruz River is not known.

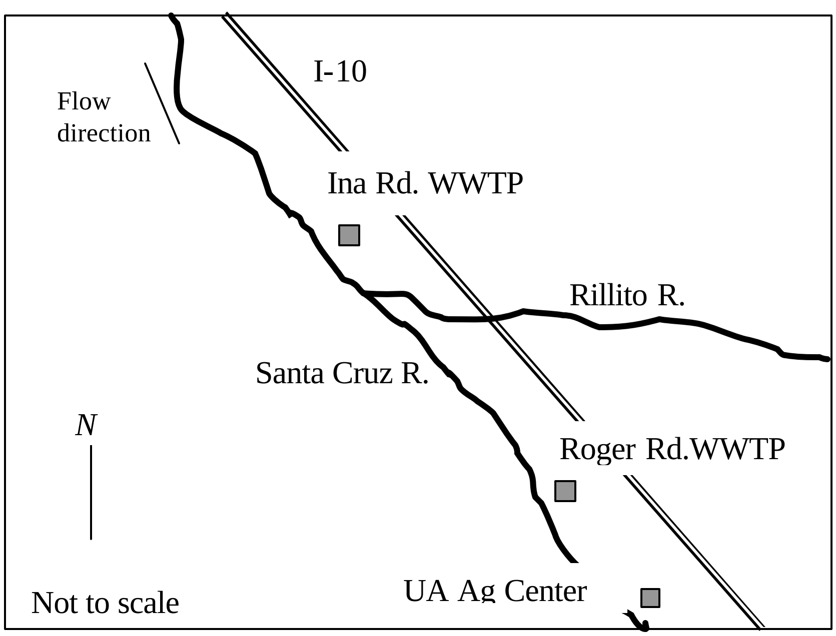


Figure 1. Schematic of Santa Cruz River study area and landmark locations.

The presence of wastewater effluent among waters withdrawn from wells along the Santa Cruz downstream from the Roger Road and Ina Road Wastewater Treatment Plants has never before been comprehensively examined. A few previous studies documented the presence of wastewater effluent in ground waters extracted from isolated wells along the Santa Cruz. Using stable oxygen isotopes ($^{18}O/^{16}O$), Bostick (1978) estimated that water obtained from a City of Tucson well (Z-1) located ½ mile from the RRTP contained 30% native ground water and 70% recharged wastewater. Similarly, Leenhouts (1998), using boron isotopes ($^{10}B/^{11}B$), calculated that an irrigation well in the Cortaro-Marana Irrigation District contained 75% native ground water and 25% municipal wastewater at the beginning of an irrigation season. The percentage of irrigation return flow in well water increased during the irrigation season.

Wastewater effluent contains traces of many compounds that are added during water use. A number of pharmaceutically-active compounds (PhACs) are known to survive secondary treatment and to persist in surface waters influenced by effluent disposal (Kolpin *et al*., 2002). Although previous studies indicated that bulk organics are efficiently removed during percolation through surface soils and sediments (Wilson *et al*., 1995; Quanrud *et al*., submitted), the fate of PhACs during the infiltration of effluent is poorly understood.

A variety of known estrogenic compounds elicit measurable ecological changes at or below nanomolar concentrations in water. These compounds afford analytical challenges when presented in a complex aqueous matrix at those levels. Furthermore, it is not possible to anticipate estrogenic effects due to the many, largely uncharacterized, trace organic residuals in treated wastewater. Consequently, *in vitro* tests were used to measure estrogenic activity in whole-water samples and organic concentrates derived from those water samples.

In this project, we established the volume contribution of reclaimed water in wells proximate to the Santa Cruz and explored the relationships between fractional effluent content, dissolved organic carbon (DOC) concentration and the results of *in vitro* measurements of estrogenic hormonal activity in a contemporary set of water samples. Boron and boron isotope measurements were used to establish the volume contribution of wastewater effluent in monitoring wells along the Santa Cruz River. Volume fraction of wastewater origin and estrogenic activity were correlated in the same set of samples. Results suggest that incidental recharge of effluent in the Santa Cruz River bed affects the quality of proximate ground waters.

Endocrine Disruptors: Literature Review

Endocrine disrupting compounds (EDCs) include a large number of natural and synthetic hormones, pharmaceuticals, pesticides, and industrial/household chemicals. EDCs have been detected in wastewater. Some resist biochemical degradation, persist in the environment, and bioaccumulate. EDCs in the environment can adversely affect wildlife and may be associated with human health effects.

A number of observable ecological effects arise from exposure to EDCs in aquatic environments. In the United Kingdom, for example, vitellogenin, an egg precursor protein, was detected in male trout and other fishes immediately downstream from the outfalls of wastewater treatment plants (Jobling *et al*., 1998). Wastewater-derived compounds that have been implicated as a source of such effects include human estrogen and its metabolites, pharmaceutical estrogens and alkylphenols from industrial cleaners (Desbrow *et al.*, 1998; Snyder *et al*., 1999,2001).

Because chemicals interfere with endocrine system function in several ways, it is probable that no single assay can predict the nature and extent of hormone-disrupting activities by mixtures of compounds or wastes. *In vitro* assays for estrogenic activity that have received attention is this regard include receptor binding, reporter gene, and cell proliferation assays. However, test-dependent sensitivities to aqueous-phase 17β-estradiol (E2), the primary human estrogen, differ by orders of magnitude. Assays also require very different levels of effort and time. The receptor-binding (ligand displacement) test used here is particularly fast and requires no extraordinary skills to perform.

The receptor-binding assay is based on displacement of a fluorescent ligand from a human estrogen receptor (ER-β) as a measure of estrogenic activity in water samples or concentrates derived from water samples. The same test was used previously in our laboratory to show that estrogenic compounds surviving secondary treatment are substantially removed during the managed infiltration of domestic wastewater effluent for groundwater replenishment (Turney *et al*., 2002).

B. Methodology

Water samples were collected from shallow wells located along the Santa Cruz River starting at the University of Arizona's West Campus Agricultural Center just upstream (south) of the SRF and continuing downstream well beyond the outfall of the Ina Road Wastewater Treatment Plant (Figure 2). Sampling points provided waters with significantly different reclaimed water content, due primarily to screened interval (Figure 3) and distance from Roger Road and Ina Road Wastewater Treatment Plant outfalls. Surface water samples were collected from the Santa Cruz River at the points indicated in Figure 2. These were subjected to the same battery of analyses as the ground waters.

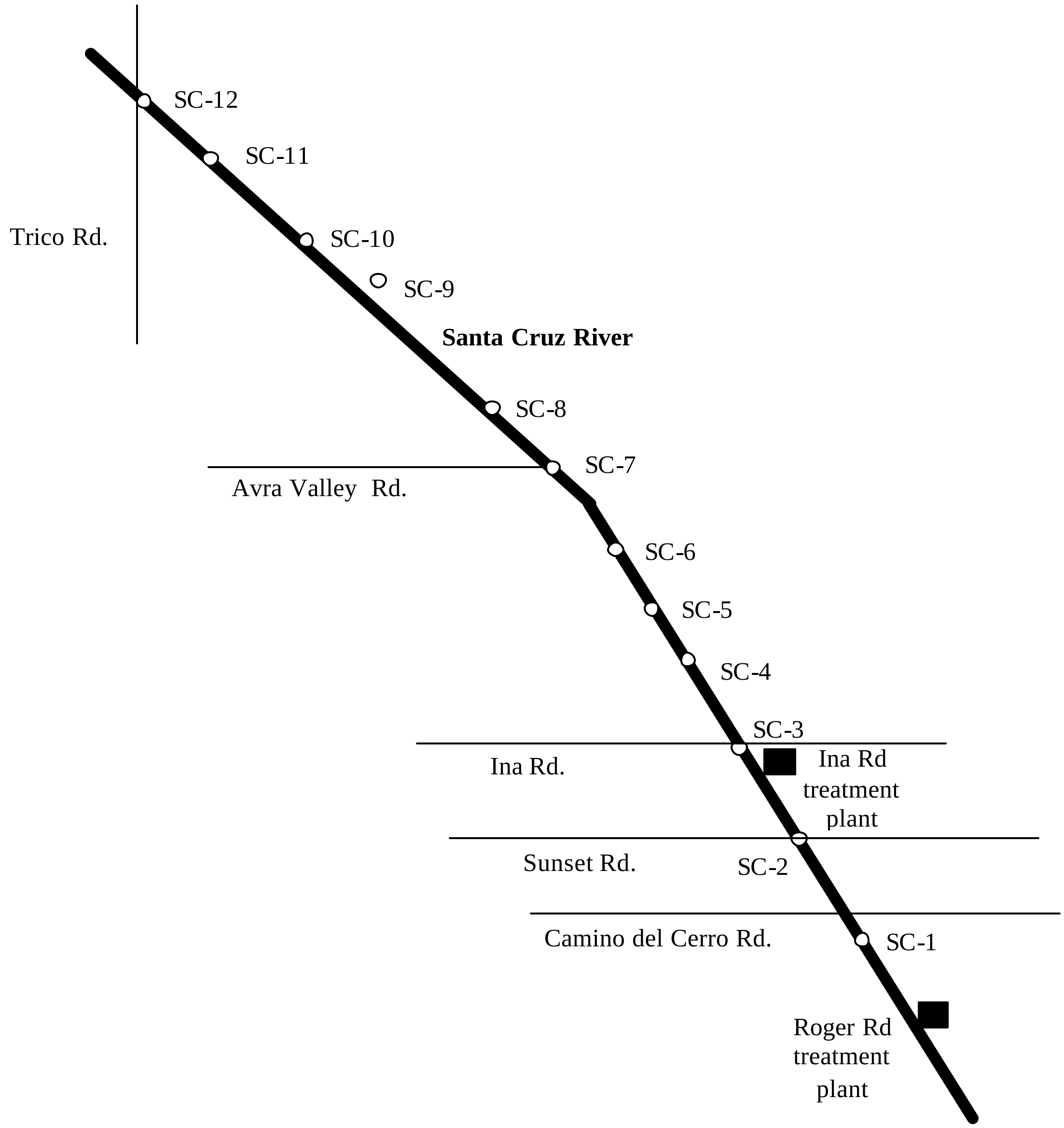


Figure 2. Locations of wells along the Santa Cruz river sampled during this study.

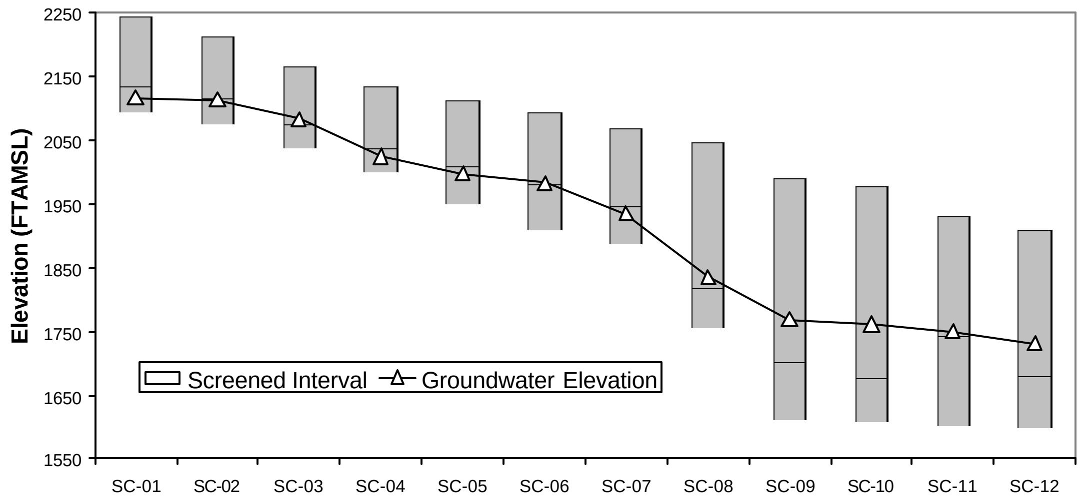


Figure 3. Santa Cruz monitoring well elevations (above mean sea level), screen intervals, and water table elevation. Tops of the lightly shaded portions of each bar represent the local elevation of land surface at the SC-series wells.

Samples for analysis of estrogenic activity were collected in 1-L amber glass bottles that had been acid washed and muffled (550^{o}C). All samples were filtered using 0.45-µm membrane filters (Millipore®) and stored at 4°C pending analysis. Water samples were tested for DOC (dissolved organic carbon), and boron/boron isotopes, as well as for estrogenic activity. Methods for concentrating samples prior to measurement of estrogenic activity are provided in a later section.

Dissolved Organic Carbon. DOC was analyzed using a combustion technique with a TOC-5000 Total Organic Carbon Analyzer. All samples were acidified to pH 2 using 2N HCl2 using 2N HCl and sparged for 4 minutes using ultrapure hydrocarbon-free air, then analyzed 4-6 times to produce a coefficient of variation $\leq$0.02. Standard solutions (made using potassium hydrogen phthalate) were included in each instrument run, and reported values were derived from a standard curve that was obtained via linear regression analysis. The lower level of detection and practical quantitation limit for DOC measurement with this analyzer were 0.2 and 0.5 mg/L, respectively.

*Boron Isotope Ratio***.** Boron is present as a dissolved constituent in essentially all water sources. Because both the boron concentration and the ratio of stable isotopes $^{11}B/^{10}B$ are variable, waters generally carry a boron signature or "fingerprint." The boron fingerprint in domestic wastewater is frequently very different from that of native ground water (Bassett, 1990; Davidson and Bassett, 1993; Bassett *et al*., 1995). This is particularly useful in groundwater recharge investigations since boron-related measurements (boron concentration and $\delta^{11}B$) can then support estimation of fractional contributions of wastewater and waters from other sources in groundwater samples. Total boron concentration and $^{11}B/^{10}B$ are essentially conserved during wastewater treatment, infiltration, and subsurface transport and storage of groundwater. In this work, boron isotopes ratio were measured in wastewater effluent and ground waters that were potentially influenced by recharged effluent.

The relative abundances of boron isotopes ^{11}B and ^{10}B are commonly represented by delta B eleven ($\delta^{11}B$) values. The value of $\delta^{11}B$ is calculated using:

$$d\ ^{11}B\ ‰ = \left(\frac{(^{11}B/^{10}B)_{sample} - (^{11}B/^{10}B\ )_{standard}}{(^{11}B/^{10}B\ )_{standard}} \right) x\,1000 \qquad (1)$$

where the standard value is based on a specific chemical source, NBS SRM-951. The $^{11}B/^{10}B_{standard} = 4.04362 \pm 0.00137$.

The ratio $^{11}B/^{10}B_{sample}$ was obtained from mass analyses by Thermal Ionization Mass Spectrometry (TIMS), and then compared to a standard ratio corresponding to the National Bureau of Standards Standard Reference Material 951, given above. The value resulting from equation (1) is in units of per mil, ‰.

Based on previous analyses, local wastewater effluent has an average isotopic signature of approximately +2.7‰. Background (ground water) $\delta^{11}B$ values are much higher (+15 to +30‰). The value obtained for each water sample, $d^{11}B_{sample}$, was used to calculate a volume fraction of each end member (source water) by:

$$d^{11}B_{sample} = \frac{\sum_i \left(d^{11}B_i\right)(C_i)(V_i)}{\sum_i (C_i)(V_i)} \qquad (2)$$

where C = total boron concentration
V = endmember volume fractions in the water sample
i = water source (effluent or native ground water)
$d^{11}B_i$ = per mil value of source water i.

The volume fractions of wastewater and groundwater origin in a given sample were determined from equation (2) after measuring $d^{11}B_{sample}$ after assuming the sum of the two volume fractions was equal to one.

Estrogen receptor--b competitor assay. Samples for measurement of estrogenic activity (500-1000 mL) were extracted on C18 disks (Empore, 3M) and eluted using two successive 10-mL washes with reagent-grade methanol. Eluates were combined and evaporated to dryness under nitrogen. Residual organics were resuspended in water containing 0.15 M NaCl to achieve volume concentration factors of 100-200x. Compounds that are efficiently separated from water on C18 disks include natural and synthetic hormones, polychlorinated biphenyls, organochlorine pesticides, phenoxyacid herbicides, phthalates and tirazines—in short, most of the wastewater contaminants that have been implicated in endocrine disrupting activities (manufacturer's data). Previous work in our laboratory demonstrated that constituents in secondary effluent that are responsible for disruption of ES2/ER-β binding are efficiently removed by passage through the C18 disks (Turney *et al.*, 2002). Process blanks were established using the same concentration/elution procedure.

Analytes for estrogenic activity consisted of unconcentrated well samples or C-18 concentrates in reagent buffer solutions (Pan Vera Corporation). The competitive binding assay is based on displacement of a commercially prepared fluoromone from ER-β. Fluorescence polarization (FP) was used to measure displacement of the fluoromone. Results are frequently reported as the fraction of sample needed to displace 50% of the bound fluoromone from the estrogen receptor (IC_{50}). The competitive-displacement or receptor-binding assay followed procedures established for the Estrogen Receptor-β Competitor Assay developed by the PanVera Company (Bolger *et al.*, 1998). Method detection limits for 17β-estradiol are ~10^{-9} M (Figure 4). The concentration of 17β-estradiol necessary to displace 50% (IC_{50}) of the fluorescent estrogen ligand is about 9 nM. Results were converted to estradiol equivalent (EEQ) concentrations using the results of individual assays (IC_{50} values) and corresponding IC_{50} values derived from positive controls involving 17β-estradiol (Figure 4).

The primary advantages of the competitor assay lie in cost and simplicity. The entire assay can be completed in hours using standard laboratory skills. The procedure detects, but does not differentiate between, agonist (chemicals that stimulate estrogen production) and antagonist (estrogen blocking) compounds. Because the endocrine receptor/fluorochrome complex was directly exposed to the test compounds, without benefit of an intervening cell envelope, test results may not accurately represent the whole-organism response.

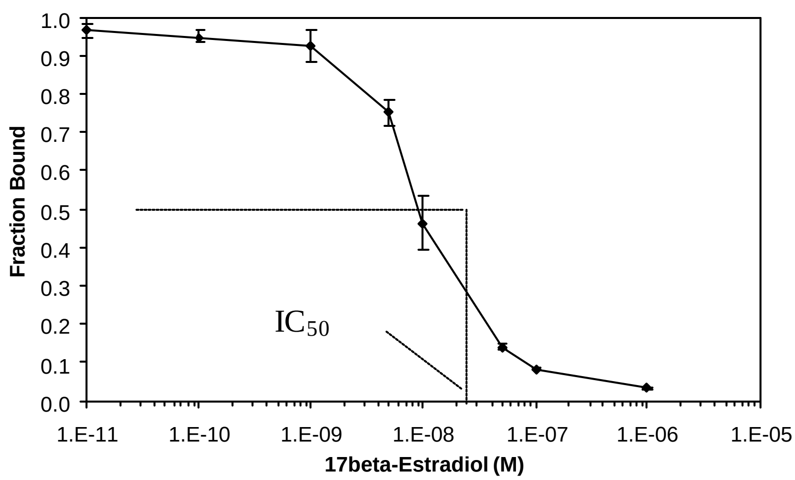


Figure 4. Estrogen receptor-binding assay response for 17β-estradiol. The vertical axis is fraction of the fluorescent ligand bound to the estrogen receptor. Ligand displacement arises from to the presence of competitive (estrogenic) compounds in the sample tested.

C. Principal Findings and Significance

DOC concentrations and estrogenic activities in surface-water samples taken from the Santa Cruz River at positions indicated previously are summarized in Figure 5. It is evident that only modest water quality changes occurred along the 30-mile reach that was sampled. Boron isotope ratios indicated that waters of the Santa Cruz were entirely of wastewater origin (data not shown) over the length monitored. Estrogen activity measurements were typical of wastewater effluents from the Roger Road and Ina Road Wastewater Treatment Plants, as indicated by previous work (results not shown). Furthermore, estrogenic activity showed little evidence of attenuation with distance traversed or time of travel in the river. Bulk organic levels were similarly conserved. Dry weather flow in the Santa Cruz River below the Roger Road and Ina Road outfalls is typically shallow, from just inches to several feet in depth. Because dry weather travel times along the reach sampled are on the order of hours to days, it is concluded that sunlight, including its ultraviolet component, has little effect on estrogenic compounds in conventionally treated secondary effluents. Similarly, biodegradation does not seem to have a dramatic effect on estrogenic activity or bulk organic composition over periods of days in surface waters. Since the samples were taken in June 2001, during which the average daily temperature was 85.6° F (NOAA), it is unlikely that biochemical activity in the river has a greater effect during another time of year.

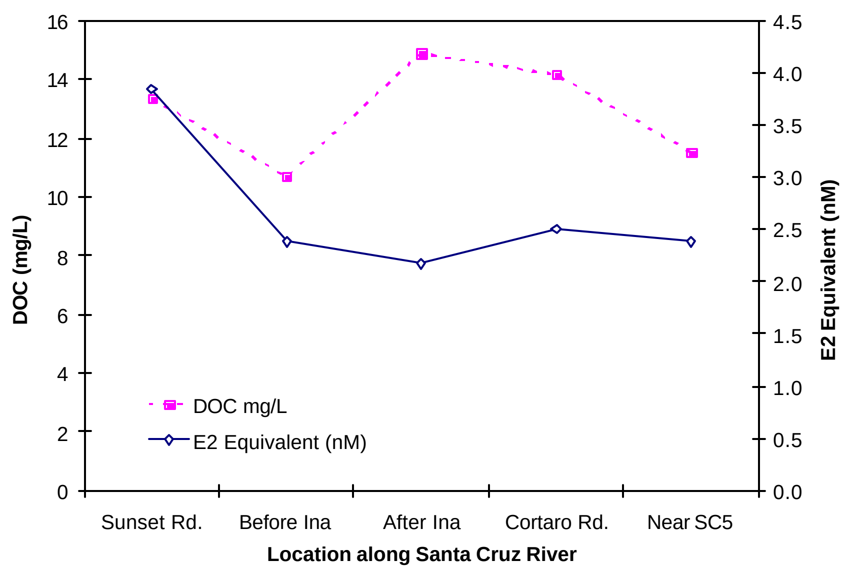


Figure 5. DOC concentrations and estrogenic activities in surface-water samples taken from the Santa Cruz River.

Water quality data for the Santa Cruz series wells (SC-01 through SC-12) show considerable spatial variation (Figure 6). At least three of the shallow (relative to the groundwater table) wells were dominated by water of wastewater origin—SC-01, SC-03 and SC-06. Somewhat unexpectedly, waters from the intervening wells SC-02, SC-04 and SC-05 indicated that the volume fraction of wastewater origin was no greater than about 0.30. Overall, results suggest that waters in as least some of the Santa Cruz series wells consist of a mixture of effluent and native ground water. The sizable contribution of native ground water may originate from water use/disposal activities at the surface, such as gravel washing operations. Alternatively, waters from wells with only modest effluent components may simply be diluted with native ground water at points of particularly high permeability and subsurface flow.

The tri-linear diagram (Figure 6) shows two very distinct water types and one intermediate. The first main grouping includes SC-01 and SC-02, which are similar to SC-03 through SC-07. Monitor well data for SC-08 appears to be an intermediate between the two groupings and SC-09 through SC-12 make up the second grouping. SC-02 lies directly over SC-01 so it is not shown for clarity. This is also true for SC-04 through SC-07, which plot over SC-3, and SC-10 through SC-12 which plot over SC-09. The Rillito Narrows (near Avra Valley Road and well SC-07) separates the Upper Santa Cruz sub-basin from the Avra Valley sub-basin. Monitoring wells SC-9 through SC-12 lie in the Avra Valley sub-basin. There is a large increase in depth to groundwater north of the narrows (Figure 3).

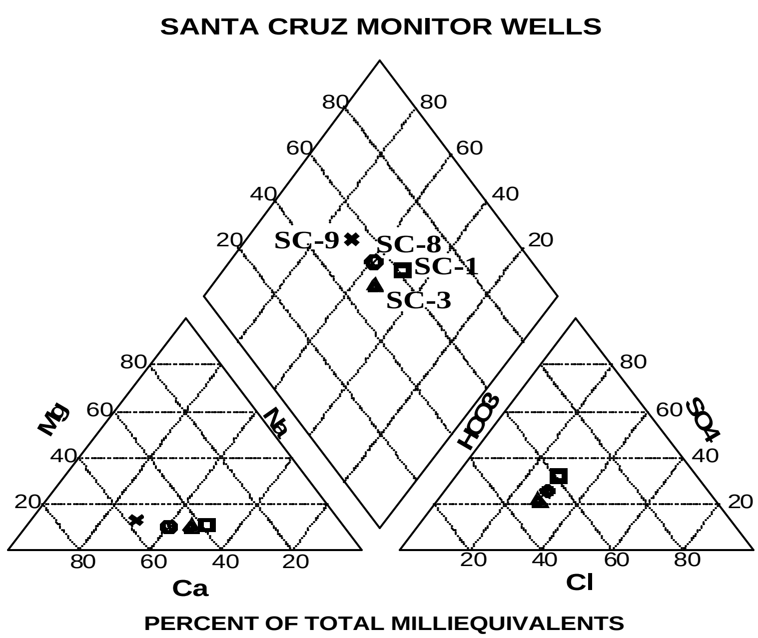
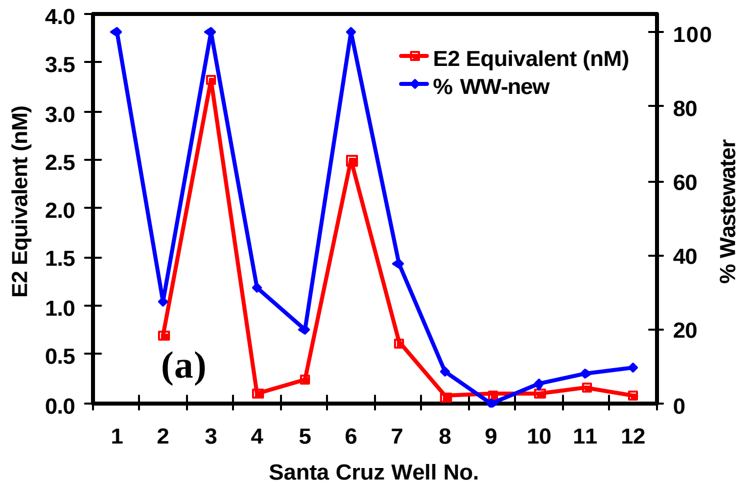


Figure 6. Tri-linear diagram for the Santa Cruz series wells (SC-01 through SC-12).

None of the wells downstream (north) of SC-07 was much affected by infiltrating wastewater effluent, suggesting that local infiltration or groundwater flow patterns in that region transport effluent away from those sampling points.

Estrogenic activities (in units of equivalent E2 concentrations) were highly correlated (r^2 = 0.92) to fractional wastewater content in well samples (Figure 7). That is, wells that contained the highest volume contributions of wastewater generally showed the highest estrogenic activity. Wells further north (downstream) than SC-07 contained waters at or near our detection limit for estrogenic activity. Those that were dominated by effluent produced E2 equivalent concentrations that were comparable to those in Santa Cruz surface waters. Results suggest that little attenuation of compounds contributing to measured estrogenic activity occurred during infiltration from the surface to well withdrawal points and/or subsequent storage as ground water. Well SC-01 offers the lone contradictory data point. Boron isotopes indicate that this water is entirely of wastewater origin. Nevertheless, estrogenic activity and DOC concentration (see below) were low. The anomalous result cannot be rationalized without additional monitoring work.



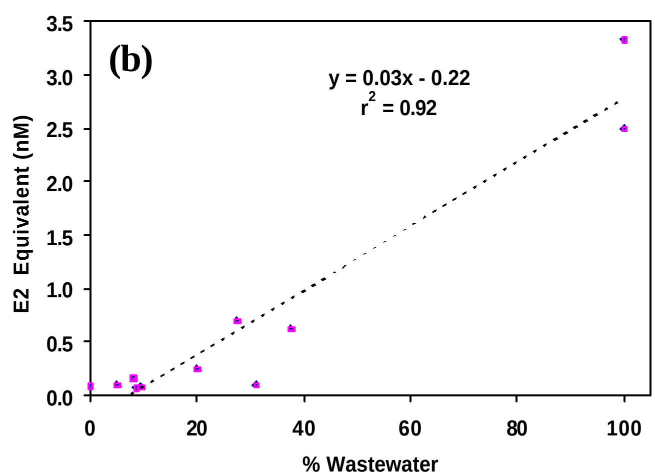


Figure 7. Estrogenic activity (in units of E2 equivalent concentration) and fractional wastewater content in SC well samples (a) and regression analysis illustrating the dependence of estrogenic activity on volume wastewater contribution in the samples (b).

DOC concentrations were also strongly related to boron isotope data ($P < 0.0003$) (Figure 8). DOC concentrations in the Santa Cruz well series never exceeded 2.8 mg/L and were significantly above 2.0 mg/L in just one sample. This is in contrast to DOC values in plant effluent (typically 12-15 mg/L) and values in Santa Cruz River water (10-14 mg/L) during the study. From DOC values in SC-01, SC-03 and SC-06, it is evident that bulk organic residuals in Roger Road and Ina Road Wastewater Treatment Plant effluents are further attenuated during infiltration and storage as ground water. Compounds that contribute to the measured estrogenic activity are not similarly affected by infiltration and storage.

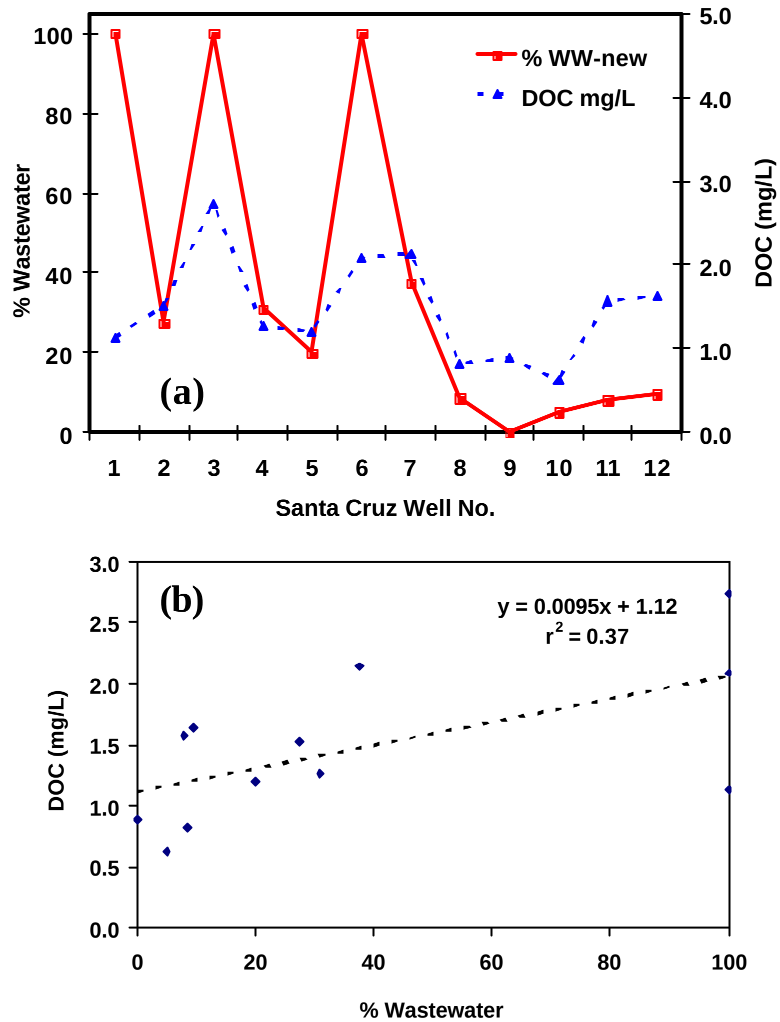


Figure 8. DOC concentration and boron isotope data for SC well samples (a) and regression analysis showing the dependence of DOC concentration on fractional (volume) contribution to the sample (b).

In contrast to these results, previous work (Turney *et al.*, 2002) showed that both DOC concentration and estrogenic activity are efficiently removed during the managed infiltration of wastewater effluent for ground water replenishment. In that study, DOC was typically reduced by >90 percent and estrogenic activity (competitive displacement assay, as here) was lowered by a factor of about 20 during managed infiltration through about 100 feet of unconsolidated sediment. Infiltration basins were operated by alternating wet and dry periods that were several days in length. Such basins typically develop a biochemically active surface layer (schmutzdecke) that is disproportionately important to organic attenuation processes. Among the potentially important differences between managed and incidental (in-stream) recharge is the continuous maintenance of a schmutzdecke in zones where most of the water infiltrates.

Conclusions and Recommendations

Results of the study support the following conclusions and recommendations for follow-on work.

i. When surface water samples were taken from the Santa Cruz River, the entire reach sampled was dominated by reclaimed water. There were no other major water contributors to the river over the 30-mile region sampled.

ii. There was little or no evidence of attenuation of estrogenic activity with distance traveled among surface water samples. Since the river is fairly shallow at most points and times of travel in the reach sampled are on the order of hours to days, it is likely that solar irradiation plays a modest or inconsequential role in transforming compounds that are responsible for residual estrogenic activity in reclaimed water.

iii. At several points along the river, shallow ground waters are strongly affected by reclaimed water. The bulk of water samples derived from three wells (SC-01, SC-03, and SC-06) were of wastewater origin, as indicated by measurements of boron isotope ratios. Much lower volume contributions of reclaimed water at intervening wells SC-02, SC-04, and SC-05 indicate that mixing processes arising from water use patterns at land surface (e.g. gravel washing using well water) or subsurface dilution with native ground water also contributes to groundwater quality characteristics at these locations.

iv. There is a strong relationship between the fractional (volume) contribution of reclaimed water and estrogenic activity in the SC well series. There is a weaker, yet significant relationship between DOC concentration and estrogenic activity in the same set of samples. Results suggest that water quality in shallow wells at some locations along the Santa Cruz River may be affected by the infiltration of reclaimed water from the Roger Road and Ina Road Wastewater Treatment Plants.

v. In the Santa Cruz wells with large volume contributions of reclaimed water, estrogenic activity and DOC concentrations were high relative to values in wells dominated by reclaimed water at the Sweetwater Recharge Facilities. These findings suggest that managed infiltration of wastewater effluent can produce water quality benefits that are not realized, at least not immediately, during the unmanaged, incidental recharge of reclaimed water in a river bed.

vi. Although study results present a fairly consistent picture, data from SC-01 are anomalous in that boron isotopes indicate that the water is dominated by effluent, but measures of both DOC and estrogenic activity are in the low range of values encountered in the study. Some additional thought and/or monitoring is necessary to clear up this apparent inconsistency.

vii. The competitive-displacement assay for estrogenic activity should be backed up by a more physiologically interpretable assay in subsequent work—at least until reliable correlations among the results of different assays for complex water samples are available.

References

Bassett, R.L. 1990. A critical evaluation of the available measurements for the stable isotopes of boron. *Applied Geochem.* **5**: 541-554.

Bassett, R.L., P.M. Buszka, G.R. Davidson, and D. Chong-Diaz. 1995. Identification of groundwater solute sources using boron isotope composition. *Environ. Sci. Technol.* **29**: 2915-2922.

Bolger, R., Weise, T.E., Ervin, K., Nestich, S., and Checovich, W. 1998. Rapid screening of environmental chemicals for estrogen receptor binding capacity. *Environ. Health Perspect*. **106**:551-557.

Bostick, K.A. 1978. A stable isotope investigation of recharge to the Tucson Basin Aquifer from the Santa Cruz Rvier. *Unpublished M.S. Thesis*. Department of Hydrology. The University of Arizona.

Davidson, G.R., and R.L. Bassett. 1993. Application of boron isotopes for identifying contaminants such as fly ash leachate in groundwater. *Environ. Sci. Technol.* **27**: 172-176.

Davidson, E.S. 1973. Geohydrology and water resources of the Tucson Basin, Arizona. U.S. Geological Survey Water-Supply Paper 1939-E.

Desbrow, C., E.J. Routledge, G.C. Brighty, J.P. Sumpter and M. Waldock. Identification of estrogenic chemicals in STW effluent. 1. Chemical fractionation and in vitro biological screening. *Environ. Sci. Technol.* **32**: 1549-1558.

Gaylean, K. 1996. Infiltration of wastewater effluent in the Santa Cruz river channel, Pima Couty, Arizona. U.S. Geological Survey Water-Resources Investigation Report 96-4021.

Jobling, S., M. Nolan, C.R. Tyler, G. Brighty and J.P. Sumpter. 1998. Widespread sexual disruption in wild fish. *Environ. Sci. Technol.* **32**: 2498-2506.

Kolpin, D.W., Furlong, E.T., Meyer, M.T., Thurman, E.M., Zaugg, S.D., Barber, L.B., and Buxton, H.T. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000: a national reconnaissance. *Environ. Sci. Technol*. **36**(6):1202-1211.

Lacher, L.J. 1996. Recharge characteristics of an effluent dominated stream near Tucson, Arizona. *Unpublished PhD Dissertation*. Department of Hydrology and Water Resources. The University of Arizona.

Leenhouts, J.M. 1998. Utilization of intrinsic boron isotopes as co-migrating tracers for identifying potential nitrate contamination sources. *Ground Water*. **36**(2):240-250.

Quanrud, D.M., Hafer, J., Karpiscak, M.M., Zhang, J., Lansey, K.E., and Arnold, R.G (2002). Fate of organics during soil aquifer treatment: sustainability of removals in the field. *Submitted to Water Research*.

Snyder, S.A., Villeneuve, D.L., Snyder, E.M., and Geisy, J.P. 2001. Identification and quantification of estrogen receptor agonists in wastewater effluents. *Environmental Science and Technology*. **35**(18):3620-3625.

Snyder, S.A., Keith, T.L., Verbrugge, D.A., Snyder, E.M., Gross, T.S., Kannan, K., and Giesy, J.P. 1999. Analytical methods for detection of selected estrogenic compounds in aqueous mixtures. *Environmental Science and Technology*. **33**(16):2814-2820.

Turney, K.D., Lansey, K.E., Quanrud, D.M., and Arnold, R.G. (2002). Endocrine disruption in reclaimed water—fate during soil-aquifer treatment. *Submitted to J. Environ. Eng.*

Wilson, L.G., Amy, G.L., Gerba, C.P., Gordon, H., Johnson, B., and Miller, J. 1995. Water quality changes during soil aquifer treatment of tertiary effluent. *Water Environment Research*. **67**(3):371-376.

www.wrh.noaa.gov/tucson/climate/2001/jun01.html

Develop Bioassay Capability for Modification of Water Quality Criteria & Effluent Testing Using Arid West Aquatic Species

Basic Information

Title:	Develop Bioassay Capability for Modification of Water Quality Criteria & Effluent Testing Using Arid West Aquatic Species
Project Number:	2001AZ961B
Start Date:	3/1/2001
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Focus Category:	Water Quality, Toxic Substances, Surface Water
Descriptors:	Arid Climates, Fish Ecology, Heavy Metals, Lakes, Organic Compounds, Pollutants, Regulatory Permits, Risk Management, Rivers, Toxic Substances, Wastewater, Water Quality, Water Quality Management, Water Quality Standards.
Principal Investigators:	Donald Baumgartner, Kevin Fitzsimmons, Stephen Nelson

Publication

Following is an interim report on progress in the project: Develop Arid West Bioassay Capability for Modification of Water Quality Criteria & Effluent Testing, Award # 01HQGR0113: Project # AZ 961.

Crustacean culture: We have been successful in establishing and maintaining cultures of an ostracod found in samples of soil from Mirror Lake, California. Previously these small crustaceans were identified as clam shrimp (conchostracans), but were recently found to be seed shrimp (Ostracoda). This does not affect the conceptual foundation of the project.

Cultures have been established in approximately 15-l containers of distilled water and Tucson municipal water with a 2-cm layer of playa soil. The cultures essentially become simple, self-regulated microcosms. Initially, a blue-green algae (probably *Microcystis*) begins to grow, especially around the edges of the soil layer. A diatom bloom eventually develops as well; this is almost exclusively a species of *Amphora*. The cultures develop and prosper without supplemental feeding.

We used ten replicates at three temperatures each in 150-ml flasks to assess the effect on development of the cultures. Temperatures were 23, 28, and 33 ^{o}C, maintained by water baths equipped with thermoregulators.. By the fourth day ostracod larvae began to emerge. By day ten 48 ostracods had hatched and developed into adults. Of these, 9 were in the high-temperature group, 17 in the low-temperature group, and 22 were in the middle temperature groups. This is a favorable response with respect to the warm watercourse temperatures of the arid West we must represent in the bioassays.

Crustacean bioassays: Early tests were conducted with few replicates (four or eight) to determine generally what concentrations of copper would produce mortality. As we narrowed in on the LC50, more replicates were used (up to 20). Final results indicate that our Ostracod species has a 24-hour copper LC50 of 0.11 mg/l, at a medium water hardness concentration of 75-80 mg/l as $CaCO_3$. Varying water hardness concentrations had little effect on survival, with preliminary tests showing essentially identical survival at hardness concentrations between 0 and 300 mg/l as $CaC0_3$.

Native Arid West fish culture: We have established aquaria for culturing fish for the bioassay tests, however, the candidate fish we were culturing was later determined to be non-native, so we are searching for a supplier of another species.

Work planned for the future: Non-native fish will be cultured in waters of varying hardness concentrations as a preliminary step in exposing them to varying concentrations of copper. Similar studies will be conducted on the standard EPA fish species, fathead minnow, to determine relative sensitivity. The relationship between hardness concentration and sensitivity, e.g., the copper LC_{50} will be compared to the equations EPA has developed for use in waters with lower hardness concentrations.

If resources are still available when the fish bioassays are completed we will complete the bioassay work begun on the crustacean species.

New Approaches To Addressing Tribal Water Rights

Basic Information

Title:	New Approaches To Addressing Tribal Water Rights
Project Number:	2001AZ982B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	Second
Research Category:	Not Applicable
Focus Category:	Law, Institutions, and Policy, Economics, Water Use
Descriptors:	Indian Water Issues, Policy Analysis, Conflict Resolution
Principal Investigators:	Bonnie Colby

Publication

1. Colby, B. G., and T. P. d'Estrée, Braving the Currents: Resolving Conflicts Over the Water of The American West, book manuscript under review, 207 pages, 2001.
2. Colby, B. G., "Resolving Interjurisdictional Disputes over Water and Environmental Quality," Water Resources Update 36: 20-29, 2001.
3. Colby, B. G., Economic Characteristics of Successful Dispute Resolution Outcomes, chapter in Evaluating Environmental and Public Policy Dispute Resolution Programs and Policies, R. OLeary and L. Bingham, editors, Syracuse University Press, forthcoming in 2002
4. Colby, B.G. and John Thorson, Smoke on the Water: One Hundred Years of Litigation and Negotiations Over Tribal Water Rights, book manuscript under review, 189 pages, 2002.
5. DEstrée, T.P. and B.G. Colby, Guidebook for Evaluating Success in Environmental Conflict Resolution, Institute for Conflict Assessment and Resolution, George Mason University , 2001, 97 pages

Problem: Large amounts of time and resources are expended addressing issues associated with Indian water rights in Arizona and other western states. Litigation and negotiations over tribal water rights are a primary concern among cities, rural communities, irrigators, tribes, environmental advocates and public agencies. There have been a number of new developments in seeking to reconcile tribal claims and the needs of other water users over the past ten years. The primary objective of the proposed project is to undertake the research necessary for an updated and substantially revised edition of the 1993 publication "Indian Water Rights: Negotiating the Future".

Methodology: The proposed publication is designed to update policy makers, water users, public agency staff and the general public on current approaches to addressing Indian water rights. Such information, gathered from recent developments across the western U.S., will help those private and public sector stakeholders currently embroiled in water conflicts to resolve them more effectively, and to craft more durable, cost-effective and implementable solutions. The book provides a current and user-friendly resource to transfer knowledge from experts in many different disciplines to a largely non-technical audience.

The primary research tools used were document analysis, including review of negotiated agreements and court rulings, interviews with parties involved in tribal water issues, and economic analysis of costs, benefits and financial obligations associated with different approaches used to resolve conflicts over tribal rights. Essays from contributing authors in law, environmental science, hydrology, conflict resolution and other fields assure high quality coverage of relevant expertise from differing disciplines.

Principal Findings and Significance: The book manuscript analyzes the details of negotiated settlements and litigated outcomes involving tribal water rights, highlighting the advantages and disadvantages of different means to resolve specific economic, legal, technical and political issues. It incorporates the latest thinking regarding agricultural and urban water conservation, water pricing, voluntary water transactions, intergovernmental agreements, endangered species protection, compliance with water quality regulations, environmental restoration and other matters that have played an increasingly important role in water negotiations over the last ten years

The new book includes the following, newly researched sections:

1) the use of alternative dispute resolution (with considerably more experience to draw upon now as compared to the early 1990s),
2) the implications of new developments involving the Endangered Species Act and the Clean Water Act for negotiations and for inter-jurisdictional water management,
3) the emerging role of watershed initiatives and local problem-solving approaches,
4) implementation of negotiated settlements: what problems have arisen, how have they been addressed, and how can implementation be more effectively managed in the future?
5) an overview of the federal bureaucracy and the different arms of the federal government that interact with tribal water issues,
6) a listing of new federal appointees and new chairs of congressional committees relevant to the subject, and a description (if available) of policy directions of the new administration
7) a compendium of web sites and internet resources related to tribal and western U.S. water issues.

Salt Tolerance of Southwestern Perennial Ornamentals

Basic Information

Title:	Salt Tolerance of Southwestern Perennial Ornamentals
Project Number:	2001AZ1001B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	Fifth
Research Category:	Not Applicable
Focus Category:	Water Quality, Irrigation, None
Descriptors:	Salinity, plant growth, Southwest landscape plants, plant-water relationships
Principal Investigators:	Ursula Schuch

Publication

1. Schuch, U.K., T. Mahato. 2002. Salt tolerance of Southwestern plant species. Abstract in HortSciences (July 2002 issue)
2. Schuch, U.K., T. Mahato. 2002. Salt tolerance of Southwestern ornamental plants. 2002 Turfgrass, Landscape and Urban IPM Research Summary. University of Arizona.

A. Problem and Research Objectives

Water is a limited resource in the arid Southwest. Water demand is increasing for the burgeoning population in Arizona and the Southwest, while water supply is decreasing. The increase in primarily urban population brings with it a steady demand for ornamental plants in nurseries and landscapes. One strategy to stretch the finite ground water resources is reusing or recycling used water or gray water for ornamental plant production or maintenance of plants in the landscape. While generally accepted as a good concept, use of gray water, recycled water or water with higher salinity for irrigation of ornamental plants brings potential problems of increasing soil salinity and possibly causing reduced growth, foliar injury, or death of plants over time. Irrigation water with TDS (total dissolved solids) of up to 1,280 mg/l or an EC (electrical conductivity) of up to 2.0 dS/m is considered acceptable in terms of salinity. However, evaporation without leaching will lead to salt accumulation in the soil and therefore much higher concentrations of salts in the plant root zone. Although many current sources of potable water are of good quality, salinity of pumped groundwater and Colorado River water are expected to increase in the future. In the future, plant production and landscape maintenance will have to rely on irrigation water with higher salinity than current sources.

The plant palette used for landscaping in the Southwest, especially in Arizona, has changed dramatically over the last decade. Mediterranean plants have been replaced by native Southwestern or desert-adapted plants. Many of the most common trees, shrubs, groundcovers, and accent plants were scarcely used until recently and have not previously been tested for salt tolerance. In order to efficiently use water of higher salinity than ground water for irrigation of landscape plants, we need to learn more about salinity tolerance of currently used plants. Areas concerned with using desert-adapted plants for landscaping, decreasing water supply, increasing water demand, and irrigation water with higher salinity in the future are Arizona, New Mexico, Nevada, and the Mojave desert area of California.

The objective of this study was to determine salinity tolerance and ability for osmotic adjustment of selected trees, shrubs, groundcovers, and accent plants recently introduced to landscapes in the Southwest. Three species each of trees, shrubs, groundcovers, and accent plants, with the following attributes were selected for the study: no previous knowledge is available on their salt tolerance, they are widely used across the Southwest, they are readily available from several growers, and they are durable, and long-lived.

B. Methodology

Three species of trees (*Acacia stenophylla*, *Cercidium floridum*, and *Chilopsis linearis*), shrubs (*Calliandra californica*, *Leucophyllum frutescens*, and *Tecoma stans*), groundcovers (*Lantana* 'New Gold', *Verbena rigida*, and *Hymenoxis acaulis*) and accent plants (*Muhlenbergia rigens*, *Dasyliron wheeleri*, and *Nolina microcarpa*) were used in the study. Plants were obtained from a local nursery and tree and shrub liners were transplanted into 5-gal. containers, and groundcovers and accent plants were transplanted into 2-gal. containers on May 15, 2001. Plants were grown in pure silica sand (20 grade) and were irrigated with a fertilizer solution (Peters 20-20-20) containing 50 ppm N (control). The control solution had an EC of 0.6 dS/m and was supplemented with calcium chloride and sodium chloride (1:3 ratio) to reach 2.5, 5.0 or 10.0 dS/m. On July 2, 2001 all treatments other than the control solution received supplemental salts to reach a salinity of 2.5 dS/m. The following week, salinity was increased to 5.0 dS/m for the two higher salinity treatments. On July 16, 2001, salinity of the irrigation solution was increased to 10.0 dS/m for the highest salinity treatment. Plants were irrigated with the salinity treatments for 16 weeks and harvested from November 5 until November 11, 2001.

Irrigation was supplied by one or two drip emitters on the surface of the sand for the two-gallon and five-gallon containers respectively. Irrigation was provided at approximately two hour intervals during daylight hours to prevent water stress of plants. Runoff was collected and recycled for 7 days after which all solutions were discarded and fresh ones were prepared. EC and nitrate were measured daily and irrigation solutions were adjusted to their respective salinity treatments daily. Figure 1 shows the EC of the irrigation solutions throughout the experiment.

The experiment was located at the Campus Agricultural Center of the University of Arizona on Campbell Avenue in Tucson, Arizona. Plants were grown on elevated benches in full sun. Each of the twelve species was grown under four salinity treatments with 6 replications. The experiment was arranged in a completely randomized block design.

At the end of the experiment, tree height and caliper at 2.5 cm above the media were measured. Plant height and two canopy widths, for which the average was calculated, were measured at the end of the experiment for the other nine species. Visual symptoms of foliar injury, stunted growth, and branch dieback were noted on a weekly basis. Shoot and root dry weights were determined at the end of the experiment. Biomass of dead plants at the end of the experiment was also recorded and is included in the analysis. Plant water potential and osmotic potential were measured during October 2001. Shoot tissue has been ground and will be sent for foliar analysis of Na and Cl during May 2002. Data was analyzed with the statistical package SAS.

Principal Findings and Significance

Biomass and canopy size results are summarized in Tables 1 and 2. Photographs of the plants before dry weight determinations are shown in Appendix 1.

Tree species

Growth response of the three tree species to increasing salinity ranged from salt tolerant for *Acacia stenophylla,* greater biomass production at intermediate salinity treatments for *Cercidium floridum*, and salt sensitive for *Chilopsis linearis* 'Rio Salado' (Table 1). Root/shoot ratios of tree species was little or not affected by the salinity treatments (Table 1). Shoot, root, and total biomass (Table 1) as well as caliper and height (Table 2) of *A. stenophylla* were not affected by salinity treatments. *A. stenophylla* never developed visual injury symptoms on the foliage throughout the study period.

Cercidium floridum produced the greatest shoot, root and total dry weight when irrigated with 5.0 dS/m solution (Table 1). Lowest biomass production resulted from irrigation with 2.5 dS/m solution, and was approximately one third of that produced by plants irrigated with 5.0 dS/m. Biomass production of plants treated with 0.6 dS/m or 10.0 dS/m irrigation solution did not differ from either of the other treatments. Caliper and height correspond to the biomass results (Table 2). No visual injury symptoms were observed on *C. floridum* plants throughout the study.

Chilopsis linearis 'Rio Salado' growth response indicates sensitivity to higher salinity treatments. Shoot biomass production was reduced under the 5.0 dS/m treatment compared to control and 2.5 dS/m treatment (Table 1). The 10.0 dS/m treatment further reduced both shoot and root biomass to less than 25% of the low salinity treatments. Caliper and height measurements confirm biomass data (Table 2). Fist signs of apical leaf wilting and leaf burning on *C. linearis* ‘Rio Salado’ appeared within two weeks of the onset of the 10.0 dS/m treatment. Symptoms progressed to defoliation and branch dieback from the tips of branches to the base. Within 8 weeks of the onset of the salinity treatments, plants under the 5.0 dS/m treatment started to show marginal burn on apical leaves. Within 10 weeks of treatment onset, plants irrigated with 10 dS/m solution were 80-90% defoliated and had died back severely, plants irrigated with 5 dS/m solution exhibited more leaf burning and mild defoliation, and plants irrigated with 2.5 dS/m solution showed mild leaf burning. These symptoms persisted until completion of the study.

Shrub species

The shrub species also differed in their tolerance to the salinity treatments. Shoot, root, and total biomass production, root/shoot ratio, and canopy size of *Leucophyllum frutescens* were not affected at the $p<0.05$ significance level (Table 1, 2). However, the means show a trend of approximately 50% lower biomass production for plants irrigated with 10.0 dS/m solution versus those irrigated with 0.6 dS/m solution. Although none of the plants developed foliar symptoms of injury throughout the experiment, growth response of plants was too variable to conclude that *L. frutescens* is tolerant to irrigation with solutions of up to 10.0 dS/m.

Calliandra californica tolerated irrigation solutions of up to 5.0 dS/m without reductions in biomass (Table 1). Growth of plants irrigated with 10.0 dS/m appeared stunted beginning five weeks after the onset of the treatment and had died within 12 weeks. *C. californica* never developed injury symptoms on leaves.

Tecoma stans responded to increasing salinity levels with a linear decrease in biomass production (Table 1). Height and canopy width were not significantly affected by the treatments (Table 2). Within 2 weeks of the onset of the 10.0 dS/m treatment, lower leaves started to turn yellow and subsequently dried. A week later the symptoms progressed from the base of the plant upward, and first symptoms of leaf chlorosis were observed in plants irrigated with 5.0 dS/m and 2.5 dS/m solutions. Plants irrigated with

10.0 dS/m solution were defoliated within 8 weeks of treatment onset and had died four weeks later. Plants irrigated with 5.0 dS/m solution lost most of their lower leaves, while those irrigated with 2.5 dS/m solution suffered from mild chlorosis and leaf abscission. Minor chlorosis was observed on lower leaves of plants irrigated with 0.6 dS/m solution, and can be attributed to shading and natural ageing of the vigorously growing plants.

Accent plants

Muhlenbergia rigens produced the greatest biomass among all experimental species (Table 1). Shoot and root dry weights and plant height were progressively reduced when plants received irrigation solutions of 5.0 dS/m or greater (Table 1, 2). Root/shoot ratio was greatest for plants irrigated with 0.6 dS/m solution and smaller for all other treatments. Drying leaf tips developed within three weeks of irrigating plants with solutions of 2.5 dS/m or higher, but were most pronounced and developed most rapidly for the higher salinity treatments.

Biomass production of *Nolina microcarpa* was not affected by salinity treatments, although canopy height was reduced for plants irrigated with the two higher salinity treatments compared to the 0.6 dS/m and 2.5 dS/m treatments (Table 1, 2). Plants had been transplanted from 1-gal. containers to 2-gal. containers and appeared to grow very little during the experimental period. However, plants irrigated with the 5.0 or 10.0 dS/m solution showed no more leaf tip burn than the ones irrigated with the lower salinity solutions. A longer period for evaluating the salinity tolerance of *N. microcarpa* seems appropriate due to the slow growth rate of this species.

Dasyliron wheeleri produced the smallest biomass among the experimental plants used in this experiment (Table 1). Although statistical differences were found for biomass between the 2.5 dS/m treatments and the 10.0 dS/m treatment, plant growth during the experimental period was unacceptable from a commercial point of view and from the perspective of evaluating salinity tolerance of this species. It appears that the continuous moisture that was provided to the root system prevented plants to thrive, thus making them unsuitable to be tested under our current experimental protocol. *D. wheeleri* is also known to have a slow juvenile growth rate and therefore should be tested for salinity tolerance for a longer period than 3 months.

Ground covers

Lantana 'New Gold' plants were sensitive to irrigation solutions of 2.5 dS/m which reduced shoot and total biomass by approximately 50%, and root biomass by two thirds compared to plants irrigated with the 0.6 dS/m solutions (Table 1). Defoliation of older leaves on plants irrigated with the 5.0 dS/m and the 10.0 dS/m solution began 8 weeks after the onset of all treatments, while older leaves started to turn yellow on plants irrigated with 2.5 dS/m solutions at that time. When the study was concluded, the highest to lowest salinity solutions caused the following foliar injury symptoms: more than 90% of leaves dropped, 50% of leaves dropped, about 33% of leaves dropped, and no foliar injury symptoms. The decrease in biomass production was primarily due to loss of leaves, as canopy size decreased only significantly for plants irrigated with the 10.0 dS/m solution compared to the other treatments (Table 2).

Biomass of *Verbena rigida* decreased linearly with increasing salinity treatments (Table 1). Plants irrigated with solutions of 10.0 dS/m showed leaf burn immediately after the onset of treatments, and started to die back from the apical end towards the base within two weeks of treatments. All of those plants were dead after 6 weeks of treatment. Five of the six replicate plants irrigated with the 5.0 dS/m solution were dead at the end of the experiment. Plants irrigated with 2.5 dS/m solution showed leaf burn on apical leaves. Plant height and canopy width were smaller for plants under the two higher irrigation treatments compared to the ones irrigated with 0.6 dS/m or 2.5 dS/m solutions (Table 2).

Hymenoxis acaulis liners established with difficulty and all plants irrigated with 5.0 dS/m or 10.0 dS/m had died after 8 weeks of treatments. It is unclear whether they required a longer establishment period, or are indeed very sensitive to saline conditions in the root zone. Plants irrigated with 0.6 dS/m solution developed into commercially acceptable plants by the end of the experiment, while those under the 2.5 dS/m treatment appeared stunted, but without specific foliar symptoms of injury. Even though biomass and canopy size data has been analyzed and shows that salinity of 2.5 dS/m and greater severely curtailed growth (Table 1, 2), problems with initial establishment only allow a cautious conclusion that *H. acaulis* is very salt sensitive.

Summary

Results for ten species of ornamental plants growing in containers and irrigated for 16 weeks with four solutions with an electrical conductivity of 0.6, 2.5, 5.0, or 10.0 dS/m are summarized below. The onset of injury symptoms under the four treatments varied by species. The following table provides an overview of salinity tolerance based on the treatments when biomass reduction started and when biomass was reduced to 25% or less of the control or plants had died by the end of the experiment.

Species	**EC (dS/m) when biomass reduction begins**	**EC (dS/m) when biomass $\leq$ 25% of control plants or plants are dead**
Acacia stenophylla	>10.0	>10.0
Cercidium floridum	>10.0	>10.0
Nolina microcarpa	>10.0	>10.0
Muhlenbergia rigens	5.0	>10.0
Leucophyllum frutescens	5.0	>10.0
Calliandra californica	5.0	10.0
Tecoma stans	5.0	10.0
Chilopsis linearis ‘Rio Salado’	2.5	10.0
Verbena rigida	5.0	5.0
Lantana ‘New Gold’	2.5	10.0

Table 1. Biomass and root to shoot ratio of twelve species of ornamental plants grown for 16 weeks with irrigation water of different salinity.

	EC dS/m	Shoot	Root Dry Weight (g)	Total	Root/shoot Ratio
Acacia stenophylla	0.6	88.2	22.6	110.8	0.26ab
	2.5	124.7	24.8	149.6	0.18b
	5.0	105.2	20.8	126.9	0.29a
	10.0	95.8	19.6	115.4	0.20b
Significance (p-value)		0.06	0.07	0.06	0.04
Cercidium floridum	0.6	134.2ab	40.3ab	174.5ab	0.30
	2.5	90.4b	25.1b	115.6b	0.28
	5.0	242.9a	80.6a	323.5a	0.36
	10.0	180.4ab	57.9ab	238.3ab	0.33
Significance		0.04	0.007	0.02	0.37
Chilopsis linearis	0.6	273.9a	88.5a	362.3a	0.33
'Rio Salado'	2.5	247.1a	106.2a	353.3a	0.43
	5.0	162.9b	66.1ab	229.0b	0.40
	10.0	57.1c	26.7b	83.8c	0.49
Significance		.00001	.001	.00001	0.11
Calliandra californica	0.6	39.3a	14.1a	53.4a	0.38a
	2.5	30.5ab	11.0ab	41.6ab	0.38a
	5.0	34.1ab	12.4ab	46.5a	0.41a
	10.0	0.7b	0.2b	0.9b	0.15b
Significance		0.02	0.02	0.02	0.005
Leucophyllum frutescens	0.6	57.6	5.0	62.6	0.08
	2.5	39.7	2.9	42.6	0.08
	5.0	44.0	2.6	46.7	0.06
	10.0	26.5	1.5	28.0	0.06
Significance		0.27	0.06	0.24	0.09
Tecoma stans	0.6	239.8a	42.2a	281.9a	0.18a
	2.5	197.7ab	29.4a	227.1ab	0.15ab
	5.0	142.1bc	14.5b	156.7bc	0.11b
	10.0	72.6c	9.4b	82.1c	0.13ab
Significance		0.0003	0.0001	0.0001	0.02

Table 1 continued

	EC dS/m	Shoot	Root	Total	Root/shoot Ratio
		Dry Weight (g)			
Dasyliron wheeleri	0.6	0.97ab	0.31ab	1.28	0.34
	2.5	1.19a	0.46a	1.66	0.41
	5.0	0.39ab	0.19ab	0.77	0.51
	10.0	0.33b	0.10b	0.86	0.30
Significance		0.02	0.01	0.16	0.16
Muhlenbergia rigens	0.6	647.7a	101.4a	749.2a	0.16a
	2.5	687.0a	54.7a	741.7a	0.08b
	5.0	509.5b	47.0b	556.5b	0.09b
	10.0	295.2c	31.1c	326.3c	0.11b
Significance		0.0001	0.0001	0.0001	0.0001
Nolina microcarpa	0.6	18.9	6.6	25.5	0.35
	2.5	17.1	6.5	23.5	0.37
	5.0	16.7	7.4	24.2	0.44
	10.0	15.1	7.1	22.2	0.45
Significance		0.8	0.95	0.94	0.22
Lantana ‘New Gold’™	0.6	168.2a	50.5a	210.3a	0.26
	2.5	83.8b	16.9b	100.7b	0.21
	5.0	85.0b	15.0b	100.0b	0.18
	10.0	46.8b	7.8b	54.7b	0.17
Significance		0.0001	0.0001	0.0001	0.40
Verbena rigida	0.6	104.8a	17.7a	122.5a	0.16
	2.5	75.5ab	8.5ab	84.0ab	0.11
	5.0	56.4bc	5.2ab	61.6bc	0.09
	10.0	23.1c	1.9b	25.1c	0.08
Significance		0.0001	0.01	0.0001	0.16
Hymenoxis acaulis	0.6	24.6a	3.8a	27.8a	0.15
	2.5	5.4b	0.5b	5.8b	0.06
	5.0	4.1b	0.6b	4.7b	0.11
	10.0	--	--	--	--
Significance		0.0003	0.0001	0.0002	0.52

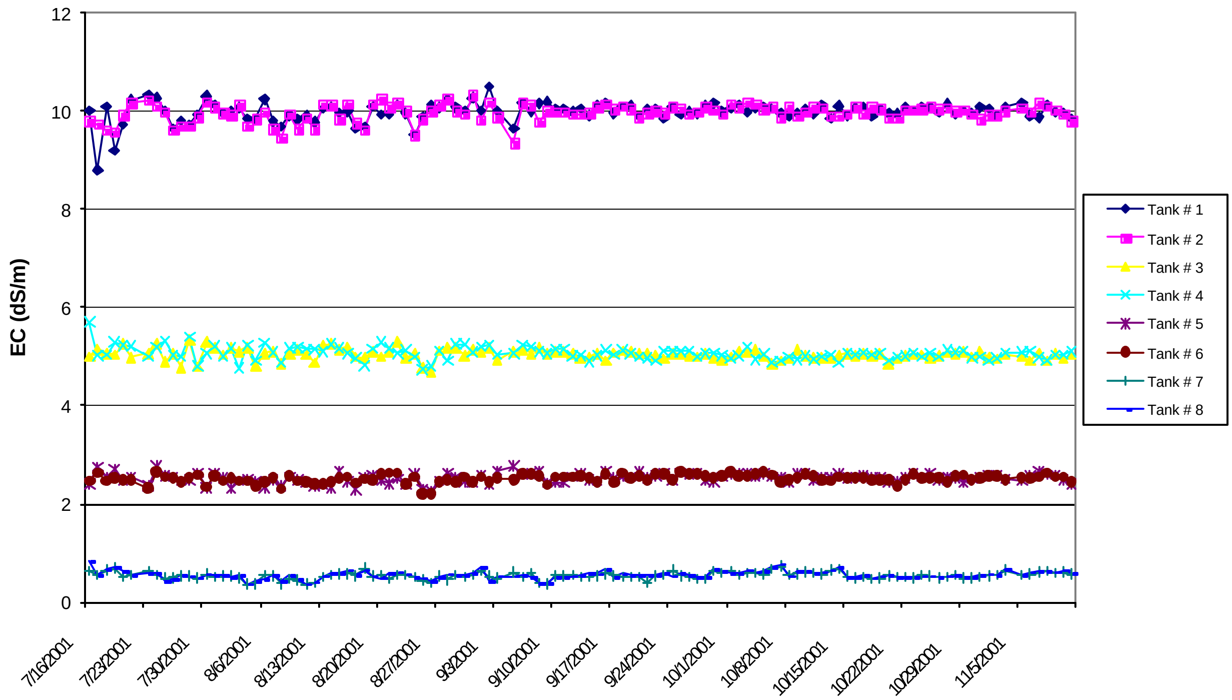
Table 2. Stem diameter of trees and height and canopy width of twelve species of ornamental plants grown for 16 weeks with irrigation water of different salinity.

Species	**EC dS/m**	**Stem Diameter (mm)**	**Height (cm)**	**Width (cm)**
Acacia stenophylla	0.6	12.5	158.6	-
	2.5	14.5	170.6	-
	5.0	11.5	140.1	-
	10.0	13.6	182.0	-
Significance (p-value)		0.71	0.46	
Cercidium floridum	0.6	15.5ab	103.5ab	-
	2.5	14.1b	81.1b	-
	5.0	19.0a	145.3a	-
	10.0	16.3ab	122.3ab	-
Significance		0.01	0.004	
Chilopsis linearis	0.6	19.0a	136.1ab	-
'Rio Salado'	2.5	18.5a	144.0a	-
	5.0	16.1ab	102.8bc	-
	10.0	11.5a	95.8c	-
Significance		0.001	0.0015	
Calliandra californica	0.6	-	41.6ab	-
	2.5	-	47.2a	-
	5.0	-	48.8a	-
	10.0	-	7.1b	-
Significance			0.03	
Leucophyllum frutescens	0.6	-	47.50	48.6
	2.5	-	45.00	50.1
	5.0	-	44.50	48.4
	10.0	-	38.17	36.2
Significance			0.58	0.19
Tecoma stans	0.6	-	76.1	78.4
	2.5	-	72.0	66.9
	5.0	-	54.5	68.6
	10.0	-	60.83	59.7
Significance			0.36	0.053

Table 2 continued

Species	EC dS/m	Height (cm)	Width (cm)
Dasyliron wheeleri	0.6	20.8a	9.7
	2.5	21.3a	10.0
	5.0	5.0b	3.6
	10.0	8.1ab	3.3
Significance		0.0007	0.01
Muhlenbergia rigens	0.6	112.3a	57.9b
	2.5	122.3a	68.7a
	5.0	96.1b	57.2bc
	10.0	60.8c	50.1c
Significance		0.0001	0.0001
Nolina microcarpa	0.6	57.5a	31.2
	2.5	56.3a	29.7
	5.0	46.8b	28.6
	10.0	40.6b	24.6
Significance		0.04	0.19
Lantana ‘New Gold’	0.6	34.1	90.7a
	2.5	23.8	77.1ab
	5.0	30.3	81.4ab
	10.0	32.2	66.1b
Significance		0.12	0.04
Verbena rigida	0.6	28.8a	56.0a
	2.5	29.6a	52.5a
	5.0	24.3a	40.3b
	10.0	13.6b	27.0c
Significance		0.0004	0.0001
Hymenoxis acaulis	0.6	14.0a	22.2a
	2.5	3.1b	4.8b
	5.0	3.1b	5.1b
	10.0	-	-
Significance		0.0001	0.0001

Figure 1. EC of irrigation solutions from June 16, 2001 to November 11, 2001. The even tank numbers contain runoff solution, the odd numbers contain solutions that were adjusted or feshly prepared.



Information Transfer Program

Introduction

The Water Resources Research Center at the University of Arizona engaged in three categories of activities, throughout the reporting period. First, the Center carried out general activities to educate the public about water issues in the state. These activities include, organizing conferences and workshops, writing reports, compiling directories, community presentations, and designing exhibits. Second, the Center has an ambitious and productive water education program for classroom teachers and educators, which reaches over 600 teachers annually and thousands of K-12 students, through Project WET. Third, the Center pursued regional water conservation efforts through the Water Conservation Alliance of Southern Arizona (Water CASA) which, since its inception in 1997, has been recognized as both a leader and innovator in the conservation field.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2001AZ1401B
Start Date:	3/1/2001
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Funding Source:	104B
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Descriptors:	WS,M&P,EDU
Principal Investigators:	Peter J. Wierenga, Joe Gelt, Val Little, Sharon Megdal, Kerry Schwartz, Terry Sprouse

Publication

1. Arizona Water Information Directory. WRRC April 2001. Combined 5th updates of Where to get Free (or almost free) Information About Water in Arizona (Issue Paper 9) and Where to Find Water Expertise at Wtate Universities in Arizona (Issue Paper 13)
2. Water Resources in Pima County. Sonoran Desert Conservation Plan Report. Pima County. 2001
3. Water Conservation in Pima County. Sonoran Desert Conservation Plan Report. Pima County. 2001
4. Environmental Justice in Pima County. Sonoran Desert Conservation Plan Report. Pima County. 2002
5. Invasive exotic species in the Sonoran region. University of Arizona Press. Tucson. 2002. WRRC staff edited and also authored two chapters in the book.
6. Currently researching and writing Environmental History of the Upper San Pedro River under contract to the U.S. Bureau of Reclamation and Cochise County in conjunction with the Arizona State Museum. Publication date Oct. 2002.

WATER RESOURCES RESEARCH CENTER

Public Outreach and Education

Community speakers

Water center staff continued its visibility with the community by providing 20 presentations to various organizations around the state, discussing water issues confronting communities and the state. Staff communicates with local newspapers, such as the "Arizona Daily Star" to provide information to reporters on water-related issues.

WRRC staff also gave six presentations on the historic navigability of Arizona rivers as part of a seven-state Moving Water Program, sponsored by the Council on Humanities. Presentations were at Tucson Public Library, Salome Public Library, Parker Public Library, Buckskin Mountain State Park, Western Arizona College, Yuma Public Library, and the Southern Arizona Engineering Society.

Water Conference

Water Conference Water Planning for the Future, the conference highlighted the efforts of the Governor's Water Management Commission to make suggestions to revise the Groundwater Management Code and get Arizona on the road to sustainable use of water. The conference was designed to help inform legislators, water professionals and citizens about water issues addressed by the Water Management Commission.

Binational Water Management Planning

Two WRRC staff participated in Border Institute IV: Binational Water Management Planning: Consideration of Opportunities, Costs, Benefits, and Unintended Consequences, Secure and Sustainable Water in the Border Region by 2020. The Southwest Center for Environmental Research and Policy (SCERP) sponsored the Institute. The WRRC also arranged for a field trip to allow institute participants to view water resources in Nogales, Sonora, Mexico.

Arizona Water Map Poster

Revisions were made to update the popular Water Map Poster that the Center first published in 1994. Copies of the map, which was very popular with schoolteachers, state and federal agencies, as well as the general public, have been distributed and is now out of print. The new Water Map Poster includes revised and updated text, map, graphics, and photographs. As the previous one, the new map presents complex subject matter in a format suitable

Revision of the WRRC's Desert Landscaping Compact Disk.

Desert Landscaping: Plants for a Water-Scarce Environment is a truly useful CD-ROM plant selector covering over 600 low water-use plants. Users can search by plant name, browse award-winning landscapes, compare groups of similar plants, or use the plant selector to precisely describe the plants you seek. The rich multimedia database includes plant size and growth rate, soil and sun requirements, irrigation needs, place of origin, allergens, wildlife interactions, and dozens of other useful factors. Additional information is provided through links to landscaping tips and a bibliography. The original CD-ROM was produced in 1996 and was very popular throughout Arizona. The revised version will operate more quickly and efficiently, have more and newer photos, and provide vastly more information on desert landscaping plants.

Nogales Revegetation Project

In November 2001 personnel from the Water Resources Research Center installed a demonstration water catchment system in Covarrubias Elementary School in Nogales, Sonora, the first of its kind known to exist in the city. WRRC personnel gave an overview of some theory and practice of water catchment. The catchment system was designed to be used to water new plants which were being used to revegetate areas of Nogales, Sonora to reduce the impacts of hillside runoff.

Pima Association of Government, Environmental Planning Committee

WRRC staff serves as a representative center on the Pima Association of Governments, Environmental Planning Advisory Committee (EPAC) and Water Quality Subcommittee. WRRC staff participated in the development of the EPAC strategic plan.

Field Manuel for Water Quality Sampling

WRRC staff are collaborating with the Arizona Department of Environmental Quality, the University of Sonora and the Technological Institute of Sonora to revise the bilingual Field Manual for Water Quality Sampling. The field manual will serve as a field reference guide for the collection of water quality samples from surface water and ground water. The objective of the manual is to provide consistent field sampling protocols for the numerous agencies and individuals who require water quality information.

Water Education Programs

The WRRC Education Program Coordinator is the state representative for the National Project WET (Water Education for Teachers) program. As such, the WRRC Education Program Coordinator is responsible for promoting an understanding of water and water-related issues statewide. Project WET activities provide an opportunity for people of all ages in all places to better understand the water resource issues facing their community and the world.

WRRC has an ambitious and productive water education program for classroom teachers and educators. WRRC coordinates a network of 30 trained facilitators that lead teacher training workshops for over 600 teachers per year and reach thousands of K – 12 students. This program reaches classroom teachers in public and private schools, youth groups leaders, tribal governments, environmental education centers (including gardens), community colleges and state universities.

The Education Program Coordinator for WRRC supervises a cooperative for the Phoenix metropolitan area, Environmental Educator whose job is to teach and promote the Project Learning Tree (PLT), natural resources-based program. Three student assistants also report to me as the Education Program Coordinator.

Project WET (Water Education for Teachers)

Teachers and educators trained this year in Project WET workshops numbered 632 with the capacity to reach a minimum of 18,000 students about water resources. Considerable effort has gone in to obtaining grant with ADWR to train 20 new facilitators who will then reach out to 2,250 teachers with the capacity to reach more than 50,000 students. The 6-day intensive Arizona water resources training will be held in July 2002. As a result of an interagency agreement grant, sixteen-hour teacher training workshops are conducted for City of Phoenix Schools including 24 School Districts. In addition, I have facilitated workshops through Cooperative Extension specialists, the Science Coordinators and/or the Staff Development Coordinators for many School Districts in Arizona, Arizona State Parks, and the Natural Resource Conservation District Education Centers.

Considerable coordination efforts were involved in the successful 2-day workshop held in cooperation with the NAU Institute for Tribal Environmental Professionals (ITEP) and the Cooperative Extension Office in Shiprock on the Navajo Reservation. Water Education training workshops have been coordinated for the Arizona Sonora Desert Museum and Tohono Chul Park docents incorporating hands-on groundwater flow model training with in-depth discussion of local water issues.

National Water Education Day – Water Festival

The Project WET coordinator, is responsible for planning, organizing and implementing an annual Water Festival for National Water Education Day. The Arizona water festival is one of the simultaneous water festivals being held in all 50 states. In this and other efforts, the coordinator has a responsibility to stay connected to the education community as well as the water community.

The Water Festival celebrating National Water Education Day, held in September 2001, benefited from the sponsorship of the U.S. Bureau of Reclamation, Arizona Department of Water Resources, Salt River Project, Central Arizona Project, Intel, Keller Equipment, Empire Southwest, Brown and Caldwell, Carollo Engineers, and Mesa School District

Elementary Schools. An extraordinary, interactive educational opportunity was offered to 1000 4th grade students and their teachers in Arizona and 38,924 nationwide.

Tucson Interactive Water Education Exhibit

The Tucson Interactive Water Education Exhibit was created to offer schools state of the art information on water in the Tucson AMA. The exhibit was set up at elementary schools so that librarians and teachers could lead students through the exhibit over the course of a week or two. The color-coded sections of the Tucson Interactive Water Education Exhibit included:

I. Water in the Desert
II. Water Cycle
III. Sources of Water
IV. Water Uses
V. Water for the Future
VI. Water History

In 2000, the Tucson Interactive Water Education Exhibit was hosted in four different school districts and been toured by more than 5,472 students. The response from teachers and librarians was so overwhelmingly positive that the Tucson AMA funded a new grant cycle for 2002. During the summer months, the Interactive Water Education Exhibit will be set up at the Arizona Sonora Desert Museum.

Groundwater Flow Model Demonstrations

As a resource for teachers seeking water resources education information, the Project WET coordinator trains teachers to use water oriented teaching tools. The groundwater flow models are an incredibly good tool for teaching about groundwater and aquifers. Groundwater flow model demonstrations are conducted with visiting scientists, government employees, and at all educator workshops. Groundwater presentations conducted with WRRC flow models reached 1,810 students and 507 adults this year. Groundwater flow models are maintained by WRRC staff for use by teachers and for use at training workshops.

Arizona-specific Educator Resources distributed by the WRRC include:

$ **National Project WET K-12 Curriculum & Activity Guide**
  - *6-hour Educator Training Required*

$ **Conserve Water Educators Guide**
  - *Educator Training available*

$ **WOW the Wonder of Wetlands Educators Guide**
  - *Educator Training available*

$ **Arizona WET K-8 Guide with Student Activities**
  - *Educator Training available*

$ **Arizona WET K-6 Nonpoint Source Water Pollution Curriculum**
  - *Educator Training available*

- $ **Arizona WET Grade 9-12 Curriculum On Nonpoint Source Water Pollution**
    - *Educator Training available*
- $ **Groundwater Flow Models**
    - *Educator Training and*
    - *Available on a loan basis*
- $ **EnviroScape Water Pollution Awareness Model**
    - *Educator Training and*
    - *Available on a loan basis*
- $ ***Liquid Treasure* Water History Trunks**
    - *Available on a loan basis*

- $ In addition, the WRRC Education Program Coordinator organized and coordinated a statewide ***Water Resources Education Assessment*** effort for University of Arizona, Cooperative Extension.

WATER CASA

Formed in 1997, the Water Conservation Alliance of Southern Arizona (Water CASA) provides a means for member water providers to augment their individual conservation programs and to improve the region's overall water conservation efforts. Water CASA's membership includes Avra Water Co-op, Community Water Company of Green Valley, Flowing Wells Irrigation District, Town of Marana Water Department, Metro Water District, Oro Valley Water Utility, Pima County Wastewater Management, and the U.S. Bureau of Reclamation.

This alliance has rapidly become an organization effectively using economies of scale and providing a strong, unified voice on water conservation issues regionally. Summaries of Water CASA's services, activities, and accomplishments over the past four years follow. More detailed information is available on the Water CASA website: www.watercasa.org .

Water on the Web

Water CASA is currently piloting a program that enables its members' customers to access individual water consumption and conservation information via the web. The goal of Water on the Web is to provide water customers a convenient way to review their monthly water consumption in a format that most importantly enables them to compare their usage with that of their neighbors and the community. Water CASA believes that this pilot program creatively and effectively promotes water conservation by allowing customers to make comparisons through seasons, from year to year, and to similar households.

The analytical comparison of consumption will promote customer water awareness resulting in additional, voluntary conservation. Customers also receive water savings tips and a pat on the back, depending on their water usage. Water on the Web is a valuable service to Water CASA members that lack the ability to provide this information as part of their water bills. This pilot program, funded by the U.S. Bureau of Reclamation, will operate for a year. Following an effective evaluation, the program will be available to all Water CASA members for their customers.

Conservation Devices

Bulk orders of conservation devices are made for, and divided among, the members of Water CASA. This is a good example of Water CASA's effectiveness in the use of economy of scale. Water CASA is able to purchase conservation devices at the lowest possible price by bulk ordering. In addition, the US Bureau of Reclamation supports this program with $10,000 toward the purchase of the showerheads and faucet aerators. These conservation devices are included in Welcome Packets for new customers moving into older homes and are also available to water customers on request. Field staff who respond to customer questions or complaints also hand out devices, which has proved to be an effective customer service.

Dual Metering Study

Exterior residential water use as a percent of overall use has never been accurately measured in the Tucson area, and the modeled estimates of exterior water use have proven increasingly inaccurate through time. Additionally, annual landscape water use has not been studied relative to the needs of landscape plants during the establishment, maturation, and climax stages. Water providers, regulators, and planners have repeatedly expressed the need for a study that accurately tracks indoor and outdoor water usage beginning with new construction and continuing for many years. In response to these data needs, Water CASA has embarked on a long-term project to install second meters in two large samples of single family residences to measure indoor and outdoor water use in a variety of subdivisions: starter homes, mid-range homes, and high end.

The Dual Metering Study began when Water CASA, the Genesee Company, and Flowing Wells Irrigation District partnered to install second meters for outdoor water use in 38 units of the Sagewood development. Funded by the U.S. Bureau of Reclamation, this study will provide data on actual water use pattern variations for both indoor and outdoor water use through seasons and over years as landscapes mature. The water use patterns in each of the three subdivisions will be compared among a variety of socio-economic levels. The results will be used to develop the most effective and efficient water conservation program for Water CASA members, and inform decisions makers for public policy and community design.

Graywater B Water Harvesting Workshops

The Arizona State Land Department awarded Water CASA one of sixteen Urban and Community Forestry Grants. With the $4,530 grant funds, Water CASA developed and organized a series of workshops demonstrating the how and why of water harvesting and graywater reuse for residential landscape irrigation with an emphasis on urban trees. The workshops were held throughout the Tucson area in the service areas of Water CASA members.

Collaboration with Jordan

The Center for the Study of the Built Environment invited Water CASA to travel to Amman, Jordan to participate on a team of water experts to provide water conservation and appropriate plant material information to their counterparts there in Amman, Jordan. The Association for Educational Development, the U.S. Embassy, and the Center for the Study of the Built Environment sponsored the trip. Water CASA shared the results of its Residential Graywater Reuse Study. A portion of the trip included an extensive tour of Jordan's centuries old water harvesting structures and techniques.
This unprecedented trip established a relationship with the Center and successfully resulted in an exchange of ideas and information beneficial to both groups. The Center has again invited Water CASA to visit in January 2002 to continue the exchange of information and explore opportunities for collaboration on a demonstration water conservation garden.

News Articles & Press Releases

Water CASA staff draft press releases and news articles on its activities and water conservation topics for use by the regional media throughout the year. These items are either used as is by local newspapers, adapted as features by the print media, or are used in Water CASA member newsletters to customers.

Ordinances

At the request of Pima County, Water CASA drafted and submitted to the County, ten potential water conservation ordinances. Those ordinances are awaiting adoption within the County's Sonoran Desert Conservation Plan. Pima County's adoption of our suggested water ordinances will
strengthen conservation efforts not only in Water CASA members service areas but will benefit the entire County as well.

Safe Yield Dialogue

Water CASA has consistently promoted development of a dialogue within the region and throughout the State to look at overall effective water management. Water CASA Manager, Val Little, continues to serve as co-chair of the Conservation subcommittee and is a member of the TAMA Safe Yield Task Force. Water CASA Board Member, Alan

Forrest, serves on the statewide Technical Advisory Committee for the Water Management Commission.

Conservation Information Sharing Meeting

Water CASA hosted the September 2001 Conservation Information Sharing Meeting, which brought together more than 30 representatives of water providers and water conservation programs to exchange information on programs, activities, and policy. Water CASA members attended the meeting and participated in sharing information on Water CASA=s programs and activities. Water CASA also arranged for tours of recharge facilities as a morning activity.

Hot Topics Cool Solutions Conference

In the Fall of 2001, Water CASA participated on the Graywater B Rainwater Harvesting panel of the Hot Topics Cool Solutions Conference. This Conference address sustainability issues for communities and focuses on solutions to these issues. Val Little of Water CASA presented the exchange of information between Water CASA and Jordan and the results of the Residential Graywater Reuse Study. With standing room only, this panel was one of the most popular of the Conference.

Tohono Chul Landscape Awards

In August 2001, Water CASA sponsored the Tohono Chul Landscape Award for a Water Efficient Garden. The Award recognized and promoted efficient water use in residential, commercial, institutional landscapes in several categories.

THE ARIZONA WATER RESOURCE NEWSLETTER

The Arizona Water Resource Newsletter is a 12-page newsletter presenting general news, events and issues analysis for the Arizona water community. Sections include: Water Vapors, News Briefs. AZ Water Community News, Guest View, Legislation and Law, Publications, Special Projects, Announcements and Outside Readings. Below are the feature articles for the past year.

March-April 2001 Issue.

FEATURE ARTICLES

“New Arizona Power Plants Pose Water Questions, Raise Issues”

“Urban Ecology, Nature in an Urban Setting”

May-June 2001 Issue

FEATURE ARTICLE

"Settling Water Rights is Peer Review Process in Santa Cruz AMA"

July-August Issue

FEATURE ARTICLES

"Do Waterborne Pathogens Pose Risks to Wastewater Workers"

"Earliest North American Canals Found in Tucson"

September-October Issue

FEATURE ARTICLE

"Governor's Water Management Commission Ponders Replenishment"

January-February 2002 Issue

FEATURE ARTICLES

"Is That My Groundwater or Your Surface Water"

"Managing water Outside AMAs Gains Interest, Some Support"

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3	5	0	0	0
Masters	0	3	0	0	0
Ph.D.	0	1	0	0	0
Post-Doc.	0	1	0	0	0
Total	3	10	0	0	0

Notable Awards and Achievements

Dr. Bonnie Colby was the only faculty member from University of Arizona appointed to serve as technical advisor to Arizonas Water Commission, and one of only two academics in the state appointed to serve in the two year Commission process.

Dr. Bonnie Colby (the PI) and the books co-author, John Thorson, have each given a number of invited presentations on the subject matter of the book over the grant period. Examples for Colby include:

Keynote Speaker, University of Colorado Natural Resources Law Center Conference Two Decades of Water Law and Policy Reform; A Retrospective and Agenda for the Future, Boulder Colorado

Invited Speaker, Governors Water Management Commission, 2001

Invited Speaker, University of Nebraska, annual Williams Endowment Lecture on Water Resources, 2001

Invited Speaker, NSF Science and Technology Center conference on Sustainability of Semi-Arid Hydrology and Riparian Areas, Economic Aspects of Tribal Water Negotiations, 2001.

Invited Panelist, Arizona Dept, of Water Resources/ Department of Agricultural Economics Workshop on Water Research and Economic Policy Issues, 2001

Publications from Prior Projects

None