The Residential Runoff Reduction Study

Municipal Water District of Orange County

Irvine Ranch Water District

July 2004

Study Participants

A & N Technical Services

CalFed Bay-Delta Progam

California Department of Pesticide Regulation

California Environmental Protection Agency

California Regional Water Quality Control Board

HydroPoint Data Systems, Inc.

Irvine Ranch Water District

Metropolitan Water District of Southern California

Montgomery Watson Labs

Municipal Water District of Orange County

National Water Research Institute

County of Orange

Southern California Coastal Water Research Project

State Water Resources Control Board

United States Department of the Interior Bureau of Reclamation

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Study Background and Rationale

In 2001, the Irvine Ranch Water District (IRWD), the Municipal Water District of Orange County (MWDOC), and the Metropolitan Water District of Southern California (MWD) completed a small-scale study of weather-based evapotranspiration (ET) irrigation controllers. This study, known as the "Westpark Study," tested the effectiveness of ET controller technology in residential applications. After 40 such controllers were installed in the Westpark neighborhood of Irvine, California, water demand and runoff in the study area were measured. The resulting average water savings for this study were 37 gallons per day, or 7 percent of total household water use and 18 percent of irrigation water use.

Based upon the findings of the Westpark Study, IRWD and MWDOC partnered on new research, the Residential Runoff Reduction (R3) Study, in which the number of sites studied was increased, a baseline area where no changes were made was included, and an "education only" area where printed educational materials were distributed was also included. This made the R3 Study one of the first studies to attempt to quantify the effectiveness of public education alone versus a technology-based plus education approach to reducing residential irrigation water usage. Figure ES-1 presents the study participants and their respective roles within the R3 Study.

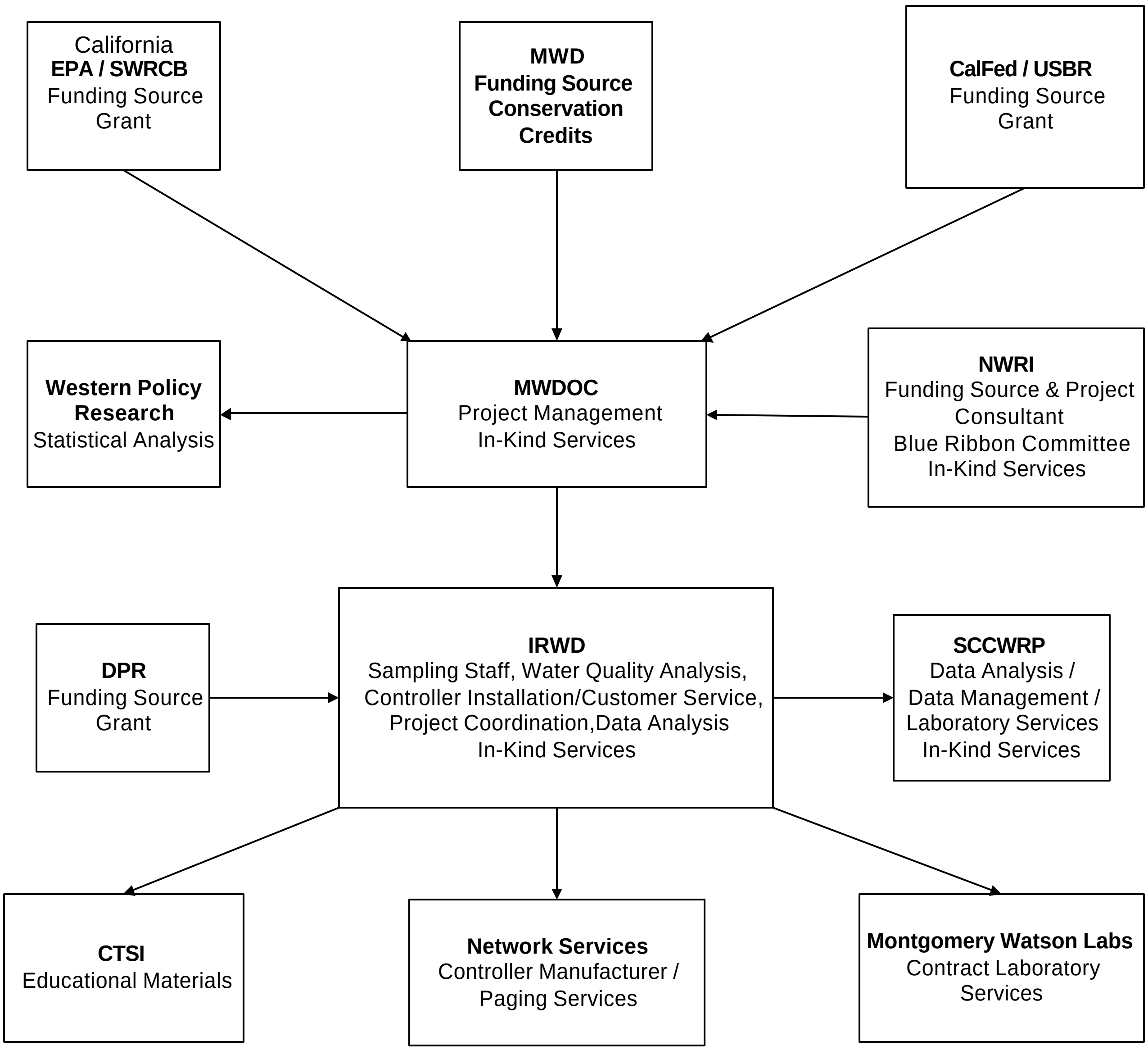
The R3 Study had four primary purposes:

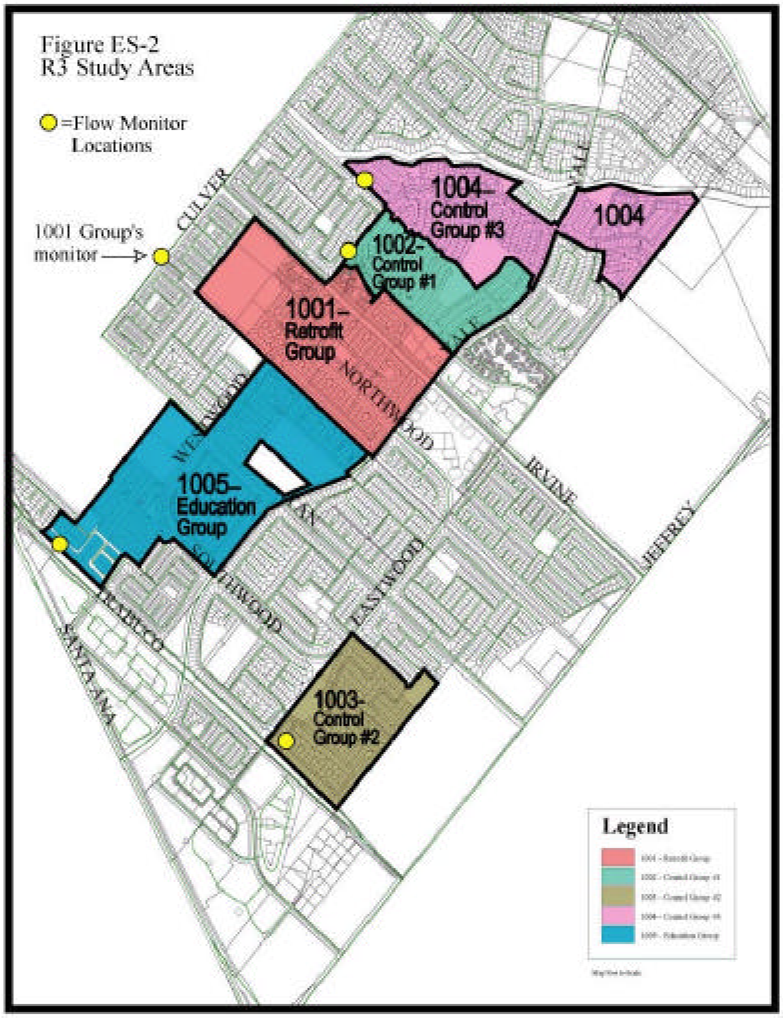
1) To test the use of weather-based irrigation technology, also known as ET controllers, to manage irrigation water for residential homes and large landscape areas;
2) To evaluate the effectiveness of a targeted education program on residential homeowners;
3) To determine the correlation between proper water application in landscape irrigation and the quantity and quality of urban dry-season runoff; and
4) To gauge the acceptance of water management via the controller technology.

Study Methodology

The R3 Study area included five similar neighborhoods (Sites 1001 through 1005) in Irvine, California, each with its own single point of discharge into the urban storm drain system. The five sites are shown on Figure ES-2. At these points of discharge from each study area, the runoff volume was monitored and water quality samples were taken. The five sites were divided into three separate areas. The first area, Site 1001 (retrofit group), used ET controller technology and public education. The second area, Site 1005 (education group), received educational materials, but did not receive controllers. The third area (control group) consisted of three separate neighborhoods (Sites 1002, 1003, and 1004), which received neither ET controllers nor educational materials.

Figure ES -1
R3 Study Participants





Evaluation Results

After the initial 18-month study period was completed, the data was compiled and evaluated for water conservation savings, dry season runoff changes, and changes in the quality of the dry season runoff water. The following summarizes the results:

a) Water Conservation Savings

Water conservation savings from the typical participant in the retrofit group were 41 gpd, or approximately 10 percent of total household water use. The bulk of the savings occurred in the summer and fall (Figure ES-3. Residential Water Savings: Technology + Education). The education group residential customers saved 26 gpd, or about 6 percent of total water use. The savings from this group were more uniform throughout the year (Figure ES-4, Residential Water Savings, Education Only). The retrofit group also included 15 dedicated landscape accounts (ranging in size from 0.14 acres to 1.92 acres), which showed average water savings of 545 gpd. The net result was eight times more water savings than with the single-family residential controller, strongly indicating that the larger the landscape, the better the savings per controller.

Figure ES -3
Residential Water Savings: Technology + Education

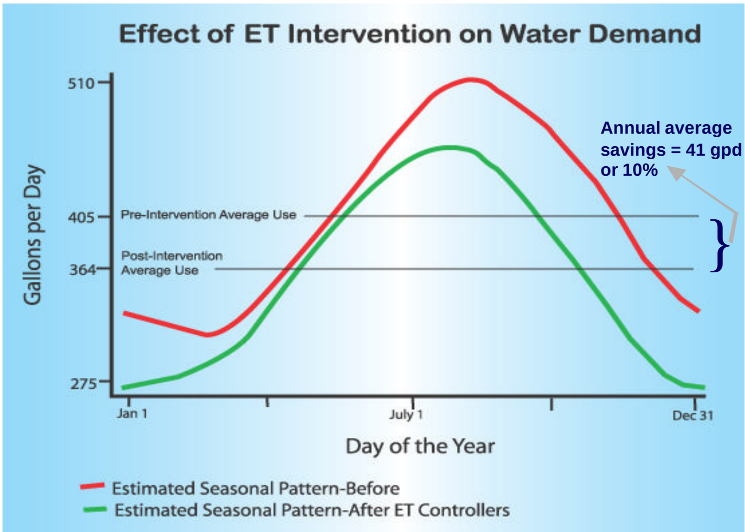


Figure ES-4
Residential Water Savings: Education Only

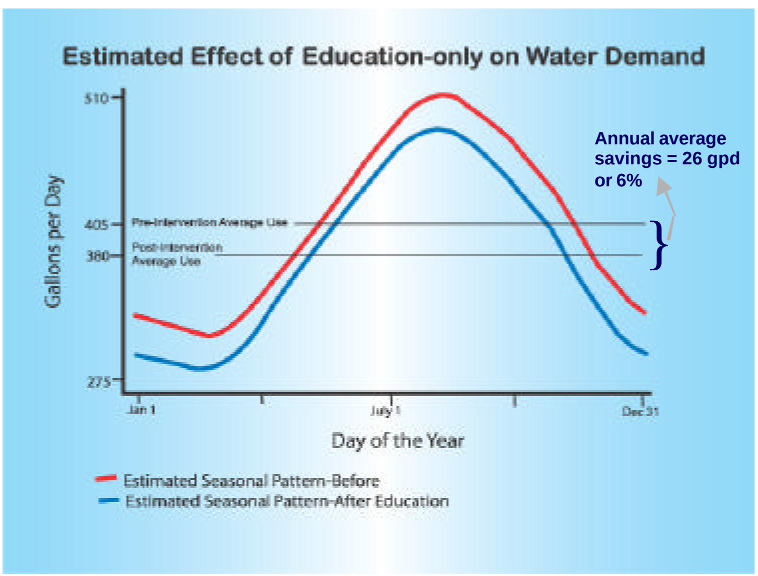


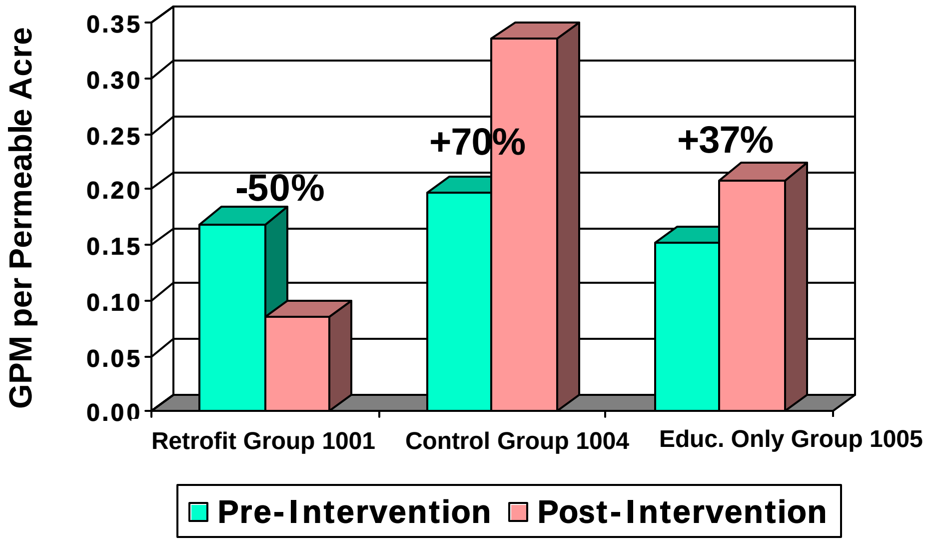
Figure ES -5
Changes in Runoff Within Each Site

b) Dry Season Runoff Changes

The retrofit group experienced a 50 percent direct reduction in water runoff (pre-intervention runoff compared to post-intervention runoff) during dry season periods. When the retrofit group is compared to the control group, the dry season runoff shows a statistical reduction of approximately 71 percent. In contrast, a comparison of direct pre-intervention and post-intervention runoff from the education group increased 37 percent, while runoff increased 70 percent within the control group. Other than the presence of an

ET controller, the primary difference between these groups is the participation of the 15 landscape accounts in the retrofit group. These accounts irrigated approximately 12 acres of landscape versus between 4 to 5 acres of total irrigated area for the 112 residential homes. Figure ES-5 presents R3 Study changes in runoff within sites.

Figure ES -5
Changes is Runoff Within Each Site



Note: It is also possible to compare post-intervention runoff *between* the study sites. These comparisons suggest a higher reduction in runoff for Site 1001 (between 64 and 71 percent) than was observed for the "within site" pre and post comparison, and a reduction in runoff of 21 percent for Site 1005. However, as described more fully in the text, these comparisons are less reliable than the "within site" pre and post comparisons shown here.

c) Changes in Runoff Water Quality

The study gathered a great deal of information on the water quality constituents present in urban runoff. In almost all cases, the data showed no changes in the concentration of these constituents in the runoff. The most significant fact to come out of the urban runoff water quality data is that the decrease in runoff volume from the retrofit group did not appear to result in an increase in the concentration of pollutants in the runoff. Thus, it is probable that a reduction in total pollutant migration could be achieved by reducing total dry season urban runoff.

d) Public Acceptance of Water Management

While there were some customer service-related issues, the retrofit group had a generally positive response to the ET controller, with 72 percent of participants indicating that they liked the controllers. The retrofit group also found that the controller irrigation either maintained or improved the appearance of the landscape. This has very positive implications. The water district customers receive a desired benefit of a healthy landscape, and the community receives several important environmental benefits from

the conservation of valuable and limited water resources and the reduction in dry season urban runoff.

Findings, Conclusions, and Recommendations

The R3 Study showed that weather-based irrigation controllers, which provide proper landscape water management, resulted in water savings of 41 gpd in typical residential settings and 545 gpd for larger dedicated landscape irrigation accounts. The observed reduction in runoff from the retrofit test area was 50 percent when comparing pre-intervention and post-intervention periods and 71 percent in comparison to the control group. The education group saw reductions in water use of 28 gpd, and a reduction in runoff of 21 percent in comparison to the control group. Water quality parameters in both study areas were highly variable, and very few differences in the level of monitored constituents were detected. In terms of water savings per controller (and cost-effectiveness), the study clearly indicated that larger landscape areas (parks and street medians) should provide the initial targets for the expansion of similar programs.

Chapter 1: Introduction

1.1 Overview

Weather-based evapotranspiration (ET) irrigation control has long been a tool of large agricultural operations, maximizing crop yields through pinpoint management of crop watering. The Residential Runoff Reduction (R3) Study was conducted to evaluate the applicability of ET technology for other uses. This chapter of the study report presents the following:

- Background information on study rationale;
- Specific study goals and objectives;
- Identification of study partners and their roles/contributions to the study.

The organization of this report is also described, and commonly-used abbreviations and acronyms are listed. References used during the study are presented in Appendix A.

1.2 Background

Approximately 58 percent of residential water demand is used for outdoor purposes, primarily for home landscape irrigation (AWWARF Residential End Uses of Water, 1999). Excess irrigation results in inefficient use of valuable water supplies and increased runoff that is the transport mechanism of pollutants that enter natural waterways and, ultimately, the Pacific Ocean for areas along the west coast.

Landscape water use efficiency/water conservation and watershed management in the urban sector are linked. Water agencies throughout the state are implementing 14 Best Management Practices (BMPs) to increase the efficient use of urban water supplies including landscape irrigation efficiency. Cities and counties are also implementing National Pollutant Discharge Elimination System (NPDES) permit requirements containing BMPs for watershed management focused on runoff reduction.

Recent studies in Orange County have had promising results. In 1998-1999, Irvine Ranch Water District (IRWD), Municipal Water District of Orange County (MWDOC), and the Metropolitan Water District of Southern California (MWD) conducted a study that evaluated the use of weather-based ET irrigation control technology at 40 residential homes in the Westpark area of Irvine. The report from this research, entitled "Residential Weather-Based Irrigation Scheduling: Evidence from the Irvine 'ET Controller' Study," showed water savings that translated to 37 gallons per day (gpd), or 7 percent of total household water use/16 percent of irrigation water use.

In April 2001, water savings from the ET Controller study in Westpark were evaluated through September 2000, or the second post-retrofit year. This evaluation confirmed the persistence of water savings observed during the initial evaluation. More specifically, this evaluation concluded that ET Controllers were able to reduce total household water consumption by roughly 41 gallons per household per day, representing an 8 percent reduction in total household use, or an 18 percent reduction in estimated landscape water use.

The R3 Study represents the next phase of research associated with the new irrigation control technology linking benefits to watershed management.

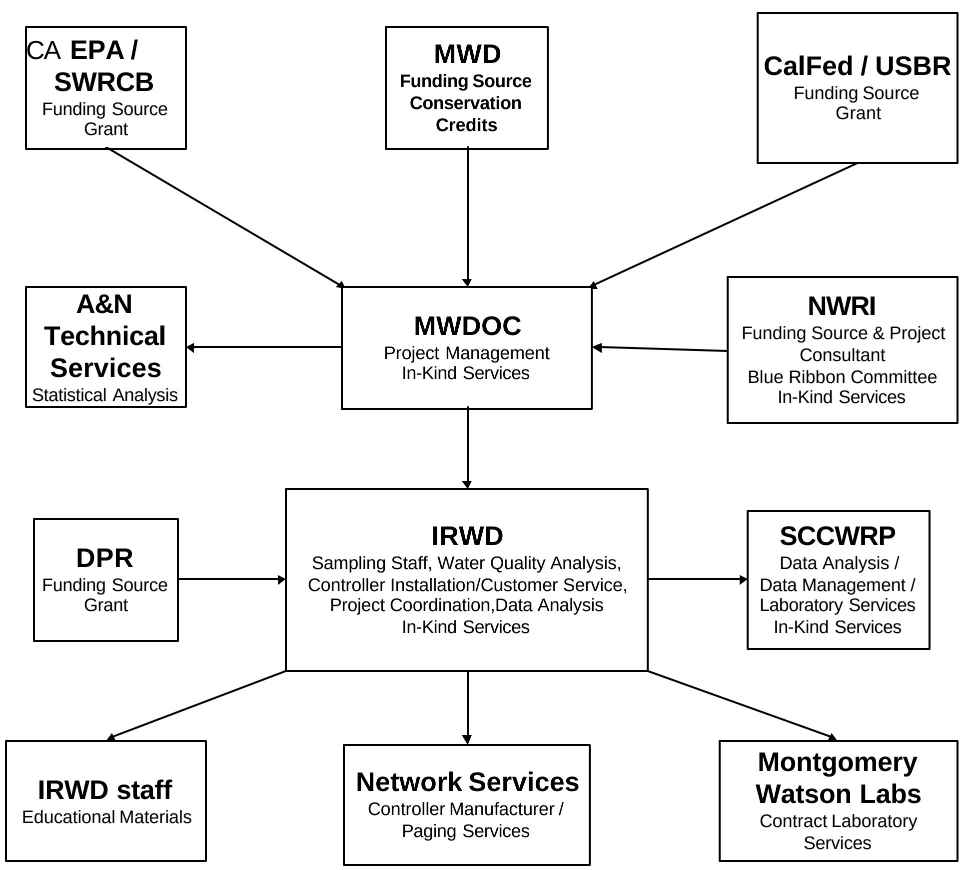
1.3 Study Goal and Objectives

The goal of the R3 Study was to quantify ET Controller savings for single-family residences and large landscape users. The study had four primary purposes: 1) to develop and expand the application and use of pager-signal (electronic controller) technology to manage irrigation water for residential homes and large landscape areas; 2) to evaluate the effectiveness of a targeted education program; 3) to determine the connection between proper water use in the landscape and the quantity and quality of dry weather runoff; and 4) to gauge the acceptance of water management via the controller technology.

1.4 Study Partners

The R3 Study was made possible through a partnership of agencies and organizations committed to improved water use efficiency and watershed management. The members of the partnership are shown on Figure 1-1. The figure also indicates the roles played by each study partner.

Figure 1-1
R3 Study Partners



As shown on Figure 1-1, the R3 Study involved a diverse mix of study participants and funding agencies bringing equally diverse interests and visions to the project. In general, the study was based on the premise that runoff from poor irrigation practices from urban areas in the San Diego Creek watershed constitutes non-point source pollution and contributes to water quality problems both in the Creek and in Newport Bay, the receiving water for the Creek. Although water quality problems in the Creek and Bay have been well documented, data on the specific sources of these pollutants is limited.

The R3 Study was intended to focus on and analyze both the quality and quantity of runoff from relatively small sub-areas of the watershed to provide insight into the sources of pollution in the Creek and Bay. In addition to providing this baseline information, the study was intended to evaluate the effectiveness of two methods of reducing runoff and improving water quality: 1) education; and 2) education combined with ET controller technology. Furthermore, since irrigation runoff is 100 percent water waste, the water agency participants were very interested in the ability of the study intervention methods to reduce customer water usage.

The R3 Study presented a good opportunity to develop valuable information about the relative effectiveness of structural (retrofit) versus non-structural (public education) controls. A technology + education (retrofit group) BMP was applied in one neighborhood, an education-only BMP was applied in a second neighborhood, and a control was established through three additional neighborhoods.

A more detailed discussion of the study participants is provided below. For purposes of simplicity, the organizations are categorized as agencies responsible for water quality, agencies responsible for water supply, and "supporting participants." However, in many cases, these objectives are overlapping and are not mutually exclusive.

1.4.1 Agencies Responsible for Water Quality

Study participants whose major area of responsibility is water quality include the California Environmental Protection Agency (CAEPA), the State Water Resources Control Board (SWRCB), the Regional Water Quality Control Board (RWQCB), the California Department of Pesticide Regulation (DPR), the County of Orange, and the Southern California Coastal Water Research Project (SCCWRP). These agencies are charged with regulating, enforcing, implementing, or researching and monitoring federal and state laws pertaining to water quality and the control of constituents which may degrade water quality. For example, the RWQCB is responsible for establishing limits on the amount of pollutants that can be discharged to Newport Bay. These limits are defined as "Total Maximum Daily Load" (TMDL). The County of Orange, which provided indirect funding to the study through DPR, is the primary permittee on the Municipal Separate Storm Sewer System (MS4) Permit issued by the RWQCB. The County's primary interest in the study relates to their efforts to implement a comprehensive program of BMPs to meet the TMDLs as required by the MS4 permit. In addition to providing improved baseline water quality and runoff information, these agencies focus on gauging the

effectiveness of the two study intervention methods in reducing the quantity of runoff and improving the quality of the water that does run off.

l.4.2 Water Agencies

IRWD and MWDOC are water districts whose primary mission is to provide safe and reliable water service to customers within their respective service areas. The reliability of water service, in particular, is directly related to the efficiency of water use. In other words, since supplies of reasonably priced water are essentially fixed, increases in efficiency can result in additional supplies being available for storage until they are needed during periods of supply shortages.

Both IRWD and MWDOC, as well as MWDOC's "parent" agency, MWD, operate various water efficiency/conservation programs within their service areas. Some progress has been made on increasing water use efficiency from programs targeting outside use for landscape irrigation (which generally accounts for about 50 percent of total urban water use). However, water use in this sector remains closely linked to the ability and responsiveness of landscape personnel with responsibility for controlling and adjusting irrigation control timers.

Two basic issues are associated with this "people to water use efficiency" link. First, there is a wide variation in the abilities of personnel to properly set baseline irrigation schedules based on site factors (type of plant material, soil, exposure, slope, irrigation equipment, etc.). Second, for various reasons, it is believed that very few of these timers are adjusted on a sufficient frequency to promote optimum water use efficiency. Consequently, the water agencies are very interested in technologies such as the irrigation controller tested as a part of the R3 study. This technology allows irrigation schedules to be automatically adjusted based on real-time weather conditions. Equally important, the technology provides the ability to set appropriate base irrigation schedules by site conditions, particularly the soil type (infiltration capacity) and slope. This capability is critical to reducing runoff.

In addition to the potential effectiveness of the water management/irrigation controller program, IRWD and MWDOC were also very interested in determining if the focused educational and communication efforts tested in the study could yield customer water savings. This is particularly important since these efforts can be a very cost-effective way to achieve water savings.

In addition to water conservation, water agencies are becoming increasingly aware of their role as providers of water which, if not used efficiently, may ultimately become a nuisance or source/carrier of non-point source pollution. Consistent with its vision to optimize the use of resources as demonstrated by its globally-recognized recycled water reuse program, IRWD in particular has taken a leadership role in addressing irrigation runoff/non-point source pollution within its service area, which covers a majority of the San Diego Creek watershed. In addition to the current study focusing on potential source control measures, IRWD has prepared a master plan outlining a system of constructed wetlands which will capture and treat runoff and improve water quality in the watershed and Newport Bay.

1.4.3 Supporting Participants

The remaining study participants provided vital support for various aspects of the study. Network Services Corporation (now HydroPoint Data Systems, Inc.) manufactured the ET controllers used in the study and was responsible for compiling weather data and transmitting this information to the controllers. The National Water Research Institute (NWRI) provided input on the study design and evaluation, and A&N Technical Services prepared the detailed analysis of water savings and runoff reduction under a contract. Similarly, a portion of the water quality analysis was conducted under a contract by Montgomery Watson.

1.5 Report Organization

The R3 Study report is organized into two main parts: a body, consisting of seven chapters, followed by eight Appendices containing references and the analyses prepared by the study partners and presented in their entirety.

The first two sections of this report (Chapters 1 and 2) present general information about study goals and methodology. Chapter 1 presents study rationale, goals and objectives, and participating organizations. Chapter 2 describes how the study area was developed and presents the methodology used to develop information on the four main study areas: water conservation savings, dry season runoff/reduction savings, water quality impacts, and customer acceptance/public education.

Chapters 3 through 6 present the evaluations for the four main study areas, respectively, water conservation, dry season runoff, water quality, and customer acceptance. Each chapter provides an overview, summarizes the evaluation approach, presents results, and summarizes major conclusions. More detailed information on the evaluations is presented in the Appendices.

The final section of this report (Chapters 7) integrates study results and describes relevance for future planning and policy. Key findings, conclusions, and recommendations are presented.

The Appendices to this report contain eight sections. Appendix A, References, lists reports, articles, and other documents utilized during the R3 Study. Appendix B, Study Design, provides support information for Chapter 2, Study Methodology, and provides details on the techniques and methods used for data collection, sampling, and analysis. Appendix C, Water Conservation, presents the detailed water conservation evaluation conducted by A&N Technical Services, Inc., and includes detailed information on data models developed for the analysis. Appendix D1, Statistical Analysis of Urban Runoff Reduction, and Appendix D2, 2003 Runoff Data, present the detailed statistical analysis of runoff reduction. These analyses were also prepared by A&N Technical Services, Inc., and include detailed information on the data collection and analysis approach. Appendix E1 and E2 present Water Quality information. E1 was prepared by SCCWRP, and E2 was prepared by GeoSyntec Consultants. Finally, Appendix F, Public Education, presents information on customer acceptance and public involvement.

1.6 Abbreviations and Acronyms

The following abbreviations and acronyms are used in this report:

ADP	antecedent dry period
ANOVA	analysis of variance between groups
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
BACI	before-after control impact
BMPs	Best Management Practices
CAEPA	California Environmental Protection Agency
Calfed	consortium of state and federal agencies who address California and San Francisco Bay-Delta water issues
cfs	cubic feet per second
CIMIS	California Irrigation Management Information System
CTR	California Toxic Rule
DPR	California Department of Pesticide Regulation
ET	evapotranspiration
fps	feet per second
GIS	geographic information system
gpd	gallons per day
HOA	homeowners association
IRWD	Irvine Ranch Water District
K-W	Kruskal-Wallis
mgd	million gallons per day
mg/acre/day	milligrams per acre per day
mg/L	milligrams per liter
mL	milliliters
MPN	most probable number
MS4	Multiple Separate Storm Sewer System
MWD	Metropolitan Water District of Southern California
MWDOC	Municipal Water District of Orange County
NPDES	National Pollutant Discharge Elimination System
NWRI	National Water Research Institute
OCPFRD	Orange County Public Facilities and Resources Department
OP	organophosphorus
ng/L	nanograms per liter
PCF	pressure control facility
R3	Residential Runoff Reduction Study
RWQCB	Regional Water Quality Control Board
SCCWRP	Southern California Coastal Water Research Project
SWRCB	State Water Resources Control Board
TIN	total inorganic nitrogen
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TN	total nitrogen

TP	total phosphorous
ug/L	micrograms per liter
USBR	United States Bureau of Reclamation
USEPA	Untied States Environmental Protection Agency

Chapter 2: Study Methodology

2.1 Overview

Historically, water agencies have utilized educational programs and in some cases allocation-based rate structures to achieve improved irrigation efficiency in urban landscapes. With the introduction of "smart" weather-based irrigation controller technology, which in early studies generated quantifiable and reliable irrigation water savings over time, water agencies may now have a new and effective management tool to introduce to residential and other customers. The R3 Study compared, in a controlled setting, water savings and watershed management benefits of a remote, weather-based "ET" automated irrigation controller technology. This chapter of the report presents information on the methodology used in the following areas:

- Study design, including study area development, flow monitoring and water quality sampling procedures, and determination of a viable ET irrigation controller operation and selection process.
- Evaluation of water conservation savings.
- Quantification of dry season runoff reduction savings.
- Assessment of water quality impacts.
- Approach to public acceptance/public education.

More information on study design is presented in Appendix B. Evaluation-specific information on study design, data collection/analysis, and results is presented in Chapters 3 through 6 for water conservation, dry season runoff reduction, water quality, and public education, respectively. Additional details are provided in Appendices C through F.

2.2 Study Design

Study design included developing a viable study area, which provided for accurate data collection and comparison. Identifying appropriate flow monitoring equipment and determining an effective ET irrigation controller operation and selection were also important.

The goal of this study is to compare the effectiveness of technological BMPs versus public education for reducing the volume, concentrations, and mass emissions of potential pollutants in dry weather runoff from irrigated landscapes. The technological BMP consisted of ET controllers that communicate with irrigation systems of individual households and selected large landscapes, such as street medians, parks, etc. This technology is designed to optimize watering times for landscaped areas, hence reducing over-watering and resultant runoff. (See Section 2.2.3.) The public education campaign focused both on appropriate watering times and on the correct application of pesticides, herbicides, and fertilizers. (See Section 2.3.4.) These two types of BMPs were tested in residential neighborhoods, typically the most common land use in urban watersheds (Wong et al.1997). The goal was to determine if technology or education provides more pollutant reduction so that urban runoff managers can select optimal runoff pollutant minimization strategies.

2.2.1 Development of the Study Area

When developing the R3 Study area, the study partners focused on identifying watersheds with similar characteristics that would enable them to confirm water savings identified in the previous “Westpark” study, a water conservation evaluation (IRWD, MWDOC and MWD, 200l). Because a parallel purpose was to expand upon the findings of the Westpark study by measuring changes in dry weather volume (dry season runoff evaluation) and pollutant content of residential runoff (water quality evaluation) associated with improved irrigation management practices, both single-family residences and medium-size landscapes were considered. The R3 Study area is located within IRWD’s service area as shown on Figure 2-1.

The R3 Study involved data collection and evaluation not previously attempted at such a large scale. In order to ensure reliable and accurate results, the study team sought to minimize the effects of outside variables that might produce “skewed” results. The team designated a study area that included five similar neighborhoods in Irvine, California. The study area was configured so that meaningful data could be provided for the water conservation, dry weather runoff reduction, and water quality evaluations. Runoff from each of the neighborhoods could be isolated and sampled at a single point from within the municipal sewer system, enabling each neighborhood to be treated individually. At these points of drainage, the runoff volume was monitored, and water quality samples were taken. The five neighborhoods are summarized in Table 2-1 and depicted graphically on Figure 2-2.

Table 2-1
Summary of Neighborhoods

Name	Description/Purpose	Comments
Site 1001 Retrofit Group	The homes in this group were retrofitted with an ET controller and also received education information.	The Retrofit Group area consisted of: • 112 residential landscapes • 12 City of Irvine streets • 2 condominium associations • 1 homeowners association
Sites 1002 – 1004 Control Groups	The homes in this group were monitored as experimental control groups and received no ET controller and no public education materials.	The Control Group area had evaluation-specific variations in size and configuration. In addition, some evaluations assessed “matched” and “unmatched” controls from within and outside of the study area.
Site 1005 Education Group	The homes in this group received information materials only (the same education information as supplied to the Retrofit Group).	The Education Group consisted of 225 homes identified by visual selection. This area also included one large school site.

Figure 2-1
Location of R3 Study Area Within Southern California

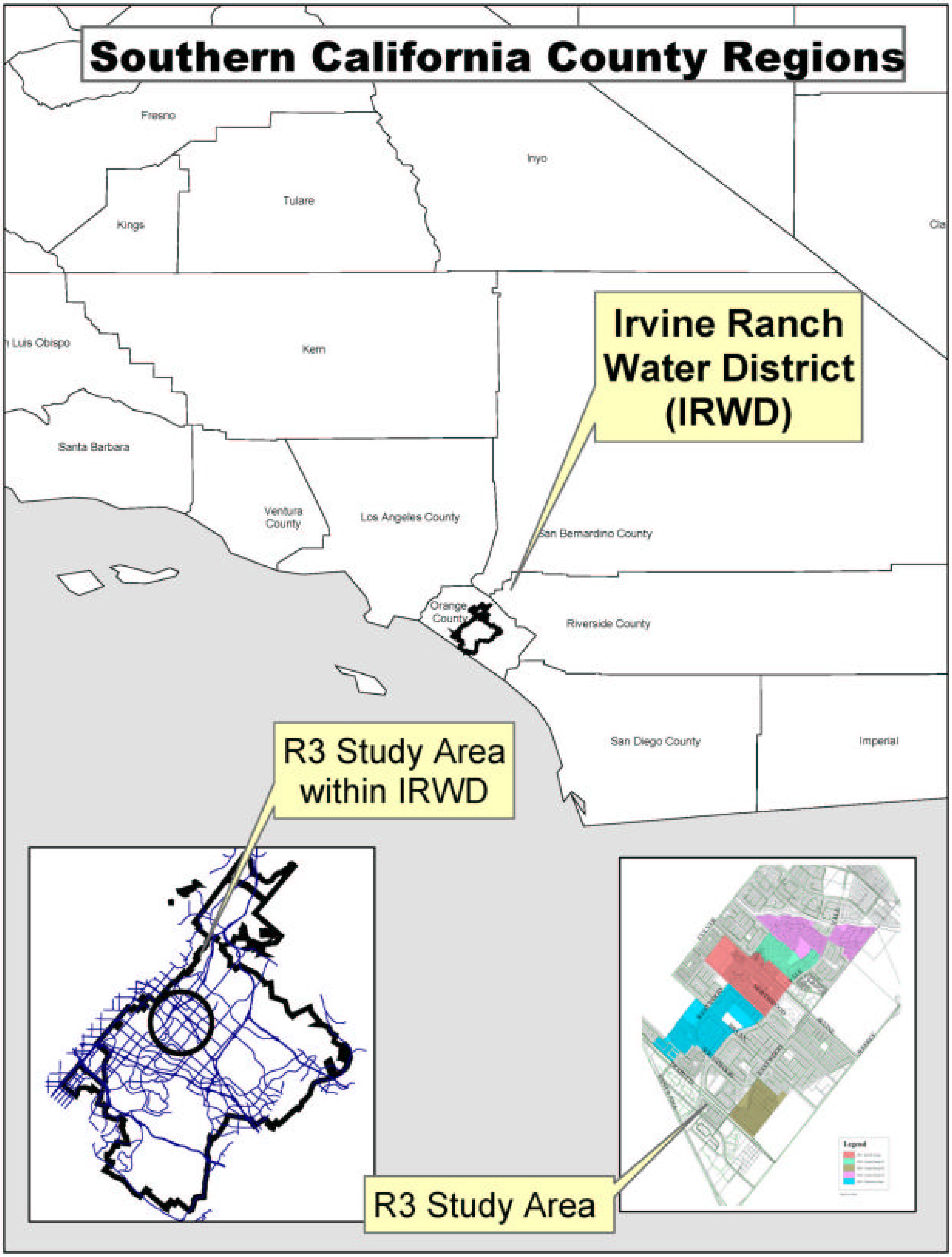
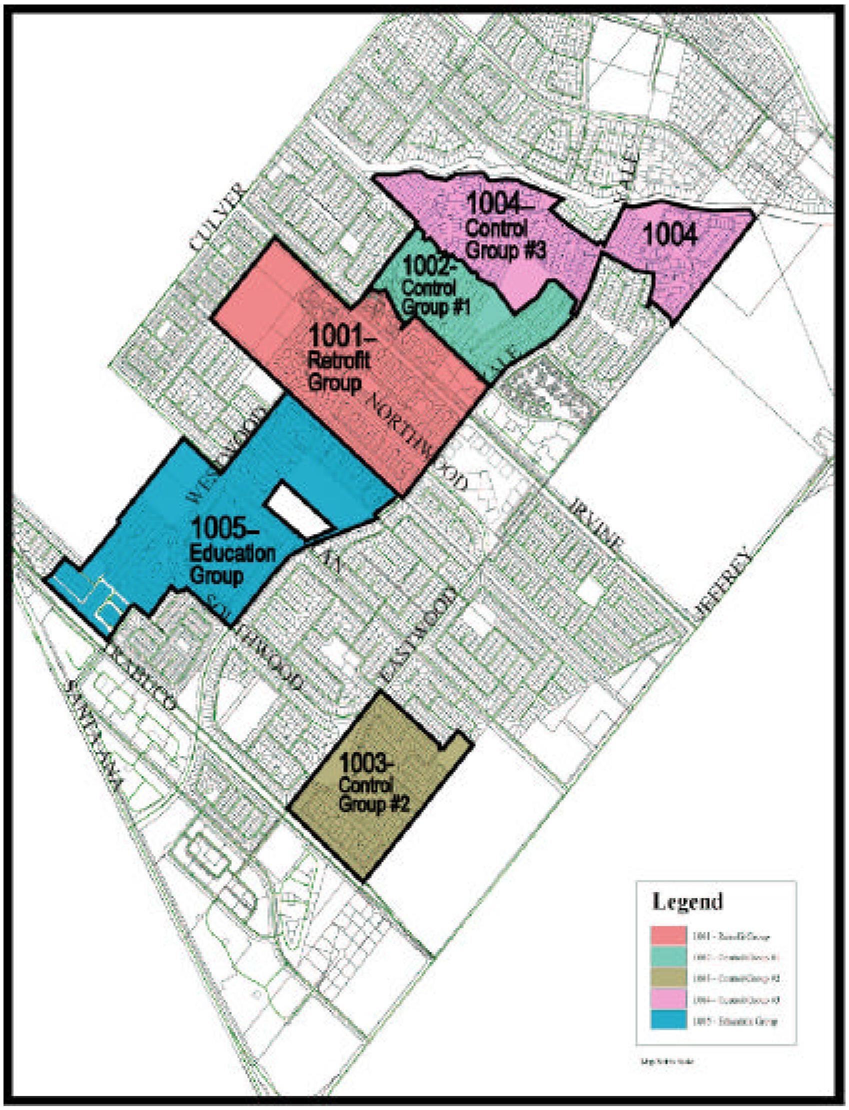


Figure 2-2
R3 Study Neighborhood Areas



In the first of the neighborhoods (Site 1001 or retrofit group), participating homes received a site evaluation and installation of an ET controller to automatically adjust irrigation schedules. Additionally, the residents at these homes received information regarding environmentally-sensitive landscape maintenance practices. The controllers were installed in 112 residential homes, 12 city street landscapes in the City of Irvine, two condominium associations' landscapes, and one homeowners association (HOA) landscape. The HOA landscape had three distinctive sites: 1) pool/park/tennis courts, 2) park, and 3) streetscapes.

The second neighborhood (Site 1005, or education group) received the same environmentally-sensitive landscape maintenance information as the first group, as well as a suggested irrigation schedule.

The three remaining neighborhoods (Sites 1002 – 1004, or control group) did not receive ET controllers and were not provided educational materials. Residents in the control groups had no knowledge of the study and were used only for comparison purposes. The make-up of the control group varied depending upon the evaluation. In the water conservation evaluation, "matched controls" were used in addition to the control group sites. In the water conservation and the dry weather runoff evaluations, only data from Site 1004 was used, as discussed in Sections 2.3.1 and 2.3.2. Data from all three sites was used in the water quality evaluation.

The five neighborhoods were selected based on the following criteria: 1) isolation from other neighborhood watersheds, 2) climate, 3) land use, 4) development age, and 5) irrigation water management techniques. These parameters are described in greater detail in Appendix B.

2.2.2 Flow Monitoring / Water Quality Sampling

This section summarizes the approach to flow monitoring and water quality sampling.

2.2.2.1 Flow Monitoring

Two main criteria were established for the study's flow monitoring equipment. First, the monitor could not alter the pipe or channel. Second, the monitoring had to be sufficiently accurate to distinguish seasonal flow changes and any flow change that resulted from the two study treatments (retrofit and education). Because the storm drain systems used for flow monitoring are designed to convey peak storm flows, and the focus of the R3 study was on changes in dry season (low flow) runoff associated with the treatments, the flow monitors had to be able to detect relatively small differences in low volume flows in large diameter storm drains. This situation was exacerbated by the fact that only a portion of each tributary neighborhood received the study treatments. Two flow monitoring technologies were determined to meet these criteria:

- Manning's equation plus a level sensor
- Velocity sensor and level monitor (area-velocity)

The area-velocity method was chosen due to lack of slope information for the storm drain system. The selected equipment was an American Sigma 950, which is battery-operated and can record data every minute. The equipment has an ultrasonic transmitter and a velocity sensor, both of which were installed in the storm drain. The ultrasonic transmitter establishes the water surface level and area, while the velocity sensor determines the velocity of the water in the pipe. Flow is calculated by the equation:

- Flow = Area x Velocity

Because four of the five monitoring locations were in a pipe, several variations on the ultrasonic transmitter / velocity sensor were tested before the combination of sonic and velocity wafer were finalized.

The accuracy of the flow monitoring equipment was tested at all study sites. This was accomplished by metering flow (at three different levels) from a fire hydrant within each tributary watershed and comparing these metered flows to flows measured at the flow monitoring locations. As expected, the accuracy of the flow monitors varied from site to site depending on the nature and condition of each storm drain. For example, some settling of the storm drain was noted near the flow monitor for Site 1002, resulting in an accumulation of sediment. This physical "anomaly" altered the hydraulic characteristics of the pipe and affected the accuracy of flow measurements. However, based on the flow test results, it was believed that these issues were manageable. The subsequent analysis of flow data as presented in Chapter 4 of this report suggests that this belief was partially correct; although flow monitoring problems required data from two of the three control sites to be discarded, the data from the other three sites (two treatments and one control) was sufficiently accurate to allow for the determination of meaningful statistical results.

2.2.2.2 Water Quality Sampling

The water quality sampling program quantified constituents found in residential runoff flows. This program consisted of two phases: 1) pre-study and 2) dry weather sampling. More information about water quality sampling and analysis is provided in Section 2.3.3, Chapter 5 and Appendices B and E.

2.2.3 ET Irrigation Controller Operation and Selection Process

The technology-based BMP consisted of an ET controller + education. The ET controller selected was similar to most automatic sprinkler timers available at home improvement stores and nurseries, but with the capacity to receive radio signals that will alter sprinkler timing based on current weather conditions. If the weather is hot and dry, the radio signal calls for longer or more frequent irrigation. If the weather is cool and moist, such as recent precipitation, the radio signals call for shorter or less frequent irrigation. For the R3 Study, the existing sprinkler timers that are set manually by the homeowner were replaced with the radio-controlled ET controller systems. Trained technicians were used to ensure successful installation because the ET controller requires programming for each valve including area (size of yard or planter per valve), soil type (clay, sand, etc.), and landscape type (turfgrass, shrubbery, etc.). The remaining irrigation system was unchanged, including piping and sprinkler head configuration.

Since residential areas include landscapes other than the homeowners, these "common area" and streetscape landscape areas ("medium-size" landscapes) were included in the water management component of the R3 Study. As shown in Table 2-2, the medium-size landscapes accounted for an estimated 70 percent of the total landscape area treated in the retrofit group (Site 1001). The installation process for both residential and medium-size landscapes is described in Appendix B.

2.2.3.1 Controller Installation

The study evaluated the performance of the engineering of irrigation management techniques to reduce the consumption and residential runoff while maintaining the quality of the landscape. A typical irrigation controller is difficult to program and limited in the scope of the scheduling

ability. Proper scheduling requires calculations based on real time ET data, landscape topography, and plant type, which are beyond the capabilities of typical controllers. The landscaper in the field is left to guess or rely on past experience as to the correct amount of water, the correct runtime to prevent runoff, and the correct number of days of the week to water.

The controllers were installed following the general principle that an ET controller is a water management tool and that professional operation should result in conservation and reduction of runoff. A picture of the controller is shown on Figure 2-3. More information is provided in Appendix B.

Figure 2-3
ET Controller

2.2.3.2 ET Controller Operation

The operation of the ET controller in this study was optimized by proper irrigation scheduling. As discussed further in Chapter 4 and Appendices B, D1 and D2, the ET controller must meet three key criteria: cost, ease of operation, and ability to conserve water and reduce runoff.

2.3 Study Evaluations

This section summarizes the water conservation evaluation, the quantification of changes in dry season runoff reduction savings, the analysis of water quality impacts, and the approach to customer acceptance / public education.

Table 2-2
Study Sites Land Use and Treatment Summary

Site 1001

Land Use	No. of Lots	Acres	Treatment Sites	Treatment Acreage*	No. of Controllers
SFR	565	66.8	112	6.6	112
Condo	109	10.3	2	1.9	8
HOA	4	5.9	1	0.9	3
School	2	4.6			
Landscape	10	19.4	12	11.2	15
Street	97	49.7			
Unmetered	64	11.5			
Total	**851**	**168.1**	**127**	**20.5**	**138**

***Note: All acreage except SFR were considered "medium-size" landscapes.**

Site 1002

Land Use	No. of Lots	Acres	Treatment Sites	Treatment Acreage	No. of Controllers
SFR	-	-	control	control	control
Condo	-	-	control	control	control
HOA	-	-	control	control	control
School	-	-	control	control	control
Landscape	-	-	control	control	control
Street	-	-	control	control	control
Unmetered	-	-	control	control	control
Total	**-**	**-**			

Table 2-2 (continued)
Study Sites Land Use and Treatment Summary

Site 1003

Land Use	No. of Lots	Acres	Treatment Sites	Treatment Acreage	No. of Controllers
SFR	-	-	control	control	control
Condo	-	-	control	control	control
HOA	-	-	control	control	control
School	-	-	control	control	control
Landscape	-	-	control	control	control
Street	-	-	control	control	control
Unmetered	-	-	control	control	control
Total	**-**	**-**			

Site 1004

Land Use	No. of Lots	Acres	Treatment Sites	Treatment Acreage	No. of Controllers
SFR	417	47.8	control	control	control
Condo	-	-	control	control	control
HOA	1	0.9	control	control	control
School	1	8.0	control	control	control
Landscape	2	0.0	control	control	control
Street	42	25.0	control	control	control
Unmetered	61	7.1	control	control	control
Total	**524**	**88.8**			

Site 1005

Land Use	No. of Lots	Acres	Treatment Sites	Treatment Acreage	No. of Controllers
SFR	559	67.9	225	13.0	n/a
Condo	-	-	-	-	n/a
HOA	1	1.5	-	-	n/a
School	2	12.1	-	-	n/a
Landscape	2	0.0	-	-	n/a
Street	45	0.0	-	-	n/a
Unmetered	8	2.7	-	-	n/a
Total	**617**	**84.2**	**225**	**13.0**	**0**

2.3.1 Water Conservation Evaluation

The water conservation evaluation was conducted by A&N Technical Services, Inc. The firm performed a statistical analysis of historical water consumption records from, roughly, July 1997 to August 2002. Two main types of water use were reviewed: single-family residences and medium-size landscapes. For the single-family residences, data was compared among the retrofit group, the education group, and the control group. For the medium-size landscape accounts, a slightly different approach was used. Accounts within the study area were compared to "matched" and "unmatched" controls in the City of Irvine, both within and outside of the study

area. Matched controls were similar in sun exposure, irrigation type, soil type, etc. Unmatched controls were areas not similar enough to be used for direct comparison but areas that could be used for weather normalization. A detailed description of the methods used to evaluate water savings for the single-family residence and medium-size landscape sites is provided in Chapter 3 and Appendix C of this report.

2.3.2 Dry Season Runoff Reduction Savings Quantification

In addition to the water conservation evaluation, A&N Technical Services, Inc., performed a statistical analysis of the reduction of runoff induced by ET controller and irrigation education. With the assistance of IRWD staff, who collected runoff data, A&N developed regression models to estimate mean runoff by site.

Two of the control sites (1002 and 1003) had recurring measurements issues that produced generally unreliable data. Site 1002 was found to have a physical hydraulic jump, which caused sediments to build in such a way that flows avoided the monitor. At Site 1003, there was an occurrence of illegal dumping of cement into the storm drain. This event reshaped the monitoring area, led to continuous collection of debris, and caused the monitor to perform erratically. Thus, it was only possible to use data from Site 1004. More details are provided in Chapter 4 and Appendices D1 and D2.

2.3.3 Water Quality Impacts Assessment

As described in Section 2.2.2.2, the water quality sampling program quantified constituents found in residential runoff flows. Two independent reviews of the water quality data were performed. The initial review, conducted by SCCWRP, used parametric statistical techniques (t-test; analysis of variance [ANOVA]), which provide a good descriptive review of the study. However, these techniques are generally considered to have less power for detecting differences in data than other statistical tests. A subsequent statistical overview was performed by Geosyntec Consultants to review alternative and possibly more “robust” data analysis techniques. This work, which included the review of only a portion of the data set, focused on additional descriptive techniques (time series plots; box plots; probability distributions) and the use of non-parametric statistical techniques (rank-sum test; Kruskal-Wallis [K-W]). The SCCWRP and Geosyntec Consultants reports are presented in Appendix E-1 and E-2, respectively.

2.3.4 Public Acceptance / Public Education Approach

The public acceptance evaluation was conducted to compare the effectiveness of proposed BMPs for ET controller technology + education and education only. The participating ET technology retrofit group homes received a site evaluation and installation of an ET controller to manage the irrigation system. Additionally, the residents of these homes received information regarding environmentally-sensitive landscape practices. The education-only group received an initial informational packet containing three items: an introductory letter, an informational booklet, and a soil probe to measure the water content of landscaped soils.

In addition to the initial packet, monthly reminders were mailed to each homeowner that included tips for maintaining the irrigation system. Suggested sprinkler run times (for the non-ET controller neighborhood) and tips on fertilizer or pesticide application usage, including non-toxic alternatives, were also provided in the monthly newsletter. A telephone log was kept to monitor incoming customer calls relating to the R3 Study, and a pre- and post-program survey was developed to measure customer impact of the study. More details are provided in Chapter 6 and Appendix F.

Chapter 3: Water Conservation

3.1 Overview

This chapter describes the statistical analysis of water savings (water conservation) among customers who installed ET controllers and customers given irrigation education in the study area. Specific information includes:

- A summary of study methods and evaluation approach.
- Evaluation results for large landscape customers and for single-family residences.
- Effect of ET controllers on seasonal peak demand.

More detailed information is provided in Appendix C.

3.2 Evaluation Approach

This section summarizes the overall evaluation approach, the records, review process, and data assessment techniques.

3.2.1 Overall Evaluation Approach

Historical water consumption records for a sample of participants and for a sample of nonparticipating customers were examined statistically. The hypothesis was that installation of new irrigation technology or better management of existing equipment would reduce the observed water consumption of customers participating in this program. This study empirically estimates the water savings that resulted from two types of "interventions"—1) customers receiving both ET controllers and follow-up education and 2) customers receiving an education-only intervention. Both single-family residences and medium-size landscapes were evaluated. (See Tables 3-1 and 3-2.)

Table 3-1
Summary of Water Conservation Evaluation Approach for Single-family Residences

Site	Number of Usable Accounts	
Site 1001 Retrofit Group	Retrofit Non Participants	97* 213
Site 1004 Control Group		264
Site 1005 Education Group	Education Non Participants .	192* 346

*Note: These sample numbers are smaller than the total number of original participants in each group due to changes in tenants, anomalous data, and other data quality issues.

Table 3-2
Summary of Water Conservation Approach for Medium-size Landscapes

Type	Number of Usable Accounts	Average Acres Per Account
Participating Landscapes	15*	0.93
Matched Controls	76	0.92
Unmatched Controls	895	0.96

Note: This sample number is smaller than the total number of original study participants due anomalous data, and other data quality issues.

Since installation of ET controllers required the voluntary agreement of the customer to participate, this sample of customers can be termed "self-selected." Customers in the education–only group were initially approached by mail about their interest in participating in the study. 137 customers initially expressing interest were included in the study group. However, because sufficient interest in the study was not generated through this mailing to meet the study saturation goals for this group, the remaining 112 participants self selected. While this analysis does quantitatively estimate the reduction of participant's water consumption, one may not directly extrapolate this finding to nonparticipants. This is because self-selected participants can differ from customers who decided not to participate.

The explanatory variables in these models include:

- Deterministic functions of calendar time, including
  - the seasonal shape of demand
- Weather conditions
  - measures of air temperature
  - measures of precipitation, contemporaneous and lagged
- Customer-specific mean water consumption
- "Intervention" measures of the date of participation and the type of intervention

3.2.2 Records Review Process

Consumption records were compiled from IRWD's customer billing system for customers in the study areas. Billing histories were obtained from meter reads between July 1997 and August 2002. It is important to note that a meter read on August 1 will largely represent water consumption in July. Since the ET controllers were installed in May and June of 2001, the derived sample contained slightly more than one year of data for each participant. More information is presented in Appendix C.

The landscape-only customers (15 accounts) were handled separately. Two control groups were developed for these irrigation accounts: A matched control group was selected by IRWD staff by visual inspection, finding three-to-five similar control sites for each participating site. Similarity was judged by irrigated area and type of use (HOA, median, park, or streetscape). Since the City of Irvine was improving irrigation efficiency on the City-owned sites during the post-intervention period, this matched control group also had potential water savings. A second control group was developed where the selection was done solely based on geographic area. In this way, the statistical models could separately estimate the water savings effects for each group. (See Appendix C.)

3.2.3 Data Assessment Techniques

The first major issue with using meter-read consumption data is the level and magnitude of noise in the data. The second major issue is that records of metered water consumption can also embed non-ignorable meter mis-measurement. To keep either type of data inconsistencies from corrupting statistical estimates of model parameters, the modeling effort employed a sophisticated range of outlier-detection methods and models. These are described in Appendix C.

Daily weather measurements—daily precipitation, maximum air temperature, and evapotranspiration—were collected from the California Irrigation Management Information System (CIMIS) weather station located in Irvine. Daily weather histories were collected as far back as were available (January 1, 1948) to provide the best possible estimates for "normal" weather through the year. Thus, 54 observations were available upon which to judge "normal" rainfall and temperature for January 1^{rst} of any given year.

Robust regression techniques were used to detect which observations were potentially data quality errors. This methodology determines the relative level of inconsistency of each observation with a given model form. A measure is constructed to depict the level of inconsistency between zero and one; this measure is then used as a weight in subsequent regressions. Less consistent observations are down-weighted. Other model-based outlier diagnostics were also employed to screen the data for any egregious data quality issues.

3.3 Evaluation Results

This section presents evaluation results for single-family residences and landscape-only customers. The effect of ET controllers on peak demand is also discussed.

3.3.1 Estimated Single-family Residential Water Demand

Table 3-3 presents the estimation results for the model of single-family water demand in the R3 study sites. Twenty-one variables are listed. This sample represents water consumption among 1,525 single-family households between June 1997 and July 2002. This sample contains 97 ET controller/education participants (in Site 1001) and 192 education-only participants (in Site 1005). This sample is smaller than the total number of participants in each group due to changes in tenants and anomalous data.

The constant term (1) describes the mean intercept for this equation. (A separate intercept is estimated for each of the 1,525 households, but these are not displayed in Table 3-3 for reasons of brevity.) The independent variables 2 to 8—made up of the sines and cosines of the Fourier series described in Appendix C (Equation 2)—are used to depict the seasonal shape of water demand.

Table 3-3
Single-family Residential Water Demand Model

Dependent Variable: Average Daily Metered Water Consumption in gallons per day (gpd)		
Independent Variable	**Coefficient**	**Std. Error**
1. Constant (Mean intercept)	405.6593	3.1660
2. First Sine harmonic, 12 month (annual) frequency	-45.4215	0.9636
3. First Cosine harmonic, 12 month (annual) frequency	-89.1494	0.9629
4. Second Sine harmonic, 6 month (semi-annual) frequency	3.6549	0.6798
5. Second Cosine harmonic, 6 month (semi-annual) frequency	1.0709	0.6733
6. Third Cosine harmonic, 4 month frequency	1.7312	0.7151
7. Fourth Sine harmonic, 3 month (quarterly) frequency	4.4016	0.7403
8. Fourth Cosine harmonic, 3 month (quarterly) frequency	3.3491	0.7865
9. Interaction of contemporaneous temperature with annual sine harmonic	48.7897	17.1559
10. Interaction of contemporaneous temperature with annual cosine harmonic	-72.4672	22.3626
11. Deviation from logarithm of 31 or 61 day moving average of maximum daily air temperature	284.7163	13.542
12. Interaction of contemporaneous rain with annual sine harmonic	10.1102	1.8546
13. Interaction of contemporaneous rain with annual cosine harmonic	5.9969	2.6904
14. Deviation from logarithm of 31 or 61 day moving sum of rainfall	-34.0117	1.8931
15. Monthly lag from rain deviation	-13.3173	1.0549
16. Average Effect of ET controller/Education (97 participants)	**-41.2266**	**4.0772**
17. Interaction of ET intervention with annual sine harmonic	38.9989	5.3327
18. Interaction of ET intervention with annual cosine harmonic	-6.3723	4.8980
19. Average Effect of Education-only intervention (192 participants)	**-25.5878**	**2.8081**
20. Interaction of Ed.-only intervention with annual sine harmonic	6.0357	3.5870
21. Interaction of Ed.-only intervention with annual cosine harmonic	-3.0703	3.3826
Number of observations	94,655	
Number of customer accounts	1,525	
Standard Error of Individual Constant Terms		120.85
Standard Error of White Noise Error		129.81
Time period of Consumption	June 1997 - July 2002	

The predicted seasonal effect is the shape of demand in a normal weather year. This seasonal shape is important because it represents the point of departure for the estimated weather effects (expressed as departure from normal). The effect of the landscape interventions on this seasonal shape was also tested.

The estimated weather effect is specified in "departure-from-normal" form. Variable 11 is the departure of monthly temperature from the average temperature for that month in the season. (Average seasonal temperature is derived from a regression of daily temperature on the seasonal harmonics.) Rainfall is treated in an analogous fashion (Variable 14). One month lagged rainfall deviation is also included in the model (Variable 15). It is also noted that the contemporaneous weather effect is interacted with the harmonics to capture any seasonal shape to both the rainfall (Variables 12 and 13) and the temperature (Variables 9 and 10) elasticities. Thus, departures of temperature from normal produce the largest percentage effect in the spring growing season. Similarly, an inch of rainfall produces a larger effect upon demand in the summer than in the winter.

The effect of the landscape conservation program interventions is captured in the following rows. The parameter on the indicator for ET controllers/education (Variable16) suggests that the mean change in water consumption is 41.2 gpd (reduction) while the education only participants (Variable 19) saved approximately 25.6 gpd. Because residential meters serve both outdoor and indoor demand, the model cannot say whether education-only participants saved this water through improved irrigation management or by also reducing indoor water consumption. Since the sample includes only one year of post-intervention data, the model cannot say how persistent either effect will be in future years.

3.3.2 Estimated Landscape Customer Water Demand

Table 3-4 presents the estimation results for the model of medium-size landscape (irrigation-only) customer water demand in the R3 study sites. Seventeen variables are listed. This sample represents water consumption among 992 accounts between June 1997 and August 2002 and contains 21 ET controller accounts, 76 matched control accounts, and 895 unmatched control accounts.

The constant term (1) describes the intercept for this equation. The independent variables 2 to 9—made up of the sines and cosines of the Fourier series described in Appendix C (Equation 2)—are used to depict the seasonal shape of water demand. The estimated weather effect is specified in "departure-from-normal" form. Variable 10 is the departure of monthly temperature from the average temperature for that month in the season. (Average seasonal temperature is derived from a regression of daily temperature on the seasonal harmonics.) Rainfall is treated similarly (Variable 11). One month lagged rainfall deviation is also included in the model (Variable 12). The next variable accounts for the amount of irrigated acreage on the site. (Note that while measured acreage is available for all irrigation-only accounts, this is not true for single-family accounts.)

The effect of the landscape conservation program interventions is captured in the following rows. The parameter on the indicator for ET controllers (Variable 14) suggests that the mean change in water consumption is 545 gpd (reduction), approximately 21 percent of the pre-intervention water use. The matched control group (Variable 16) did experience water savings, approximately 241 gpd or 8.7 percent of their pre-intervention water use. As noted previously, this group included City of Irvine landscape accounts for which a parallel water efficiency program was

conducted. The variables testing for differences in pre-intervention use cannot distinguish any differences between the different types of accounts.

Table 3-4
Landscape Customer Water Demand Model

Dependent Variable: Average Daily Metered Water Consumption (in gallons per day)		
Independent Variable	**Coefficient**	**Std. Error**
1 Constant (Mean intercept)	2624.0890	235.5602
2. First Sine harmonic, 12 month (annual) frequency	-810.6712	26.4690
3. First Cosine harmonic, 12 month (annual) frequency	-1979.1650	26.1149
4. Second Sine harmonic, 6 month (semi-annual) frequency	103.7890	26.7195
5. Second Cosine harmonic, 6 month (semi-annual) frequency	-18.6126	27.1067
6. Third Sine harmonic, 4 month frequency	-123.5511	28.2926
7. Third Cosine harmonic, 4 month frequency	106.4412	28.6328
8. Fourth Sine harmonic, 3 month (quarterly) frequency	38.3819	30.6999
9. Fourth Cosine harmonic, 3 month (quarterly) frequency	-61.4848	30.9128
10. Deviation from logarithm of 31 or 61 day moving average of maximum daily air temperature	6293.6890	565.6084
11. Deviation from logarithm of 31 or 61 day moving sum of rainfall	-748.2235	52.1792
12. Monthly lag from rain deviation	-209.9027	46.5477
13. Irrigated Acreage (in acres)	485.1284	140.1746
14. ET controller sites, test for difference in pre-intervention use	-327.6321	1511.6870
15. Average Effect of ET controller (21 accounts)	-545.3841	330.3669
16. Matched accounts, test for difference in pre-intervention use	-166.6455	693.9447
17. Average Effect of city efficiency improvements (76 accounts)	-240.4067	148.4015
Number of observations		56666
Number of customer accounts		977
Standard Error of Individual Constant Terms		5766.8
Standard Error of White Noise Error		4189.5
Time period of Consumption	June 1997 - July 2002	

3.3.3 Effect of ET Controllers on Seasonal Peak Demand (Single-family Residential)

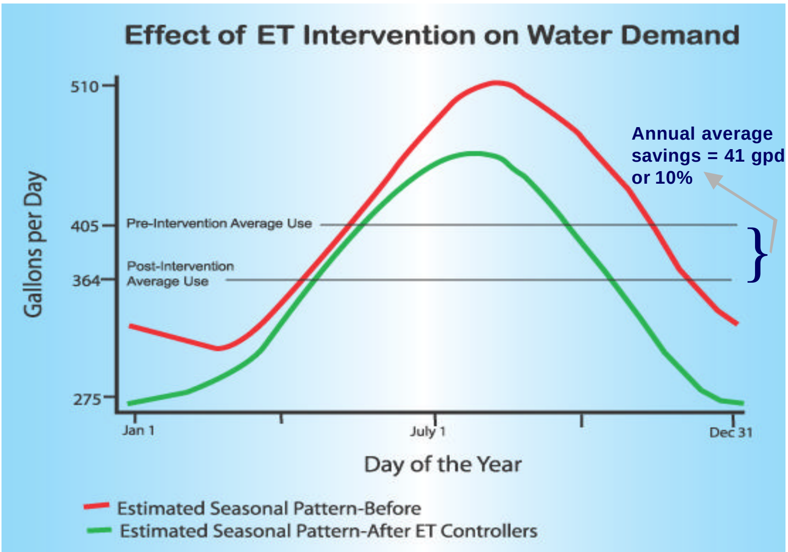
The question of how these programs affected the seasonal shape of water demand can be interpreted from the remaining interactive effects—the indicators interacted with the first sine and cosine harmonics.

When the pre / post seasonal patterns are combined with their pre / post mean water consumption, the following before and after picture can be seen throughout the year.

On Figure 3-1, several observations should be made. First, the difference between the two horizontal lines corresponds to the estimated mean reduction of approximately 41 gpd. Second,

the assumption of a constant 41 gpd effect does not hold true throughout the year. The reduction is barely noticeable in the spring growing season and is much larger in the fall.

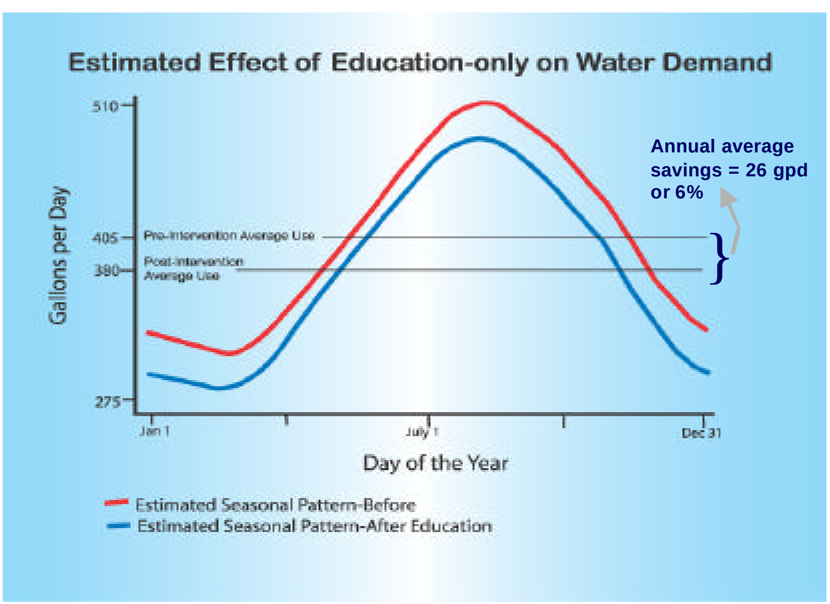
Figure 3-1
Effect of ET Intervention on Seasonal Water Demand for Single-family Residential



The reduction in peak demand—though dependent upon how the seasonal peak is defined—is greater than the average reduction. The estimated peak day demand, occurring on August 8, is reduced by approximately 51 gallons. This "load-shaping" effect of the ET controller intervention can translate into an additional benefit to water agencies. The benefits from peak reduction derive from the avoided costs of those water system costs driven by peak load and not average load—the costs for new treatment, conveyance, and distribution all contain cost components driven by peak capacity requirements

Figure 3-2 plots the corresponding estimates for the education-only intervention. The reduction in average demand is less—approximately 25 gpd. The effect upon the estimated seasonal shape of demand is much more muted. In fact, the change to the estimated seasonal shape of demand induced by the education-only intervention is not significantly different from zero at classical levels of significance.

Figure 3-2
Estimated Effect of Education-only on Seasonal Water Demand for Single-family Residential



3.4 Conclusions

This modeling effort focused on developing the best depiction of net changes in water consumption due to the landscape interventions of ET controllers and / or education. Much of the modeling effort was expended on data cleaning, diagnosis, and validation. The most serious data issues were identified and appropriately handled. To the extent that future data quality can be improved, future work could provide several statistical refinements in model specification. These are described in Appendix C.

The documentation provided in this report describes the shape of water savings achieved by the landscape interventions of ET controllers and / or education. Households participating in these programs saved significant amounts of water. Savings for the education-only program were less than for the retrofit group, but were still significant. The ET controller / education program changed both the level and shape of water demand.

Chapter 4: Runoff

4.1 Overview

This chapter presents the statistical analysis of the reduction of runoff induced by ET controllers and irrigation education. Specific information includes:

- Description of flow meters used and the data collection approach
- Discussion of the runoff analysis and analytical methods
- Presentation of evaluation results

More detailed information is provided in Appendices D1 and D2.

4.2. Evaluation Approach

The evaluation approach is summarized in Table 4-1 and discussed in more detail below.

Table 4-1
Summary of Dry Weather Runoff Evaluation Approach

Site	Description/Purpose	Controllers	Measuring Points
Site 1001 Retrofit Group	The study site contained 565 single-family residences. Of these, 112 participated in the ET/education program. In addition, 15 medium-size landscape sites also received ET controllers.	The accounts listed in Table 2-1 were allocated controllers as follows: • 112 for residential landscapes • 15 for 12 City of Irvine streets • 8 for the condominium associations • 3 for the HOA	1
Sites 1004 Control Group	This site contained 417 single-family residences and 44 large landscapes.	Not Applicable	1
Site 1005 Education Group	At this site, 225 residential customers participated in the irrigation education program.	Not Applicable	1

4.2.1 Data Collection

To measure dry weather runoff, flow monitors were installed at the five locations shown on Figure 4-1. The study used Sigma 950 flow monitors manufactured by Hach. The flow monitor applies an area-velocity calculation. The basic formula for flow is: flow (Q) equals the velocity (V) of the water multiplied by the area (A) of the water ($Q=VA$).

The first variable in the equation, velocity, was measured by velocity wafers placed below the surface of the runoff stream to measure the velocity of the water. These electronic devices were attached to metal plates positioned at the bottom of the concrete pipes that carried runoff. Each velocity wafer was centered to the width of the water flowing in the pipe. Once it is correctly

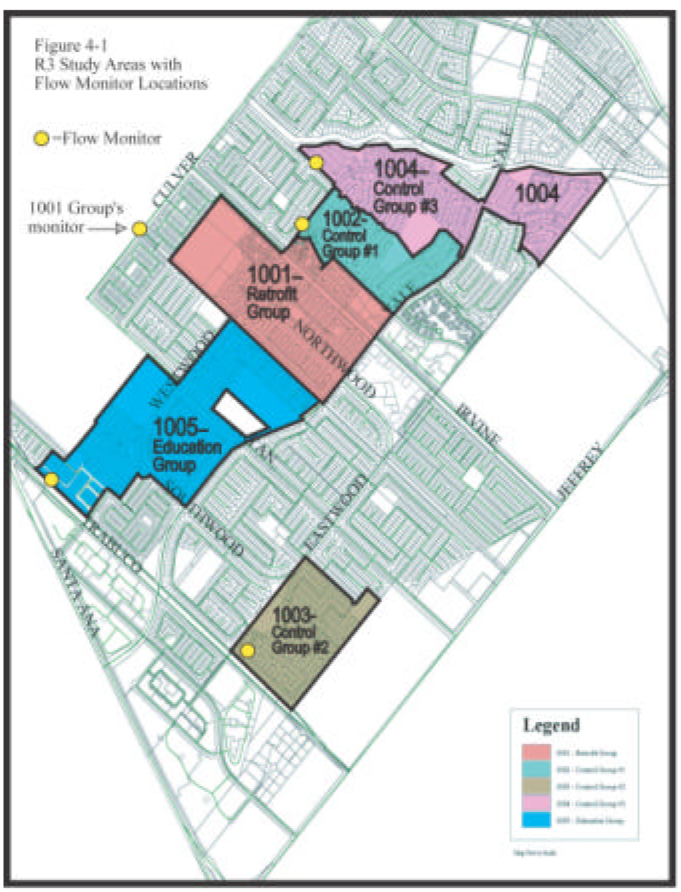
positioned, the wafer measures the velocity of the water by measuring the speed of the particles in the water. This information is then transmitted via cable to the Sigma 950.

The second variable in the water flow equation, the area of the water, also referred to as the cross sectional area, was obtained by multiplying the depth of the water by its width. This calculation is based on geometry, the diameter of the pipe, and the depth of the water. Since the geometry of the area is the arc of a circular pipe of known diameter, the Sigma 950 was able to internally calculate this measurement using data from a sonic sensor. The sonic sensor measures the depth of the water by hanging above the water surface and sending out a sonic pulse that reflects off the surface of the water.

The Sigma 950 contains a central processing unit that recorded the time, water depth, water velocity, and flow every five minutes.

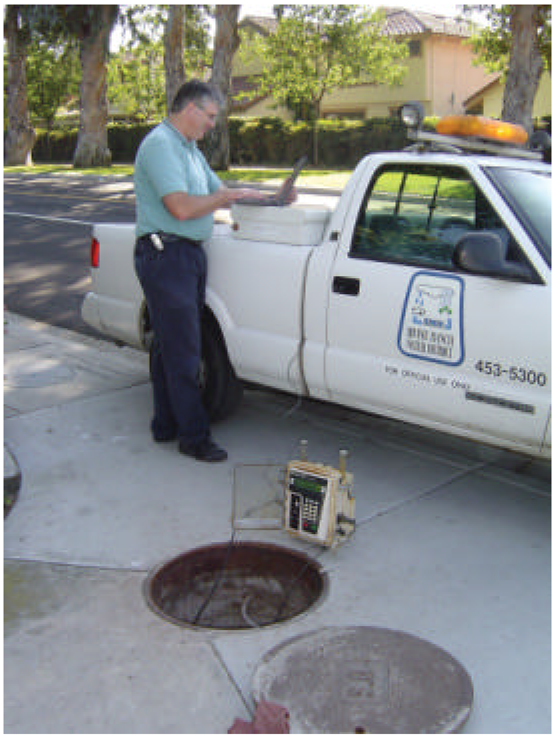
Maintaining the flow monitors in good working order required an R3 Study field staff member to visit each of the five data collection locations twice per week. At each site, staff would open the manhole and lift out the monitor. Then, the storm drainpipe would be inspected for any obstruction or interference with the flow or with the devices (velocity wafer and sonic sensor) used to measure flow.

Figure 4-1
Flow Monitor Locations



Next, staff would measure the depth of the water with a tape measure and recalibrate the flow monitor to this measurement. The velocity wafers could not be calibrated. They were adjusted for accuracy, however, during low flow and low velocity periods. To accomplish this, staff would observe an object on the surface of the water. As the object moved with the flow, staff would estimate its speed as feet per second (fps). This speed was compared to the value simultaneously registered on the flow monitor. If the observed velocity was much slower than that recorded by the monitor, staff would disconnect the velocity wafer. This action would usually reset the velocity wafer. If the problem persisted, the wafer would be replaced.

Figure 4-2:
Downloading Data from Sigma 950 Flow Monitor to Laptop



4.2.2 Ranking Collected Data

Twice per week during each site visit, data was downloaded from the flow monitor to a laptop computer. This process is depicted on the adjacent figure (Figure 4-2). When staff returned to IRWD's operations building, the data was downloaded to the District's central computer. Here the data was transferred from a text file to an excel file. At this point, staff would rank the data for each download of each site. After observing the site, recalibrating the flow monitor, and reviewing the data graphs, staff would add ranking to each site's data. The following process assigned these ranks: a) if staff observed nothing unusual and had no reason to suspect any data collection problems, the flow, depth and velocity received a ranking of "zero," b) if one of these factors was suspect or the data graph had an unusual jump in value, the rank indicator was a "one," c) if staff noted a problem which may have affected the data and changed its values beyond the tolerances of the equipment, the data was ranked with a "two."

4.2.2 Data Methods

Robust regressions techniques were used to detect which observations were potentially data quality errors. This methodology determines the relative level of inconsistency of each observation with a given model form. A measure is constructed to depict the level of inconsistency between zero and one; this measure is then used as a weight in subsequent regressions. Less consistent observations are down-weighted. Other model-based outlier diagnostics (Cook's distance, DFBETA statistics, and residual diagnostics) were also employed to screen the data for any egregious data quality issues

After screening for the known data quality problems, using the "rank" indicator, all raw meter reads were first converted to average hourly values. These were then aggregated by date to convert to daily runoff, available in both mean hourly flow and total daily volume.

Precipitation taken from the Irvine weather station was matched to the daily data and used to separate wet from dry days. It should be noted that wet weather flows were monitored and evaluated in a parallel study that assessed pesticide contributors from residential land use during dry and wet weather (SCCWRP, 2003). However, the focus of the R3 study was runoff reduction during the peak irrigation season (i.e., dry weather).

Wet weather storm flow can be a more complicated phenomenon to predict, as it depends on the timing and magnitude of the rainfall event, the moisture deficit of soils, and other factors. The relative lack of large storm events in the post-intervention period precluded examination of these more complicated forces and the effect that the landscape interventions might have on wet day runoff.

Area-standardized measures of site runoff were also created for dry/wet days, where total daily volume was divided by the estimated permeable/total area. Estimates of area for the study sites were derived from the IRWD geographic information system (GIS) system. The GIS system was queried to produce estimates of the number of lots and total area for the different land use classifications (single family residence, condo, HOA, school, landscape, street, and unknown). The GIS system also provided an estimate of the number of buildings, and building area. The area taken up by buildings is treated as impermeable. The remaining area was separated into permeable and impermeable area using a land use classification-specific assumption of impermeability. Table 4-2 provides the raw data used to construct the estimated site area. (Due to lack of usable flow measures, Sites 1002 and 1003 are not separately reported.) Table 4-3 aggregates the data by site.

Table 4-2
Estimated Area of Study Sites by Land Use

R3 GROUP	#Lots	Classification	Total Area in square feet. (sq. ft.)	Building Area in sq. ft.	Assumed Impermeable Coefficient %	Estimated Impermeable Area in sq. ft.	Estimated Permeable Area in sq. ft.
1001	64	Unmetered	499885		0	0	499885
1001	565	SFR	2911227	976574	0.5	1943900	967326
1001	109	Condo	447096	189721	0.9	421358	25738
1001	4	HOA	255208		0.75	191406	63802
1001	2	School	198676		0.9	178808	19868
1001	10	Landscape	845529		0	0	845529
1001	97	Street	2163105		1	2163104	0
1004	61	Unmetered	307556		0.0	0	307556
1004	417	SFR	2081636	719485	0.5	1400560	681076
1004	1	HOA	40165		0.8	30123	10041
1004	1	School	348739		0.9	313865	34874
1004	2	Landscape	1136		0.0	0	1136
1004	42	Street	1089143		1.0	1089143	0
1005	8	Unmetered	118370		0.0	0	118370
1005	559	SFR	2957363	1033197	0.5	1995280	962083
1005	1	HOA	66421		0.8	49816	16605
1005	1	School	264236		0.9	237812	26424
1005	1	School	261089		0.9	234980	26109
1005	2	Landscape	773206		0.0	0	773206
1005	45	Street	1736098		1.0	1736098	0

Table 4-3
Estimated Area of Study Sites

R3 Group	Estimated Impermeable Area sq.ft.	acres	Estimated Permeable Area sq. ft.	acres	Total Area sq. ft.	acres
1001	4,898,578	112.5	2,422,148	55.6	7,320,724	168.1
1004	2,833,691	65.1	1,034,683	23.8	3,868,374	88.9
1005	4,253,986	97.7	1,194,553	44.1	6,176,783	141.8

4.3 Evaluation Results

Table 4-4 presents the robust regression estimation results for the model of dry day runoff in R3 study Site 1001 (containing some customers receiving the ET controller/education intervention), Site 1004 (whose customers received no treatment), and Site 1005 (containing some customers receiving the education-only treatment). This sample represents metered dry day runoff, standardized by estimated site permeable area, between February 2001 and June 2002.

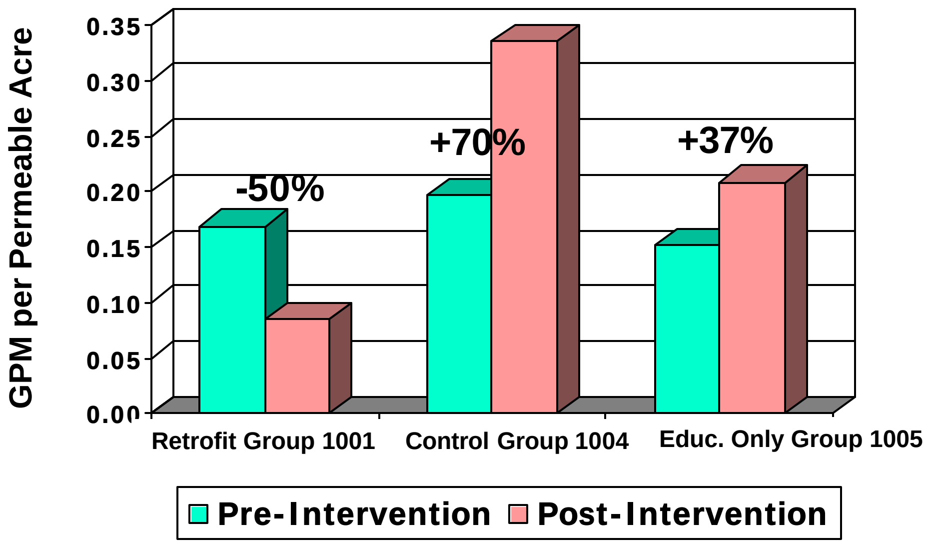
The changes in runoff estimated during the R3 study are summarized on Figure 4-3 and described in more detail below. Additional descriptions of the regression models are presented in Appendices D1 and D2.

Table 4-4
Robust Regression Estimates of Mean Dry Day Runoff

Dependent Variable: Dry Day Runoff Height (in hundredths inches per unit area) (Height=Runoff Volume/Site Area)

Variable	Coefficient	Std. Error	t	Prob.>|t|
Mean Runoff: Feb-May 2001				
1. Intercept (1001 mean runoff)	0.898563	0.120838	7.44	0
2. Difference of Site1004 in pre-period	0.143721	0.157245	0.91	0.361
3. Difference of Site1005 in pre-period	-0.092260	0.151479	-0.61	0.543
Change in Runoff: June 2001-June2002				
4. Change of Site 1001 in post-period	-0.445390	0.134540	-3.31	0.001
5. Change of Site 1004 in post period	0.878089	0.113737	7.72	0
6. Change of Site 1005 in post period	0.202553	0.106973	1.89	0.059
Number of observations	950			
F (5, 944)	74.92			
Prob. > F	0			
Quasi-R-Squared	0.35			

Figure 4-3
R3 Study's Changes in Runoff (Within Sites)



4.3.1 Pre-intervention Period

The constant term (Variable 1) in Table 4-4 defines the intercept for the model equation and can be interpreted as the mean daily runoff in Site 1001—about 0.898 hundredths of an inch per permeable acre (equal to 0.00898 inches). Variables 2 and 3, the indicators for Sites 1004 and 1005 in the pre-period, suggest that estimated difference in mean runoff is not statistically distinguishable from zero (standard error > coefficient). The estimated pre-period site mean runoff for these sites can also be inferred from these coefficients:

$m_{4,\mathrm{Pre}} \equiv m_1 + d_{4,\mathrm{Pre}} \approx 0.899 + 0.144 = 1.042$ hundredths of an inch and

$m_{5,\mathrm{Pre}} \equiv m_1 + d_{5,\mathrm{Pre}} \approx 0.899 - 0.092 = 0.806$ (See Table 4-5.)

Table 4-5
Study Site Comparisons of Pre Period Flow vs. Post Period Flow

	1001 Pre	1001 Post	1004 Pre	1004 Post	1005 Pre	1005 Post
Permeable Square feet	2,422,148	2,422,148	1,034,683	1,034,683	1,922,797	1,922,797
Permeable Acres (Table 4-3)	55.6	55.6	23.8	23.8	44.1	44.1
Coefficient from Table 4-4 (Hundredths of in/day/perm acre)	0.899	-0.445	0.144	0.878	-0.092	0.203

Table 4-5 (continued)

	1001 Pre	1001 Post	1004 Pre	1004 Post	1005 Pre	1005 Post
Hundredths of in/day/perm acre flow	0.899	0.453	1.042	1.777	0.806	1.101
in/day/perm acre flow	0.0090	0.0045	0.0104	0.0178	0.0081	0.0110
feet/day	0.04164	0.02063	0.0081	0.0178	0.0081	0.0110
Raw GPM	9.42	4.75	4.67	7.96	6.71	9.71
GPM/perm acre	0.169	0.085	0.197	0.335	0.152	0.208
Percent change in flow (Pre to Post)	**-50%**		**+70%**		**+37%**	

4.3.2 Post-intervention Period

The formal test for the change in runoff in the post-intervention period (June 2001-June 2002) can be found in the following three terms: variables 4, 5 and 6 as shown in Table 4-4. The estimated change in dry day runoff for Site 1001 (Variable 4 in Table 4-4), is -0.44 hundredths of an inch. In relative terms, this works out to approximately a 50 percent reduction. The implied mean post-intervention dry day runoff for Site 1001, is 0.89-0.44˜0.45 hundredths of an inch. This reduction in runoff is statistically distinguishable from zero at classical levels of confidence.

It should be noted that the pre- and post- periods are not comparable. The post-intervention period, June 2001 to June 2002, includes 13 months, but would be fairly close to an annual average. The period of time covered by the pre-intervention period for all sites, February to May 2001, includes at most four months. For Site 1001, the pre-intervention period only includes the months of April and May in 2001 because the flow meter produced enough invalid reads in February and March to necessitate its relocation to a new site in April. Since these are not the highest months for urban runoff, it would be reasonable to expect runoff in the post-intervention period to increase. For this reason, the reduction of 50 percent from the pre-intervention period would be a lower bound on the true estimate of runoff reduction. An examination of the other two valid sites would provide insight into how much runoff would have increased in the post-intervention period.

The estimated change in dry day runoff for Site 1004 (Variable 5 in Table 4-4) is +0.88 hundredths of an inch. This increase in runoff is statistically distinguishable from zero at classical levels of confidence. The implied mean post-intervention dry day runoff for Site 1004, is (0.89+0.88˜) 1.77 hundredths of an inch. In relative terms, this works out to a fairly large (1-{1.77-1.03}/1.03˜) 70 percent increase in the post-intervention period.

The estimated change in dry day runoff for Site 1005 (Variable 6 in Table 4-4) is +0.20 hundredths of an inch. This increase in runoff is statistically distinguishable from zero at close to classical levels of confidence. The implied mean post-intervention dry day runoff for Site 1005, is (0.89+0.20˜) 1.09 hundredths of an inch. In relative terms, this works out to a more modest (1-{1.09-0.80}/0.80=) 37 percent increase in the post-intervention period.

4.3.3 Comparison Across Sites

The last and potentially most vulnerable inference compares the time change in runoff across sites. If Site 1001 had experienced the same change in runoff as its neighbor sites 1005 or 1004, then dry day runoff would have increased from 37 to 70 percent in the post-intervention period. In absolute terms, this would imply a prediction of non-intervention runoff of 1.24 to 1.53 hundredths of inches per acre. Compared to the realized 0.45 hundredths of inches of runoff in the post-intervention period, this reduction would translate to reduction in runoff from 64 to 71 percent.

A similar counterfactual exercise for Site 1005 would require assuming that Site 1004 is a good matched control site. Then dry weather runoff in Site 1005 would have increased by 72 percent in the post-intervention period, a level of 1.38 hundredths of inches per acre. Compared to the realized 1.09 hundredths of inches of runoff in the post-intervention period, the reduction would translate into a modest but non-ignorable 21 percent decrease in runoff.

Both of these exercises require use of Site 1004 as a control site. While the unadjusted flow measures for Sites 1001 and 1005 are fairly close in the pre-intervention period, the same cannot be said for the flow measures from Site 1004. There are uncertainties as to which of the three estimates of reduction runoff for Site 1001 should be used. The direct within-site estimate of a 50 percent runoff reduction is likely biased low; runoff in the post-intervention period should have increased. The estimate of 64 percent, based on Site 1005 as a control site, may also be biased on the low side. Though Site 1005 did have pre-intervention runoff that reasonably matched Site 1001, Site 1005 also contained more than 200 homes that participated in the education-only intervention with monthly follow-up. These homes did have quantified water savings, some of which is likely to have resulted from reduced runoff. Site 1004 did not receive any treatment, but did have measurement issues. Thus, the estimate of a 71 percent reduction, using Site 1004 as a control site, has an unknown bias.

The bigger inferential uncertainties lie in how these conservation interventions will work as they are scaled in a larger program or in how implementations of these programs would work in other areas.

4.4 Conclusions

The difficulties encountered in calibrating custom configured equipment to measure dry season / low flow runoff limited the amount of pre-intervention data. This in turn precluded simple before and after comparisons of mean runoff flow. Nonetheless, a sufficient length of baseline data was collected to allow quantitative estimates of runoff reduction. If additional flow data can be collected, additional analysis would be possible: 1) the runoff reduction under wet conditions

could be examined, and 2) an estimate of the seasonal shape of runoff could be included in the models to improve the precision of the estimated runoff reduction.

Because the runoff measurement is not at a customer level, it was not possible to distinguish the relative contribution of different customers to urban runoff reduction. Thus, for Site 1001, it was not possible to determine how much the single-family ET controller/education contributed relative to the ET controller intervention with medium-size landscape customers.

However, because the medium-size landscapes accounted for an estimated 70 percent of the area “treated” with ET controllers (Table 2-2), on strictly a proportional basis it is likely that the medium-size landscapes contributed to the majority of the observed runoff reduction for Site 1001.

Chapter 5 Water Quality and Watershed Implications

5.1 Overview

This chapter describes the water quality evaluations conducted as a part of the R3 Study and outlines the potential implications of these evaluations on the San Diego Creek Watershed. Specific information includes:

- A discussion of two approaches to the evaluation of water quality
- A summary of the study methods relating to water quality
- Development of "before and after" assessments of water quality to evaluate the effectiveness of ET technology and public education
- Detailed discussions of the evaluation approaches and findings based on these approaches
- A discussion of the implications of the findings for water quality in the San Diego Creek Watershed, focusing on TMDL constituents

More detailed information is provided in Appendices E1 and E2.

5.2 Introduction

Two independent reviews of water quality measurements were conducted as a part of this study. The initial review was conducted by SCCWRP as a part of its participation in the R3 Study and is included in its entirety as Appendix E1. This review used parametric statistical techniques (t-test; ANOVA), which provide a good descriptive review of the study data, but are generally considered to have less statistical power for detecting differences in data than other statistical tests. In general, because of the variability of the data and limitations in sample quantities, this review concluded that there was virtually no difference in either the concentration or "flux" (concentration times flow) of pollutants over time or between study treatments.

A subsequent statistical overview by Geosyntec Consultants was commissioned by IRWD to review alternative and possibly more "robust" data analysis techniques that might identify differences in study data not uncovered during the initial review. This work, which included the review of only a portion of the data set, focused on additional descriptive techniques (time series plots; box plots; probability distributions) and the use of non-parametric statistical techniques (rank-sum test; K-W). For some of the parameters reviewed, these techniques suggest that differences in measured water quality did occur across time and between study treatments. The entire Geosyntec report is provided in Appendix E2.

As noted above, both of the completed statistical reviews of the study data are included in the Appendices of this report. The remainder of this chapter of the report discusses the key findings of each review.

5.3 SCCWRP Water Quality Review

This section describes the SCCWRP evaluation approach, sampling and laboratory analysis, data analysis, and interpretations of the results. Watershed implications are also discussed.

5.3.1 Evaluation Approach

A before-after, control-impact (BACI) design was used to evaluate the effectiveness of both the sprinkler technology and public education. Each neighborhood was sampled every other week between December 2000 and June 2001. In June 2001, homes in one of the neighborhoods were outfitted with the ET controllers. Since homeowners with the retrofitted ET controllers were simultaneously being educated, a well-defined public education campaign was also begun with these homeowners. To ascertain the difference between education and ET technology, homeowners in a second neighborhood were targeted with an identical public education campaign, but without effect of the ET retrofit technology. There was no education or technology intervention in the remaining three neighborhoods, which served as control neighborhoods to document the effect of no treatment. Sampling at the five neighborhoods continued every other week from June 2001 to June 2002.

5.3.2 Sampling and Laboratory Analysis

Each neighborhood was hydrologically self-contained and drained to a single underground pipe. At each of these five locations, samples were collected for flow and water quality. Stage (water depth) and velocity were recorded at 5-minute intervals using an ultrasonic height sensor mounted at the pipe invert and a velocity sensor mounted on the floor of the pipe. Flow was calculated as the product of velocity and wetted cross-sectional area as defined by the stage and pipe circumference. Despite the relatively continuous measurement of flow, many of the flow measurements were excluded due to faulty readings. Synoptic flow and water quality measurements were only available for two sites over the course of the entire study (i.e. before and after intervention), including the ET controller + education and education only sites. Flow measurements at the time of water quality sampling for the three control sites were considered faulty and discarded.

Grab samples for water quality were collected just downstream of the flow sensors in the early morning using peristaltic pumps and pre-cleaned Teflon tubing. Samples were placed in individual pre-cleaned jars, placed on ice, and transported to the laboratory within one hour. Each sample was analyzed for 19 target analytes, five microbiological parameters, and four toxicity endpoints (Table 5-1). Target analytes included trace metals, nutrients, and organophosphorus (OP) pesticides. Microbiological parameters included fecal indicator bacteria and bacteriophage. Toxicity was evaluated using two marine species, the purple sea urchin *Strongylocentrotus purpuratus* and the mysid *Americamysis bahia*. All of the laboratory methodologies followed standard protocols developed by the USEPA or Standard Methods.

5.3.3 Data Analysis

Data analysis consisted of five steps: 1) comparison of water quality among the five neighborhoods prior to intervention; 2) comparison of water quality concentrations over time by neighborhood; 3) comparison of water quality concentrations before and after intervention by

treatment type; 4) comparison of pollutant flux before and after intervention by treatment type; and 5) correlation of toxicity measures with potential toxicants in dry weather runoff.

Comparison of water quality concentrations among the five neighborhoods prior to intervention was conducted to assess if there were inherent differences among treatment sites for each

Table 5-1
Reporting Level and Method for Target Parameters

	Reporting Level	Method
Metals (ug/L)		
Antimony	0.2	EPA 200.8
Arsenic	1.5	EPA 200.8
Barium	0.2	EPA 200.8
Cadmium	0.2	EPA 200.8
Chromium	0.3	EPA 200.8
Cobalt	0.1	EPA 200.8
Copper	1.5	EPA 200.8
Lead	0.3	EPA 200.8
Nickel	0.2	EPA 200.8
Selenium	5.0	EPA 200.8
Silver	0.4	EPA 200.8
Zinc	5.0	EPA 200.8
Nutrients (mg/L)		
Ammonia as N	5.0	EPA 350.1
Nitrate/Nitrite as N	5.0	EPA 353.2
Total Kjeldahl Nitrogen	10.0	EPA 351.2
Ortho-Phosphate as P	0.5	EPA 365.1
Total Phosphorus	1.0	EPA 365.4
OP Pesticides (ng/L)		
Chlorpyrifos	20.0	IonTrap GCMS
Diazinon	20.0	IonTrap GCMS
Microbiology		
Enterococcus (MPN/100 mL)	2	SM9230B
Fecal Coliform (MPN/100 mL)	2	SM9221B
Total Coliform (MPN/100 mL)	2	SM9221B
MS2 Phage (PFU/100 mL)	2	EPA 1602
Somatic Phage (PFU/100 mL)	2	EPA 1602
Toxicity (% effluent)		
Sea Urching Fertilization EC50	NA	EPA 1995
Sea Urching Fertilization NOEC	NA	EPA 1995
Mysid EC50	NA	EPA 1993
Mysid NOEC	NA	EPA 1993

Note: ug/L = micrograms per liter; MPN/100 mL=most probable number per 100 milliliters; PFU/100mL=plaque forming units per 100 milliliters; mg/L=milligrams per liter; ng/L=nanograms per liter.

constituent. This analysis was conducted using ANOVA using Tukey's post hoc test for identifying the significantly different neighborhoods. All data was tested for normality and homogeneous variance prior to testing. Only the microbiological data was determined to be non-normally distributed, so these results were log transformed prior to data analysis.

Comparison of water quality concentrations over time was accomplished by creating temporal plots of monthly mean concentration. Comparisons of water quality concentration before and after intervention by treatment type were accomplished using a standard t-test of the mean concentration before versus mean concentration after intervention. The mean concentrations for ET controller + education, education only, and ET controller + education – education only for each sampling event were normalized by the grand mean of the control sites for the same sampling event.

Pollutant flux estimates were calculated by the product of the concentration and volume at the time of sampling and then normalized to the area of the sampled neighborhood. Pollutant flux before and after treatment was compared somewhat differently since the lack of flow data at the control sites did not permit an estimate of flux for these neighborhoods. Mean pollutant flux before and after intervention was compared using standard t-tests at the ET controller + education and education only neighborhoods without normalization to control values.

Correlation of toxicity with toxicant concentrations was accomplished using a Pearson product moment correlation. These correlations are inferential only and do not presume resulting correlations automatically identify the responsible toxicants. In order to help identify potential causative toxic agents, concentrations of the correlated constituents were compared to concentrations known to induce toxicity in the respective test organisms.

5.3.4 Evaluation Results

There were significant differences in water quality among sites prior to intervention (Appendix E1, Table WQ3). Site 1004, the control site, had the greatest mean concentrations for 15 of the 24 constituents evaluated prior to the ET controller intervention. In particular, all of the mean nutrient concentrations were greater at Site 1004 than the other sites. On the other hand, Sites 1001 and 1002 generally had the lowest average concentrations prior to the ET controller intervention. Cumulatively, these sites had the lowest mean concentrations for 17 of the 24 constituents evaluated. Site 1002 also had the least toxicity, on average, of all five sites. Finally, Site 1003 had an intermediate status. Mean concentrations of enterococcus and fecal coliforms at this site were greater than any other site (fecal coliforms significantly greater than Sites 1001 and 1002), but the mean concentrations of five trace metals (chromium, copper, cobalt, nickel, selenium) were lowest at this site.

Water quality concentrations and toxicity were highly variable over time during the study period. Temporal plots of concentrations and toxicity for each site demonstrated that there was no seasonal trend and no overall trend with time. There were, however, occasional spikes in concentrations for many constituents that appeared to fall into one of two categories. The first

category was recurring spikes in concentration that were unpredictable in timing and location. The second category of concentration spike was single or infrequent peaks. Occasionally these spikes would occur across multiple sites, without commensurate changes in concentration at the treatment sites (1001 or 1005). More often, infrequent spikes were isolated to a single site. For example, concentrations of chlorpyrifos climbed to over 10,000 ng/L in July 2001, but averaged near 50 ng/L the remainder of the year at site 1005. Similarly, concentrations of ammonia and total phosphorus spiked 10 and 25-fold prior to June 2001 at the control site (1004) with less variability and overall lower concentrations the remainder of the study.

There were few significant differences that resulted from the intervention of education, ET controller + education, or ET controller + education – education only, relative to control sites (Table 5-2). Only six of the 24 constituents evaluated showed a significant difference between pre and post-intervention concentrations after normalizing to mean control values. These significant differences were a net increase in concentrations of ammonia, nitrate/nitrite, total phosphorus, chlorpyrifos, diazinon, and fecal coliforms. These statistical analyses were the result of one of two circumstances. In the first circumstance, there were individual large spikes in concentration at treatment sites, but not at control sites following intervention. Therefore, the net difference in concentrations between controls and treatments increased following the intervention. In these cases, removal of the outlier samples resulted in no significant difference among treatment effects relative to controls before intervention compared to after intervention. In the second circumstance, there were large spikes in concentrations at control site(s) prior to the intervention that later subsided, while treatment site concentrations and variability remained steady. Therefore, the difference between treatments and controls changed following interventions, although it was not a result of the education or technology.

Although there were no significant differences in pollutant flux as a result of the intervention, significant differences were noted in pollutant flux among sites prior to intervention. Site 1001, the ET controller + education site, had the greatest mean flux for 22 of the 24 constituents evaluated prior to the ET controller intervention. The mean flux for 20 of these 22 constituents was significantly greater at Site 1001 than the mean flux at Site 1005 (t-test, $p<0.05$). Site 1005 had greater mean fluxes only for MS2 phage and ammonia. The differences among the fluxes prior to (and after) intervention were the result of two factors: greater flow and, at times, greater concentrations at Site 1001 compared to Site 1005. Mean dry weather flow at the time of water quality sampling was nearly three times greater at Site 1001 than Site 1005.

Toxicity was inconsistently found at all five of the sampling sites, and there was no change in toxicity as a result of the intervention (Table 5-3). The two species tested did not respond similarly either among sites, among treatments, or over time. Correlation of toxicity with constituent concentrations yielded few significant relationships for either species (Table 5-3). Mysid toxicity was correlated with diazinon and several trace metals, but the strongest relationship was with diazinon concentration. Moreover, the concentrations of diazinon were well above the levels known to cause adverse effects in mysid, while trace metals were not. Sea urchin fertilization toxicity was only correlated with concentrations of zinc. The concentrations of zinc were well above the level known to induce adverse effects in this species.

Table 5-2
Significance of ANOVA Results for the Effect of ET Controller + Education, Education Alone, and the Difference Between ET Controller + Education and Education Alone Relative to Control Concentrations. (No data indicates p > 0.05)

	Effect of ET Controller + Education	Effect of Education Alone	Difference Between ET Controller + Education and Education Alone
Metals			
Antimony			
Arsenic			
Barium			
Cadmium			
Chromium			
Cobalt			
Copper			
Lead			
Nickel			
Selenium			
Silver			
Zinc			
Nutrients			
Ammonia as N	0.03	0.02	
Nitrate/Nitrite as N	0.02		
Total Kjeldahl Nitrogen			
Ortho-Phosphate as P			
Total Phosphorus		0.03	
OP Pesticides			
Chlorpyrifos	<0.01	<0.01	<0.01
Diazinon		<0.01	
Microbiology			
Enterococcus			
Fecal Coliform	0.04		
Total Coliform			
MS2 Phage			
Somatic Phage			
Toxicity			
Fertilization EC50			
Fertilization NOEC			
Mysid EC50			
Mysid NOEC			

Table 5-3
Correlation Coefficients (and p value) of Constituent Concentrations with Toxicity Endpoints (No Observed Effect Concentration, NOEC and Median Effect Concentration, EC50) in Dry Weather Discharges from Residential Neighborhoods in Orange County, CA. (No data indicates p > 0.05)

	Sea Urchin Fertilization NOEC	Mysid Survival NOEC	Sea Urchin Fertilization EC50	Mysid Survival EC50
Antimony		-0.273 (0.009)		
Arsenic		-0.3396 (0.001)		
Barium				
Cadmium				
Chromium		-0.244 (0.021)		-0.219 (0.044)
Cobalt		-0.330 (0.002)		-0.279 (0.010)
Copper				
Lead		-0.215 (0.042)		
Nickel				
Silver		-0.260 (0.013)		-0.229 (0.035)
Zinc	-0.277 (0.005)		-0.274 (0.006)	
Chlorpyrifos				
Diazinon		-0.426 (0.001)		-0.468 (0.001)
Ammonia				

5.3.5 Interpretation of Results

The evaluation was unable to find large, significant reductions in concentration or pollutant flux as a result of education and/or ET controller retrofit technology. This may indicate that the technology and/or education are inefficient for improvements in water quality. Equally as important, however, was the absence of meaningful increases in concentrations. Of the small number of concentrations that showed significant increases, most could be explained by highly variable spikes in concentrations reminiscent of isolated entries to the storm drain system, as opposed to ongoing chronic inputs or the effects of best management practices evaluated in this study.

If significant changes did occur, the evaluation design may not have detected these changes due to two factors. First, the variability in concentrations within and between sites is naturally high and the evaluation simply collected too few samples. After taking into account the variability and relative differences in mean concentrations, zinc was used as an example constituent to determine what sample sizes would be required to detect meaningful differences. Assuming that the sampling yielded the true mean and variance structure that actually existed at the five sites, power analysis indicated that a minimum sample size of no less than five-fold would have been required to detect the differences observed in zinc concentrations during this study.

The second factor that could have hindered the ability to detect meaningful differences in water quality is that the technology and education treatments were applied at the spatial scale of individual homes, while the evaluation design sampled at the neighborhood scale. This problem was exacerbated because only a fraction (approximately one-third) of the homes within the

neighborhoods sampled had the technological or educational treatments. Therefore, the treatments were effectively diluted, decreasing the ability to detect differences in water quality.

5.3.6 Watershed Implications

It appears that residential dry weather flows measured in the R3 Study may contribute significant proportions of some constituents to overall watershed discharges. The study sites were located within the San Diego Creek watershed, the largest tributary to Newport Bay. The Orange County Public Facilities and Resources Department (OCPFRD) publishes monitoring data on San Diego Creek to provide environmental managers the information they need to properly manage the Bay (OCPFRD 2002). The dry weather monitoring data was compiled at the mouth of San Diego Creek from OCPFRD during 2001-2002 and compared the concentrations to our results from residential neighborhoods (Table 5-4). Mean concentrations of chlorpyrifos, diazinon, copper and zinc were much higher in upstream residential neighborhoods than concentrations measured at the mouth of San Diego Creek. These residential dry weather contributions were amplified by the fact that the San Diego Creek watershed is primarily composed of residential land uses. In contrast, concentrations of selenium, arsenic, and total phosphorus in the residential dry weather discharges were much lower than the cumulative dry weather discharges from San Diego Creek, indicating that residential areas may not be the primary source of these constituents.

Table 5-4
Comparison of Mean Concentrations (95% Confidence Intervals) in Residential Dry Weather Discharges from this Study Compared to Concentrations in Dry Weather Discharges from San Diego Creek at Campus Drive During 2001-2002. (Data from OCPFRD)

	San Diego Creek	Residential
Parameter	**Mean (95% CI)**	**Mean (95% CI)**
Nitrate	5.16 (0.72)	4.76 (1.96)
Phosphate	1.98 (0.07)	1.16 (0.20)
Diazinon	0.13 (0.07)	1.52 (0.52)
Chlorpyrifos	0.05 (0.01)	0.35 (0.44)
Copper	11.59 (2.83)	23.59 (5.65)
Arsenic	6.58 (0.40)	2.68 (0.26)
Selenium	21.22 (2.65)	2.46 (0.03)
Zinc	22.08 (2.75)	60.09 (8.26)

5.4 Geosyntec Water Quality Review

This section presents examples of alternative approaches to data analysis, data analysis methods, example results, and watershed implications.

5.4.1 Examples of Alternative Approaches to Data Analysis

These example analyses focus on TMDL constituents: nutrients (total nitrogen [TN] and total phosphorus [TP]), metals (copper, lead, zinc, cadmium), pesticides, and pathogens (fecal coliform). The analyses also focus on dry weather flows, as reduction of these flows was a major objective of the R3 Study.

5.4.2 Data Analysis Methods

Exploratory Data Analysis

Visual inspection of data and exploration of factors that could potentially influence data (e.g. seasonal trends, rain events)

1. Divide data into pre and post- intervention groups.
2. Construct time series plots to visually inspect data and visually examine for seasonal trends. Overlay storm event markers to identify any relation to rainfall volume or antecedent dry period (ADP).
3. Investigate normality or log normality of data sets. Select appropriate statistical tests.
4. Construct probability plots for pre-intervention and post-intervention periods.
5. Prepare quantile plots.
6. Prepare side-by-side box plots.
7. Calculate descriptive statistics

Hypothesis Testing

Test data for skewness, normality, and statistically significant differences. Skewness and normality tests are only needed if parametric approaches are conducted. Use of non-parametric approaches is recommended for consistency because normality will not be met in all cases. Nonetheless, examples are provided to show that several of the data sets do not come from a normal distribution.

1. Skewness hypothesis test for symmetry.
2. Shipiro-Wilkes normality test.
3. Mann-Whitney rank-sum test.
4. For the data sets that have greater than 50 percent censored data (i.e., data only known to be less than the detection limit), hypothesis tests for differences in proportions.

5.4.3 Example Results

The first step in the data analysis was to construct individual time-series plots for each site to identify seasonal periodicity, step-trends, and monotonic trends. Plotting each site individually reveals more information than plotting all sites together. Also, by overlaying storm events, the role of rainfall volumes and the ADP may be more apparent and may indicate whether additional analyses are warranted (e.g., correlating ADP with concentration). Figure 5-1 is an example

time-series plot with storm event markers overlain for TP for Site 1001. As shown on the figure, the pre-intervention period had much more rainfall, which likely added to the variability in runoff concentrations and fluxes. However, it is apparent that the winter and spring concentrations appear to be lower and less variable during the post-intervention period. The irrigation controllers may have had an effect on the runoff concentrations by reducing the amount of irrigation during moister weather conditions (i.e., high soil moisture). A similar effect for TN is shown on Figure 5-2. Additional time-series plots are provided in Appendix E2.

Figure 5-1
Example Time-series Plot of Total Phosphorus with Storm Event Markers.

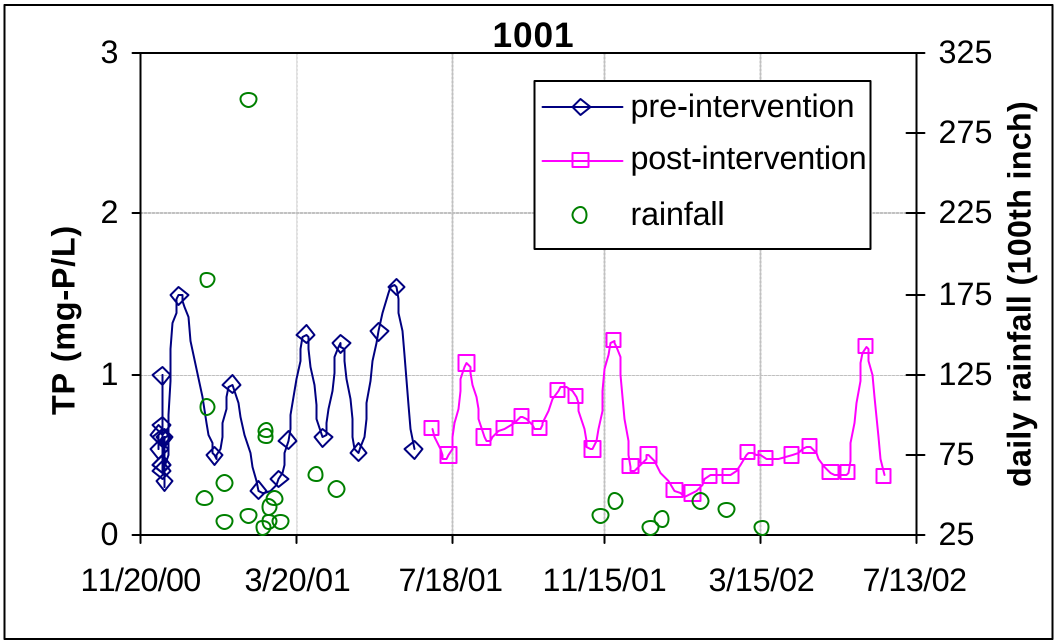
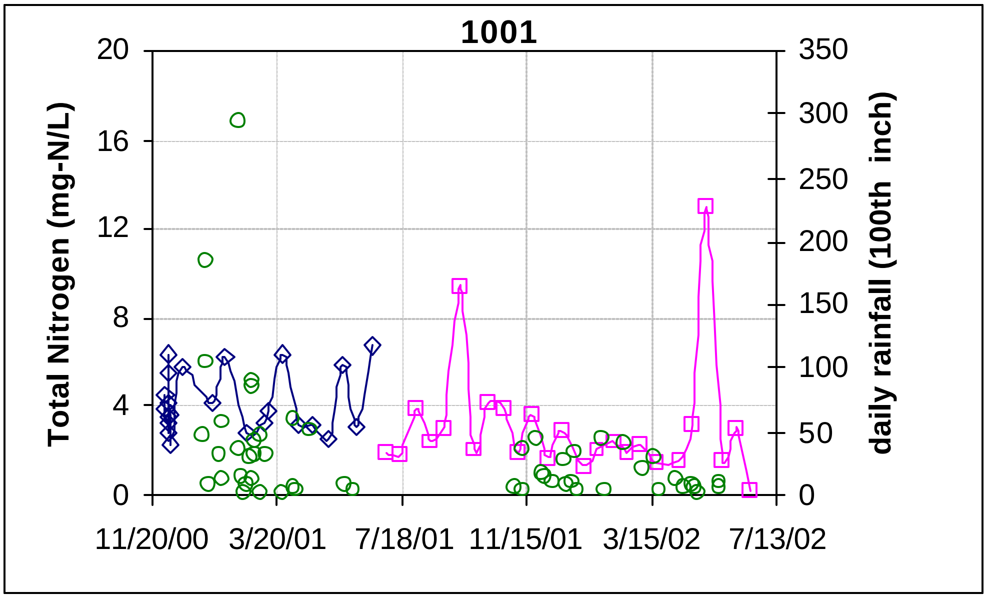


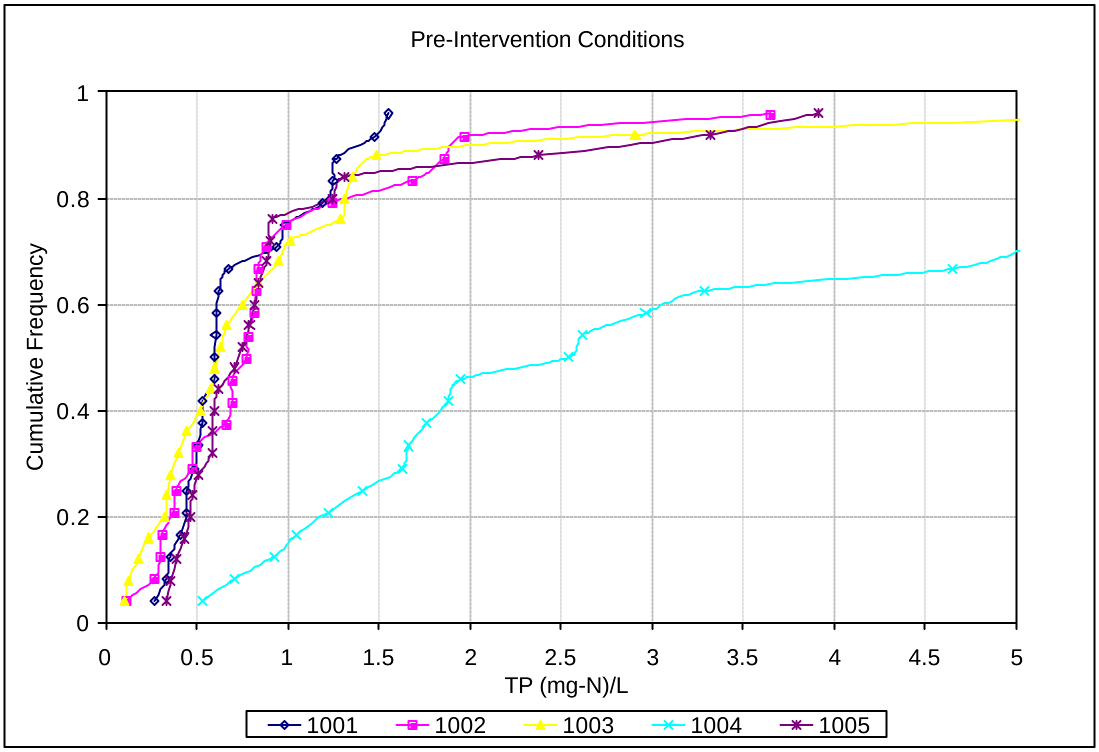
Figure 5-2
Example Time-series Plot of Total Nitrogen with Storm Event Markers.



5.4.3.1 Comparison of Water Quality Data Prior to Intervention

To visually investigate whether the test sites have similar runoff characteristics, probability plots were constructed. Figure 5-3 is an example of a probability plot for TP for all of the test sites. The figure shows that all of the sites have a similar distribution except for Site 1004.

Figure 5-3
Example Probability Plot of Total Phosphorus for All Sites Prior to Intervention.



The next step in the data analysis was to calculate parametric and non-parametric descriptive statistics. Table 5-5 is an example table of descriptive statistics for TN for all sites for both the pre- and post-intervention periods. (Additional descriptive statistics are included in Appendix E2). Table 5-5 includes the number of data points (n), the detection percent (%>MDL/RL), the mean, median, 25 percent trimmed mean, min, max, 25th percentile, 75th percentile, standard deviation, interquartile range (IQR), and the coefficient of skewness (g_s). Also included in the table are critical skewness coefficients (g_{cr}), which are readily available in statistics texts. If the coefficients of skewness are less than these critical values, then the data is symmetric. It should be noted that the measures of central tendency (mean and median) and variability (standard deviation) of the sites during the pre-intervention period are quite different, indicating the data arises from different distributions. The median values are consistently smaller than the mean (in some cases substantially smaller), demonstrating the influence of the outliers on the measure of central tendency. Only three pre-intervention data sets are symmetric, and none of the post-intervention data sets are. Failure to pass the symmetry test indicates the data is not normal. However, passing the symmetry test does not indicate the data is normal; this requires a normality test. The symmetry test, which is easier to conduct than normality tests, serves as an initial screen for normality to reduce the number of data sets needing further investigation.

Table 5-5
Example Table of Descriptive Statistics for Total Nitrogen for Each Site for Pre- and Post-intervention.

		1001		1002		1003		1004		1005	
Parameter	**Statistic**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
TN (calculated)	**n**	23	25	23	25	23	25	23	25	23	25
(mg-N/L)	**% > MDL/RL**	100%	80%	98%	90%	98%	96%	98%	96%	100%	98%
	Mean	4.24	3.09	5.31	3.44	3.66	4.42	48.00	10.18	6.89	7.74
	Median	3.84	2.27	3.95	2.55	2.66	2.50	19.01	5.57	5.06	4.36
	Trimmed mean	3.94	2.40	4.53	2.76	2.93	3.01	33.11	6.47	5.08	4.42
	min	2.30	0.30	1.50	0.78	1.46	0.45	3.28	0.74	2.48	1.07
	max	6.76	12.99	13.83	11.40	12.12	19.91	141.06	40.80	20.41	67.12
	25th percentile	3.20	1.79	2.27	2.10	2.11	2.04	9.05	2.71	3.52	3.47
	75th percentile	5.68	3.13	8.02	4.36	4.81	5.17	94.79	19.18	7.07	5.62
	St Dev	1.41	2.67	3.56	2.51	2.48	4.39	49.17	10.73	5.29	12.85
	IQR	2.48	1.34	5.75	2.26	2.70	3.13	85.74	16.47	3.55	2.15
	Skewness, g_s	0.55	2.82	0.84	1.87	2.13	2.27	0.74	1.37	1.88	4.46
	g_{cr}	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	Symmetric ($g_s < g_{cr}$)?	Y	N	Y	N	N	N	Y	N	N	N

The non-parametric equivalent to the ANOVA test is the K-W test, which tests for a difference between the medians of independent data groups. The K-W test will also test whether the datasets are derived from the same distribution.

Comparison of the mean ranks in Table 5-6 provides an indication of whether the data groups are derived from the same distribution. A p values < 0.05 indicates that two or more of the data groups have different distributions. Examination of the mean ranks in Table 5-6 shows that Sites 1001, 1002, and 1005 have somewhat similar mean ranks, and Sites 1003 and 1004 have somewhat different mean ranks. This suggests that Sites 1003 and 1004 have a different distribution than the other sites. Thus, the K-W test was performed on just Sites 1001, 1002, and 1005. These results are shown in Table 5-7. The p-value is now greater than 0.05, so the distributions of the TN data are not significantly different. Based on this analysis, Site 1002 was determined to be the only control site for comparison of TN data. Furthermore, it is clear that Site 1004 should not be considered as a control site for TN, and Site 1003 should be used with caution.

Table 5-6
Example of Kruskal-Wallis Test Results for Total Nitrogen at the Test Sites Prior to Intervention.

Test:	**Kruskal-Wallis ANOVA**		
Comparison:	**Total Nitrogen: 1001, 1002, 1003, 1004, 1005**		
Performed by:	**GeoSyntec Consultants**		
n	115		
Total Nitrogen	**n**	**Rank sum**	**Mean rank**
1001	23	1128.0	49.04
1002	23	1162.0	50.52
1003	23	774.0	33.65
1004	23	2150.0	93.48
1005	23	1456.0	63.30
Kruskal-Wallis statistic	41.71		
p	<0.0001	(chisqr approximation)	

Table 5-7
Example of Kruskal-Wallis Test Results for Total Nitrogen at Sites 1001, 1002, and 1005 Prior to Intervention.

Test:	**Kruskal-Wallis ANOVA**		
Comparison:	**Total Nitrogen: 1001, 1002, 1005**		
Performed by:	**GeoSyntec Consultants**		
n	69		
Total Nitrogen	**n**	**Rank sum**	**Mean rank**
1001	23	710.0	30.87
1002	23	761.0	33.09
1005	23	944.0	41.04
Kruskal-Wallis statistic	3.27		
p	0.1948	(chisqr approximation)	

5.4.3.2 Comparison of Water Quality Data Before and After Intervention

Side-by-side box plots and probability plot comparisons of pre-intervention and post-intervention were constructed to identify any apparent differences in the central tendency and concentration distributions between the two data sets. Figure 5-4 shows side-by-side box plots of total nitrogen at all of the test sites. Site 1004 was omitted due to its high variability. The figure shows that Site 1001 has a distinct decrease in TN while the other sites do not. However, other sites do show a decreasing trend in median concentration and inter-quartile ranges.

Figure 5-4
Side-by-side Box Plots of Pre- versus Post-Intervention for Total Nitrogen at All Sites.

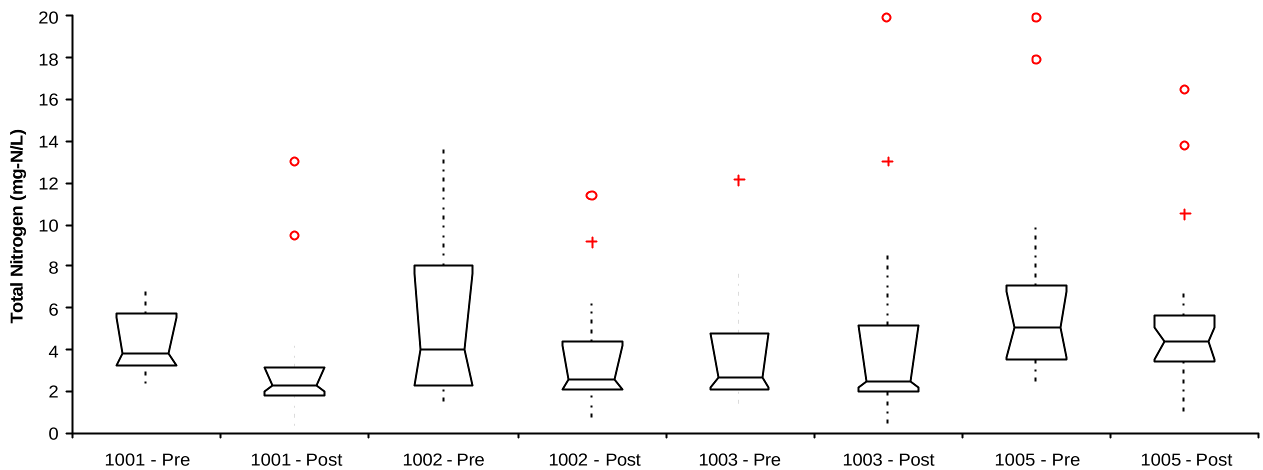
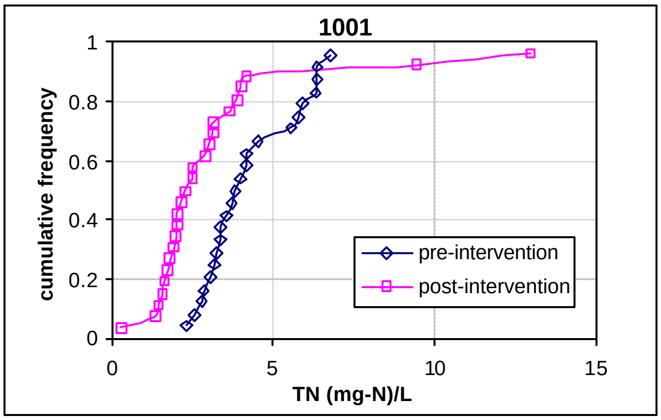


Figure 5-5 is a probability plot of TN for Site 1001 before and after intervention. (Additional probability plot comparisons are included in Appendix E2.) This figure shows a distinct reduction in TN at the site. However, since the data is from different time-periods, this difference could be related to temporal variability.

Figure 5-5
Example Probability Plot of Pre- versus Post-intervention for Total Nitrogen at Site 1001.



To evaluate if temporal variability caused by the different monitoring periods has anything to do with the difference in TN concentrations, the probability plots of the pre- and post-intervention period for Site 1001 were plotted with those for Site 1002 and Site 1005 (as these were determined to be the only valid control sites). These comparison plots are shown on Figure 5-6 and Figure 5-7. For pre-intervention, the distribution of Site 1001 more closely follows the distribution of Site 1005 than that of Site 1002, and for post-intervention the opposite is true. This indicates that the year-to-year variability alone cannot explain the reduction in TN at Site 1001.

Figure 5-6
Example Probability Plot for Total Nitrogen of Site 1001 versus Site 1002 for the Pre- and Post-Intervention Periods.

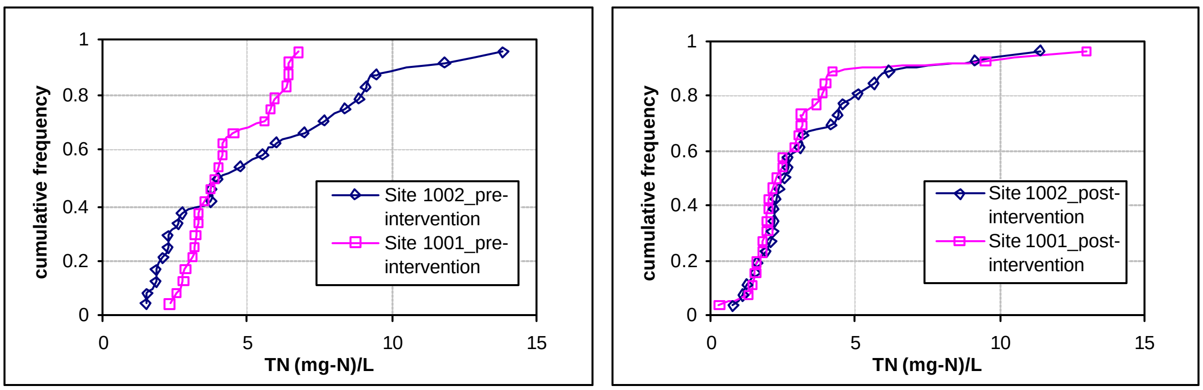
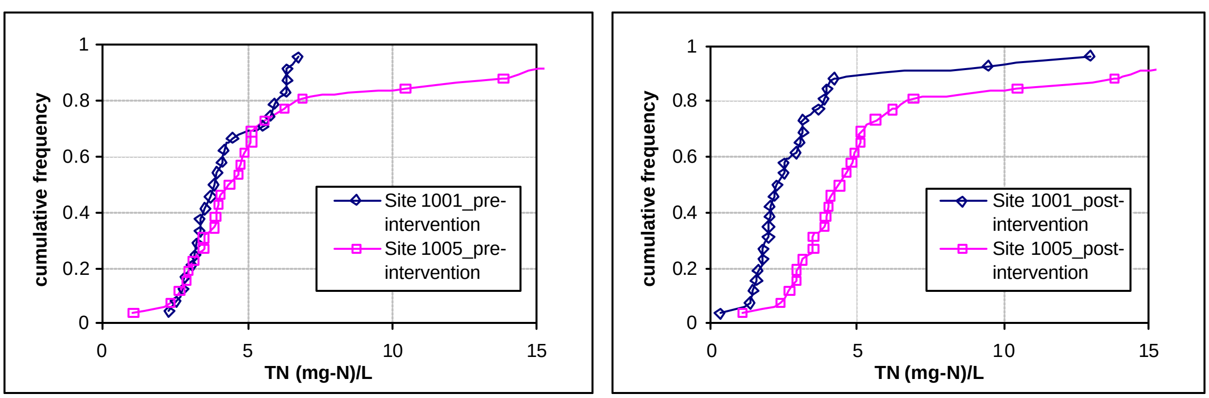


Figure 5-7
Example Probability Plot for Total Nitrogen of Site 1001 versus Site 1005 for the Pre- and Post-Intervention Periods.



The Mann-Whitney test (rank-sum) was used to determine if there is a statistical difference in the median values of two independent data sets (by rejecting the hypothesis that they are the same). Tables 5-8 through 5-10 show the output of the Mann-Whitney tests on Sites 1001, 1002, and 1005, respectively. The tables show a statistically significant difference ($p<0.05$) in the medians between the pre- versus post-intervention TN data at both Sites 1001 and 1002, but not at Site 1005. Furthermore, the difference in the medians at Site 1001 is at a higher level of confidence (more statistically significant) than the difference at Site 1002 (i.e., greater than 99 percent

significant compared to about 96 percent significant). The magnitudes of these differences (Hodges-Lehmann estimator) are about 1.5 and 1.3 milligrams of nitrogen per liter (mg-N/L) for Sites 1001 and 1002, respectively. These tests indicate that the difference in the TN medians at Site 1001 from pre-intervention to post-intervention cannot be explained by the year-to-year variation alone (e.g., the intervention appears to have had an effect). It also indicates that the public education applied to Site 1005 did not appear to make a significant difference.

Table 5-8
Example Mann-Whitney Test for Difference in Medians for Total Nitrogen at Site 1001 from Pre- Versus Post-intervention.

Test :	**Mann-Whitney test**			
Alternative hypothesis	**1001: Pre versus Post**			
Performed by:	**GeoSyntec Consultants**			
n	48			
1001	**n**	**Rank sum**	**Mean rank**	**U**
Pre	23	736.0	32.00	115.0
Post	25	440.0	17.60	460.0
Difference between medians	1.497			
95.2% CI	0.883	to +?	(normal approximation)	
Mann-Whitney U statistic	115			
1-tailed p	0.0002	(normal approximation)		

Table 5-9
Example Mann-Whitney Test for Difference in Medians for Total Nitrogen at Site 1002 from Pre- Versus Post-Intervention.

Test:	**Mann-Whitney test**			
Alternative hypothesis:	**1002: Pre versus Post**			
Performed by:	**GeoSyntec Consultants**			
n	48			
1002	**n**	**Rank sum**	**Mean rank**	**U**
Pre	23	651.0	28.30	200.0
Post	25	525.0	21.00	375.0
Difference between medians	1.289			
95.2% CI	0.065	to +?	(normal approximation)	
Mann-Whitney U statistic	200			
1-tailed p	0.0355	(normal approximation)		

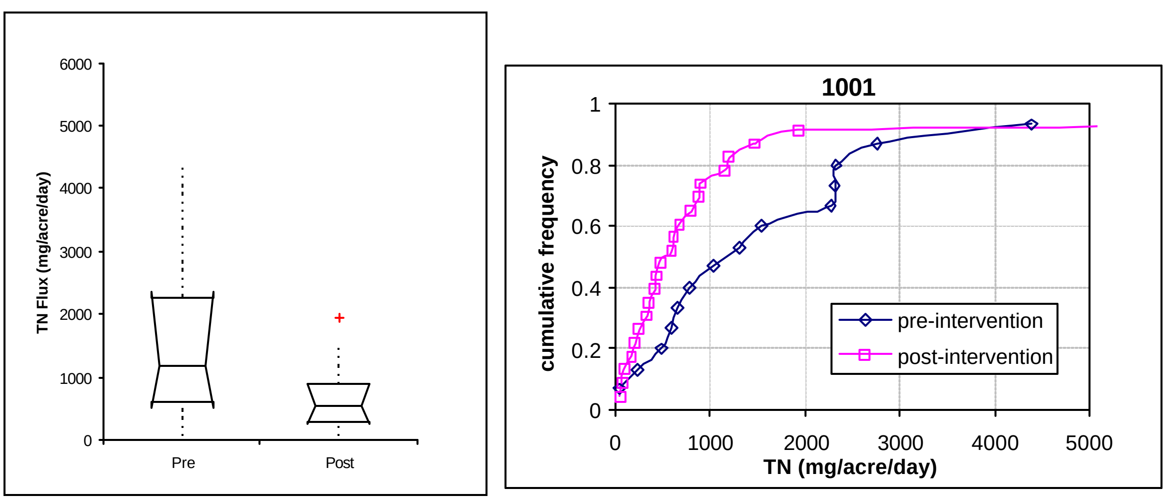
Table 5-10
Example Mann-Whitney Test for Difference in Medians for Total Nitrogen at Site 1005 from Pre- Versus Post-intervention.

Test:	**Mann-Whitney test**			
Alternative hypothesis:	**1005: Pre versus Post**			
Performed by:	**GeoSyntec Consultants**			
n	48			
1005	**n**	**Rank sum**	**Mean rank**	**U**
Pre	23	610.0	26.52	241.0
Post	25	566.0	22.64	334.0
Difference between medians	0.530			
95.2% CI	-0.446	to +?	(normal approximation)	
Mann-Whitney U statistic	241			
1-tailed p	0.1686	(normal approximation, corrected for ties)		

5.4.3.3 Comparison of Constituent Fluxes Before and After Intervention

The statistical procedures applied to the concentrations examples above were also applied to the constituent fluxes (mass loadings). For completeness, an abridged example analysis is provided here. Figure 5-8 includes side-by-side box plots and probability plots of total nitrogen flux data milligrams per acre per day (mg/acre/day) for Site 1001 at pre- and post-intervention. There appears to be a significant decrease in the median, as well as an overall reduction in the distribution of values.

Figure 5-8
Side-by-side Box Plot and Probability Plots of Pre- Versus Post-Intervention for Total Nitrogen Flues at Site 1001.



Table

Table 5-11 shows the results of the Mann-Whitney test (rank-sum) for the total nitrogen flux at Site 1001. The medians from pre- to post-intervention are statistically significantly different at the 95 percent confidence level ($p<0.05$). The magnitude of the difference (the Hodges-Lehmann estimator) is approximately 530 mg/acre/day, indicating a relatively large reduction in total nitrogen loads from the neighborhood. However, as discussed below, the extent to which the ET controllers contributed to this reduction is unclear.

The nitrogen fluxes used in this analysis were computed as the product of the measured concentration and the average daily flow. Therefore, the reduction in TN flux could be due to a reduction in flow, a reduction in concentration, or a combination of both. Analyses presented earlier showed a statistically significant reduction in median TN concentration at Site 1001 between the pre- and post-intervention periods. Similarly, analyses discussed elsewhere in this report indicate that there was a statistically significant reduction in flow at Site 1001 between the pre- to post-intervention periods; however, it was cautioned that the pre- and post-intervention periods are not comparable due to seasonal differences in the data collection period. Thus, observed reductions in flow in 1001 could be influenced by seasonal factors. Therefore, the extent to which the ET controllers contributed to a reduction in flow is unknown. Consequently, reductions in TN flux could be attributed to a combination of TN reduction, flow reduction, and/or seasonal factors.

Table 5-11
Example Mann-Whitney Test for Difference in Medians for Total Nitrogen Flux at Site 1001 from Pre-Versus Post-intervention.

Test :	**Mann-Whitney test**			
Alternative hypothesis	**1001 flux (mg/acre/day): Pre vs. Post**			
Performed by:	**GeoSyntec Consultants**			
n	36			
1001_flux (mg/acre/day)	**n**	**Rank sum**	**Mean rank**	**U**
Pre	14	320.0	22.86	93.0
Post	22	346.0	15.73	215.0
Difference between medians	529.389			
95.1% CI	115.985	to +?	(normal approximation)	
Mann-Whitney U statistic	93			
1-tailed p	0.0239	(normal approximation)		

The above results suggest that it would be valuable to complete a more robust statistical evaluation of the data because some significant management implications could be determined.

5.4.4 Watershed Implications

The water quality evaluation results were examined in the context of existing TMDLs in the San Diego Watershed. Most of the existing TMDLs are reviewed below, and possible inferences and implications of the R3 Study data for TMDL compliance are discussed. The sediment and organophosphorus pesticide TMDLs were not reviewed because sediment data was not collected

(the vast majority of sediments are transported by storm flows) and because Schiff and Tiefenthaler (SCCWRP, 2003) have previously conducted an extensive analysis of the OP pesticide data.

5.4.4.1 Comparisons with Regulatory Requirements

Mean dry-season concentrations for nutrients, toxics, metals, and pathogens at the R3 Study Sites were compared with regulatory objectives including TMDL's, California Toxics Rule (CTR) criteria, and Basin Plan objectives in Tables 5-12 and 5-13. These comparisons are strictly descriptive and provide a rough sense of dry-season residential water quality in comparison to regional water quality objectives. This comparison shows substantial variability between neighborhoods and among constituents.

Table 5-12
Comparison of Dry Season Concentrations of Nutrients and Toxics at R3 Study Sites with Regulatory Objectives

Parameter/Location	Objective	Site 1001	Site 1002	Site 1003	Site 1004	Site 1005
TIN (San Diego Creek Reach 1 / Reach 2)	13 mg/L / 5 mg/L (RWQCB-TMDL)	4.079 mg/L	0.464 mg/L	2.18 mg/L	18.16 mg/L	4 mg/L
		Percent of Samples above Toxics TMDL				
		Site 1001	**Site 1002**	**Site 1003**	**Site 1004**	**Site 1005**
Chlorpyriphos -Acute (San Diego Creek Reach 1)	18 ug/L (RWQCB-TMDL)	36.59	N/A	N/A	22.76	43.9
Chlorpyriphos - Chronic- (San Diego Creek Reach 1)	12.6 ug/L (RWQCB-TMDL)	46.34	N/A	N/A	26.02	49.59
Diazinon - Acute- (San Diego Creek Reach 1)	72 ug/L (RWQCB-TMDL)	70.73	N/A	N/A	69.11	73.17
Diazinon - Chronic- (San Diego Creek Reach 1)	45 ug/L (RWQCB-TMDL)	74.80	N/A	N/A	75.61	77.24

Table 5-13
Comparison of Dry Season Concentrations of Metals and Pathogens at R3 Study Sites with Regulatory Objectives

		Percent of Samples above CTR Criteria				
Parameter	**Objective**	**Site 1001**	**Site 1002**	**Site 1003**	**Site 1004**	**Site 1005**
Copper -Acute	13 ug/L (CTR Criteria for Metal Toxicity*)	43.59	43.59	46.14	46.15	71.79
Copper -Chronic	9 ug/L (CTR Criteria for Metal Toxicity*)	74.36	56.41	76.92	74.36	87.18
Lead -Acute	65 ug/L (CTR Criteria for Metal Toxicity*)	0	0	0	0	0
Lead -Chronic	2.5 ug/L (CTR Criteria for Metal Toxicity*)	10.26	28.21	10.26	12.82	28.21
Zinc -Acute	120 ug/L (CTR Criteria for Metal Toxicity*)	0	7.69	5.13	7.69	15.38
Zinc -Chronic	120 ug/L (CTR Criteria for Metal Toxicity*)	0	7.69	5.13	7.69	15.38
		Median Dry Season Fecal Coliform				
Parameter	**Objective**	**Site 1001**	**Site 1002**	**Site 1003**	**Site 1004**	**Site 1005**
Fecal Coliform	200 MPN/100 mL (RWQCB Basin Plan)	1400 MPN/100 mL	3000 MPN/100 mL	5000 MPN/100 mL	13000 MPN/100 mL	65000 MPN/100 mL

5.4.4.2 Nitrogen

Nitrogen Water Quality Objectives and TMDLs **–** The Basin Plan water quality objectives for nitrogen in San Diego Creek are 13 milligrams per liter (mg/L) Total Inorganic Nitrogen (TIN) in Reach 1, and 5 mg/L TIN in Reach 2 (RWQCB, 1995). Reach 1 extends from Newport Bay to Jeffrey Road, and Reach 2 extends from Jeffrey Road to the headwaters. There is no numeric standard for nitrogen in Upper Newport Bay in the Basin Plan.

The nitrogen TMDL for Upper Newport Bay is based on the general goal of reducing nutrient loads to Newport Bay by 50 percent, to levels observed in the early 1970s (USEPA, 1998b). The nitrogen TMDL sets phase-in limits on TN loads to Newport Bay (see Table 5-14). Separate loads are established for the dry and wet seasons (dry season is from April 1 to September 30). In addition, the winter load is exclusive of storm flows with an average daily flow greater than 50 cubic feet per second (cfs) in San Diego Creek at Campus Drive.

There is no TMDL for nitrogen loads in San Diego Creek, Reach 1 because it was reasoned that attainment of the 50 percent reduction in nitrogen loads to Newport Bay would result in compliance with the Basin Plan in-stream water quality standard for Reach 1 (13 mg/L TIN). However, for Reach 2, it was determined that the average in-stream nitrogen concentrations would likely remain close to or above the Basin Plan in-stream water quality standard (5 mg/L TIN), even with attainment of the Newport Bay TMDLs. Therefore a TMDL of 14 lbs/day TN

was established for Reach 2 (see Table 5-14) and is applicable for all flows exclusive of storm flows greater than an average daily flow of 25 cfs in San Diego Creek at Culver Drive.

Table 5-14
Summary of Nutrient TMDLs for Upper Newport Bay and San Diego Creek

TMDL	Dec 31, 2002	Dec 31, 2007	Dec 31, 2012
Newport Bay Watershed, TN – Summer load (4/1 to 9/30)	200,097 lbs	153,861 lbs	
Newport Bay Watershed, TN – Winter load (10/1 to 3/31; non-storm)			144,364 lbs
Newport Bay Watershed, Total Phosphorus – Annual Load	86,912 lbs	62,080 lbs	
San Diego Creek, Reach 2, daily load			14 lbs/day
Urban Runoff Allocation for the Newport Bay Watershed Summer load Winter load	22,963	11,481	38,283

Study Data Comparison with Nitrogen Water Quality Objective – The Basin Plan water quality objectives are expressed in terms of TIN, which is comprised of nitrate/nitrite nitrogen and ammonia. By far the majority of the TIN in San Diego Creek is comprised of nitrate/nitrite nitrogen, as measured ammonia concentrations were typically quite low with a majority below the detection limit. For this reason, only the nitrate/nitrate concentration data is compared to the Basin Plan objectives in this report.

Table 5-15 shows the mean and median nitrate/nitrite concentrations measured in the five study sites. The mean and median nitrate/nitrite concentration of all sites except 1004 was below the Reach 2 Basin Plan objective of 5 mg/L TIN. As discussed previously, Site 1004 may not be a representative control site because the underlying distribution of pre-intervention nitrogen data appears to be different from the other sites. Similar arguments may also be true for Site 1003. With the exception of Site 1004, mean nitrate/nitrite concentrations suggest that, on average, residential runoff from these sites does not contribute to the exceedance of Basin Plan standards for TIN in receiving waters in San Diego Creek, Reach 1 and 2. The Reach 2 water quality objective was occasionally exceeded in all sites, except for the post intervention conditions in 1001 and 1002.

Table 5-15
Mean and Median Nitrate/Nitrite Concentration (mg/l) by Site (all data).

	1001		1002		1003		1004		1005	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
n	23	25	23	25	24	25	23	25	24	25
Mean	2.56	1.47	2.57	1.07	2.13	1.71	36.50	6.61	2.61	4.13
Median	2.32	1.38	1.56	0.93	1.68	0.94	16.88	2.29	2.45	1.48
n>5 mg/L	1	0	4	0	1	2	18	8	2	1
n>13 mgL	0	0	0	0	0	0	12	4	0	1

The mean and median nitrate/nitrate concentrations in Sites 1004 and 1005 exhibit exceedances of the 5 mg/L standard during pre- and/or post intervention conditions. Site 1004, in particular, had high levels of measured nitrate/nitrite concentrations, especially during the pre-intervention period. A number of these high readings exceed the Reach 1 water quality objective of 13 mg/L TIN. The results from Site 1004 are not consistent with those from the other four study sites, and the source of the high readings is unknown. Localized conditions involving excessive fertilizer usage by a few users could possibly be a factor in these elevated readings. In particular, the R3 Study mentions an unknown connection to a neighboring watershed, which could explain the source of elevated nutrient levels.

The Mann-Whitney (rank-sum) test was performed to compare the statistical difference between median concentrations during pre- and post-intervention periods. The median nitrate/nitrite in the post-intervention period was lower at all sites, and the difference was statistically significant at the 0.05 confidence level. As the control stations exhibited this trend, the data (i.e. entire data sets with unequal seasonal coverage) cannot be used to ascertain if the structural and educational BMPs were effective in reducing the runoff concentrations of nitrate/nitrite.

Clearly another factor is contributing to reduced concentrations in the post-intervention period. One possibility that was investigated is differences in seasons, year-to-year variability, and sampling times of the pre- and post-intervention data. Table 5-16 presents mean and median concentrations for comparable seasons and sampling times. The table shows that there are still noticeable reductions in all of the median concentrations, except Site 1005. Applying the Mann-Whitney (rank-sum) test to the data, it was found that statistically significant differences between median nitrate/nitrite concentrations in the pre- and post-intervention periods occurred only at Sites 1001 and 1004, as compared to all sites when all data is considered. These results indicate that seasonal effects are present in the data and should be considered in the study evaluation. It may be inferred from these results that there were significant reductions in the nitrate/nitrite concentration in the intervention site during the wet season that may, in part, be attributable to the structural BMPs. It is unknown whether similar reductions would occur in dry weather runoff during the dry season because such data was not collected during the pre-intervention period.

Table 5-16
Mean and Median Nitrate/Nitrite Concentration (mg/l) by Site for Comparable Seasons and Sampling Times[1]

	1001		**1002**		**1003**		**1004**		**1005**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
n	18	14	18	14	19	14	18	14	19	14
Mean	2.38	1.43	1.95	0.95	2.17	1.66	26.24	6.57	2.24	6.27
Median	2.22	1.48	1.16	0.96	1.50	1.02	8.94	2.06	2.03	1.96
n>5 mg/L	0	0	2	0	1	1	13	4	1	1
n>13 mg/L	0	0	0	0	0	0	7	3	0	1

1 – evening samples were deleted from the pre-intervention data. The post-intervention data include only those data collected in months identical to the pre-intervention period.

Study Data Comparison with Nitrogen TMDLs - The nitrogen TMDL is expressed in terms of total nitrogen TN loads. TN concentrations were calculated from the monitoring data as the sum

of the nitrate/nitrite nitrogen and total Kjeldahl nitrogen (TKN) nitrogen. Table 5-17 shows the mean and median TN concentrations measured in the five study sites. The mean and median TN concentration in dry weather runoff are generally in the range of 2 to 5 mg/L, with the exception of Site 1004 where substantially higher concentrations were measured. The rank sum tests indicated that median TN concentrations were significantly lower (in a statistical sense) in the post-intervention period in Site 1001 (structural BMPs, see Table 5-8), and at Site 1002 (control, see Table 5-9). Based on the probability plots in Appendix E2, Site 1004 is expected to as well. However, Sites 1003 and 1005 did not show statistically significant reductions. These results did not change when only subsets of the data were used to consider possible effects stemming from the sampling time and sampling months.

Table 5-17
Mean and Median TN Concentration (mg/l) by Site

	1001		**1002**		**1003**		**1004**		**1005**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
All Data										
n	23	25	23	25	23	25	23	25	23	25
Mean	4.24	3.09	5.31	3.44	3.66	4.42	48.00	10.18	6.89	7.74
Median	3.84	2.27	3.95	2.55	2.66	2.50	19.01	5.57	5.06	4.36
Subsets[1]										
n	18	14	18	14	18	14	18	14	18	14
Mean	4.18	2.78	4.51	2.63	3.71	3.71	33.99	8.91	6.98	9.91
Median	3.62	2.02	3.22	2.21	2.51	2.47	12.14	3.74	4.17	3.96

1 – Data subsets with comparable sampling time and seasons. Evening samples were deleted from the pre-intervention data. The post-intervention data include only those data collected in months identical to the pre-intervention period.

TN flux estimates were calculated for Sites 1001 and 1005 (Table 5-18). The flow measurements at Sites 1002 to1004 are not reliable. Therefore, flux estimates were not calculated for these sites. Flux estimates were calculated as the product of the constituent concentration and the average daily flow occurring on the day of the sample collection. The flux estimates were found to be quite variable as they depend on both flow and concentration measurements. Table 5-18 shows that median TN flux estimates decreased from the pre- to post-intervention periods for both sites. Mann-Whitney (rank sum) tests show the reductions to be statistically significant (Table 5-11). Because comparable data is not available for the control sites, it is not possible to infer whether these reductions are influenced by the ET controllers in the intervention site (1001). Also, as previously discussed, the reduction in TN flux may be attributable to a reduction in flow, a reduction in concentration, seasonal factors, or a combination of these.

Table 5-18
Mean and Median TN Flux (mg-N/acre/day) by Site

	1001		1005	
	Pre	**Post**	**Pre**	**Post**
All data				
n	14	22	10	21
Mean	1476	1667	2104	6537
Median	1164	530	1568	1177
Subset[1]				
n	12	14	10*	8
Mean	1384	587	2104	1716
Median	902	497	1568	960

1 – Data subsets with comparable sampling time and seasons. Evening samples were deleted from the pre-intervention data. The post-intervention data include only those data collected in months identical to the pre-intervention period.
* – Same as the all data case

Although the flux estimates in Table 5-18 are limited in number, duration, and location, they can be used to speculate about the magnitude of the urban area contribution of TN loads to Newport Bay and the potential reduction in loads from structural and nonstructural BMPs. Based on the limited flux data, the annual TN load to Newport Bay in dry weather runoff from urban areas in the San Diego Creek Watershed is estimated to range between 37,000 to 50,000 lbs per year under existing land-use conditions (see Table 5-19). This is for the most part below the 2012 urban runoff allocation of 49,764 lbs. The annual TN load is estimated to increase to 50,000-67,000 lbs per year under build-out conditions.

According to the 2001 report on the nutrient TMDL (OCPFRD, 2001), the average daily TN load in San Diego Creek at Campus Drive was 540 lbs/day between July 2000 and June 2001. This converts to an annual load of about 197,000 lbs, which is below the 2007 TMDL (note: San Diego Creek is the majority but not sole contributor of TN loads to Newport Bay). Estimates in Table 5-19 suggest that dry weather runoff from urban areas account for about 20 to 25 percent of the annual TN in the San Diego Creek Watershed. If it is assumed that flux reductions observed in the post intervention period are attributable to the structural and nonstructural BMPs, and if similar interventions could hypothetically be implemented on a watershed-wide basis, then the potential reduction in annual dry weather TN loads is estimated to range between 12,500-20,000 lbs. This would represent a reduction of about 6-10 percent of the current TN loads and about 30-40 percent of the estimated current dry weather urban loads. These estimates are based on few data collected in a limited area and should therefore be considered preliminary in nature.

Table 5-19
Estimated Annual TN Loads in Dry Weather Runoff from Urban Areas in the San Diego Creek Watershed

	TN flux (mg-N/acre/d)	**Annual TN Load to Newport Bay (lbs) Existing land-use[1]**	**Annual TN Load to Newport Bay (lbs) Built-out land-use[2]**
Pre-intervention conditions	1160 – 1560	37,300 – 50,500	50,000 – 67,000
Post-intervention conditions	530 – 1180	17,000 – 38,000	23,000 – 51,000
Potential reduction		~12,500 – 20,000	~16,000 – 27,000

1 –Used 40000 acres or about 53% of the San Diego Creek Watershed area (IRWD, 2003). For comparison, urban land use in 1999 use was estimated at 35,500 acres of the watershed area at Campus Drive (Tetra-Tech, 2000).
2 – Used 53500 acres or about 71% of the San Diego Creek Watershed area (IRWD, 2003).

The following conclusion can be made based on the analyses above:

- Average and median nitrate/nitrite concentrations in dry weather runoff are below the Reach 2 water quality objective (5 mg/L), for most but not all study sites.
- Occasional exceedance of the Reach 2 water quality objective occurred in all study sites.
- The majority of measured nitrate/nitrite concentrations at Site 1004 during the pre-intervention period were greater than the Reach 2 water quality objective of 5 mg/L. The data is not consistent with those from the other sites. The cause is unknown, but could possibly be related to the unknown connection to the neighboring nursery discussed in the R3 report.
- Sampling periods (months) and sampling time (morning versus evening) were found to affect the statistical significance of differences between pre- and post- intervention median nitrate/nitrate concentration in some of the sites. The sampling period and sampling time did not affect the statistical significance of differences between pre- and post-intervention median TN concentrations.
- Median TN fluxes at Sites 1001 and 1005 were statistically smaller in the post-intervention period. The extent to which the structural and nonstructural BMPs contributed to these reductions cannot be determined due to the lack of reliable flow data in the control sites.
- Preliminary estimates of annual TN loads to Newport Bay in dry weather runoff from urban sources range between 37,000 to 50,000 lbs per year, or about 20 to 25 percent of the current TN loads.
- The potential reductions in annual dry weather TN loads due to implementation of BMPs on a watershed basis is estimated to range between 12,500-20,000 pounds per year. This would represent a reduction of about 6-10 percent of the current TN loads and 30-40 percent of the urban loads.

5.4.4.3 Phosphorus

The majority of the annual TP load in the San Diego Creek Watershed occurs in the wet season, and has been correlated with sediment loads generated by storm events (USEPA, 1998b). This

correlation suggests that a majority of phosphorus occurs in particulate form attached to sediments. The main sources of the TP are in Peters Canyon Wash and San Diego Creek above Culver Drive (USEPA, 1998b).

Phosphorus TMDL **–** There is no numeric objective for phosphorus for San Diego Creek in the Basin Plan. Because measured TP and sediment loads are correlated, it was determined in the TMDL that a 50 percent reduction in TP loads would be achieved through compliance with the sediment TMDL (USEPA, 1998a). Accordingly, the TMDL for TP was based on a 50 percent reduction of average annual load estimated at 124,160 lbs (USEPA, 1998b). The TMDLs are applicable for all flow conditions. The target compliance date was set for December 31, 2007.

The annual TP load allocation for urban areas is 4102 lbs by 2002, reducing to 2960 lbs by 2007. According to the USEPA (1998b), the TP is allocated in the same proportion as sediments. The annual urban area (stabilized vs. construction) sediment allocation for the Newport Bay Watershed is 50 tons distributed over 95.3 square miles (see Table 5 in USEPA, 1998a). This is a very small allocation over a large area. By contrast, the annual construction allocation is 6500 tons distributed over the assumed 3.0 square miles under construction in any one year. Using the same proportions of sediment load allocations, the TP load rate based on the 2007 urban allocation is 2960 lbs/95.3 square miles = 0.0485 lbs/acre/yr. If the construction and urban allocations are combined, the TP load rate based on the combined 2007 urban and construction allocations is (2960+12810) lbs/(95.3+3.0) square miles = 0.251 lbs/acre/yr.

Study Data Comparison with TMDLs **–** Similar to the nitrogen TMDL, the phosphorus TMDL is expressed in terms of total annual TP loads. Table 5-20 shows the mean and median TP concentrations measured in the five study sites. The mean and median TP concentrations in dry weather runoff are below 1.2 mg/L in all sites, with the exception of Site 1004, where substantially higher concentrations were measured. Comparison of the pre- and post-intervention median TP concentrations in all data (Table 5-20) reveals an increase in the median TP concentration during the post-intervention period for all sites except the intervention Site 1001 and Site 1004. In contrast, when subsets of the data with similar seasons and sampling times are considered (Table 5-20), there is a decrease in the median TP concentration at all sites except 1005. This indicates that there are seasonal influences in the data, which presumably are related to rainfall. Unfortunately, no data is available to permit comparison of pre- and post-intervention concentrations for dry weather flows during the dry season.

Table 5-20 Mean and Median TP Concentration (mg/l) by Site

	1001		**1002**		**1003**		**1004**		**1005**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
All Data										
n	23	25	23	25	24	25	23	24	24	25
Mean	0.73	0.60	0.92	0.84	0.98	1.21	3.33	1.50	1.01	1.19
Median	0.60	0.51	0.77	0.82	0.62	0.67	2.54	1.05	0.73	0.85
Subsets[1]										
n	18	14	18	14	19	14	18	13	19	14
Mean	0.78	0.47	0.91	0.67	1.13	0.57	2.62	1.33	0.93	1.24
Median	0.61	0.41	0.73	0.56	0.75	0.58	1.82	1.07	0.75	0.83

1 – Data subsets with comparable sampling time and seasons. Evening samples were deleted from the pre-intervention data. The post-intervention data include only those data collected in months identical to the pre-intervention period.

TP flux estimates were calculated for Sites 1001 and 1005 using the approach discussed in the nitrogen section above. Table 5-21 shows that median TP flux estimates decrease from the pre- to post-intervention periods at the intervention site (1001), but not in the education only site (1005). Mean fluxes increased at both sites. However, as discussed earlier, the mean values are strongly influenced by outliers and do not provide a good measure of central tendency for the data. Application of the Mann-Whitney (rank sum) test shows the reduction in median TP flux at Site 1001 is statistically significant. This suggests that the structural BMPs had a positive influence in reducing the TP fluxes. However, because comparable data is not available for the control sites, it is not possible to ascertain the extent to which the ET controllers contributed to these reductions. Also, as discussed previously, reductions in flux could be influenced by several factors: reduction in concentration, reduction in flow, and/or seasonal variability.

Table 5-21
Mean and Median TP Flux (mg-P/acre/day) by Site (all data)

	1001		**1005**	
	Pre	**Post**	**Pre**	**Post**
All data				
n	14	22	10	21
Mean	265	370	473	1327
Median	164	109	219	219

Similar to the previous analyses of TN loads, the TP flux estimates in Table 5-21 can be used to speculate about the magnitude of the urban area contribution of TP loads to Newport Bay and the potential reduction in loads from structural BMPs. Based on the limited flux data, the annual TP load to Newport Bay in dry weather runoff from urban areas in the Newport Bay Watershed is estimated to range between about 5,000 to 11,000 lbs per year (see Table 5-22), assuming a total urban area of 95.3 square miles obtained from Table 5 of the sediment TMDL (USEPA, 1998a). These estimated annual TP loads are greater than the urban allocation (for both dry and wet weather) and are less than the combined urban and construction allocations (Table 5-22). However, these estimates are based on dry weather data only, and it is expected that a major portion of the TP loads will occur in runoff from winter storms. Therefore, actual annual TP loads would be expected to be greater. If it is hypothesized that flux reductions observed at the intervention site (1001) could be realized over the entire watershed, then the potential reduction in annual dry weather TP loads from urban areas is estimated at 2700 lbs. As stated previously, these estimates are based on few data collected in a limited area and should therefore be considered preliminary in nature.

Table 5-22
Estimated Annual TP Loads in Dry Weather Runoff from Urban Areas in the San Diego Creek Watershed

	TP flux (mg-P/acre/d)	**Annual TP Load Rate to Newport Bay (lbs/acre/year)[1]**	**Annual TP Load to Newport Bay (lbs/year)**
2007 Urban Area Allocation for Newport Bay		0.0485	2960
2007 Combined Urban and Construction Area Allocation for Newport Bay		0.251	15770
Pre-intervention conditions (median fluxes)	164 – 219	0.132 – 0.176	8049 – 10748
Post-intervention conditions (median fluxes)	109 – 219	0.088 – 0.176	5350 – 10748
Potential reduction			2700

1 - urban area is 95.3 square miles and the construction area is 3.0 square miles based on Table 5 in USEPA,1998a

5.4.4.4 Metals

Metals TMDLs **–** The USEPA (June 2002) determined that TMDLs are required for dissolved copper, lead, and zinc in San Diego Creek, Upper Newport Bay, and Lower Newport Bay, and that TMDLs are required for cadmium in San Diego Creek and the Upper Newport Bay. The TMDLs for San Diego Creek are expressed as concentration limits, based on the California Toxic Rule (CTR) criteria at various hardness values that are associated with different flow regimes (Table 5-23). The flow regimes are based on 19 years of flow measurements in San Diego Creek at Campus Drive. The concentration-based TMDLs apply to all freshwater discharges to San Diego Creek, including discharges from agricultural, urban, and residential lands, and storm flow discharges. The applicable flow regime at any location in the entire watershed is determined on the basis of discharge at Campus Drive.

Table 5-23
Summary of Dissolved Metal TMDLs for San Diego Creek

Dissolved Metal (?g/l)	**Base flow (0–20 cfs) hardness @ 400 mg/L**		**Small flows (21-181 cfs) hardness @ 322 mg/L**		**Medium flows (182-814 cfs) hardness @ 236 mg/L**		**Large flows (>814 cfs) hardness @ 197 mg/L**
	Acute	**Chronic**	**Acute**	**Chronic**	**Acute**	**Chronic**	**Acute**
Cadmium	19.1	6.2	15.1	5.3	10.8	4.2	8.9
Copper	50	29.3	40	24.3	30.2	18.7	25.5
Lead	281	10.9	224	8.8	162	6.3	134
Zinc	379	382	316	318	243	244	208

Metals Sources **–** The USEPA (June 2002) conducted a source analysis as part of the TMDL preparation. Surface runoff is the largest contributor of metals loads in the San Diego Creek watershed, which includes natural and man made sources (USEPA, June 2002). Much of the metals loads are from natural sources. The estimated anthropogenic contributions are metal specific and range from about 33 percent for zinc to 63 percent for cadmium (USEPA, June 2002). A primary anthropogenic source of heavy metals is runoff from urban roads, which contributes to sources of cadmium (tire wear), copper (brakes, tires), lead (brakes, tires, fuels and oils), and zinc (tires, brakes, galvanized metals). Use of copper sulfate by nurseries may also be a minor source of copper loads. Other copper and zinc uses in building materials (roofing and roof drains) may be another source.

The USEPA found that metal inputs were heavily influenced by rainfall and stream flow rates. Monitoring results were reported to be highly variable due to different rainfall amounts and flows during each water year. The USEPA estimated that base flows account for 25 percent of the total metal loadings, with the remainder from low, medium and large flows caused by storms.

The USEPA's preliminary analyses suggest that: 1) a primary source of metals in dry weather runoff in the study watershed is from roads (i.e. wash off of metals in driveways, parking lots, streets, gutters, etc.); 2) the runoff concentrations will be influenced by rainfall which result in wash off of accumulated metals; and 3) the concentrations can be variable depending on the amount of rainfall.

Study Data Comparison with Base Flow TMDLs **–** The metals TMDLs for base flow conditions are based on meeting the CTR criteria at a total hardness of 400 mg/L. The CTR criteria express maximum allowable concentrations in receiving waters for acute (short term) and chronic (4-day) exposure periods. The acute and chronic criteria are expressed as values that cannot be exceeded more that once in three years. Although the criteria are applicable in the receiving waters and not in the urban runoff per se (i.e. the measured dry weather discharge), exceedance of the CTR in the urban discharge would suggest a potential for the discharge to contribute to an exceedance in the receiving waters.

Table 5-24 shows the mean and median heavy metal concentrations in the five study sites. With the exception of mean copper concentrations in some of the sites, all mean and median concentrations were below the chronic and acute CTR criteria. Copper, lead, and zinc concentrations occasionally exceeded the chronic CTR criteria, and copper and zinc concentrations occasionally exceeded the acute criteria. These exceedances suggest that the dry weather runoff can potentially contribute to an exceedance in the receiving waters. However, if intervention is determined to be effective in reducing runoff flows, then the BMPs would help to reduce impacts of these potential exceedances by allowing for greater dilution with the in-stream flows.

Table 5-24
Mean and Median Metal Concentrations (mg/L) by Site (all data)

	1001		1002		1003		1004		1005	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Cadmium										
n	23	25	23	25	24	25	23	25	24	25
Mean	0.26	0.14	0.47	0.44	0.27	0.17	0.64	0.22	0.21	0.29
Median	0.27	0.10	0.24	0.10	0.10	0.10	0.36	0.10	0.10	0.10
n>6.2 ? g/l	0	0	0	0	0	0	0	0	0	0
n>19.1 ? g/l	0	0	0	0	0	0	0	0	0	0
Copper										
n	23	25	23	25	24	25	23	25	24	25
Mean	13.5	16.9	27.3	30.3	11.5	26.6	21.8	17.7	32.1	30.8
Median	11.5	11.4	10.9	14.0	11.1	14.3	12.7	11.4	12.3	20.4
n>29.3 ? g/l	2	2	3	7	0	2	5	4	3	5
n>50 ? g/l	0	1	3	3	0	2	2	3	3	2
Lead										
n	23	25	23	25	24	25	23	25	24	25
Mean	0.8	1.6	5.9	4.7	0.8	1.6	3.5	1.5	1.0	3.2
Median	0.6	0.6	0.9	1.2	0.6	0.8	0.7	0.7	0.7	1.3
n>10.9 ? g/l	2	1	2	3	0	0	2	0	0	1
n>281 ? g/l	0	0	0	0	0	0	0	0	0	0
Zinc										
n	23	25	23	25	24	25	23	25	24	25
Mean	58.7	37.2	115.2	86.3	56.3	56.8	83.6	40.9	74.0	75.0
Median	56.0	50.2	53.4	57.2	50.7	53.9	50.8	43.8	52.4	54.5
n>382 ? g/l	0	0	1	2	0	0	1	0	0	0
n>379 ? g/l	0	0	1	2	0	0	1	0	0	0

Dry weather metals monitoring information in the Central Irvine Channel, the immediate receiving water of the study watersheds, was unavailable. OCPFRD dry weather monitoring data is available in San Diego Creek at Campus Drive, which is quite a way downstream from the study sites. Data collected between December 2001 and June 2002 (Table 5-25) shows that average dry weather concentrations at Campus Drive are well below mean and median concentrations measured in dry weather runoff from the study watershed. Similar comparisons cannot be made for lead and cadmium because the method detection limits in the OCPFRD data are greater than those in the R3 data. None of the OCPFRD dry weather data exceeded the chronic or acute criteria.

Table 5-25
Summary of OCPFRD Dry Weather Monitoring Data of San Diego Creek at Campus Drive (12/01 to 6/02)

	Cadmium	Copper	Lead	Zinc
Sample number	24	24	24	24
Range	All < 1 ?g/l	<2 – 16 ?g/l	<2-2.4 ?g/l	<10-16
Mean		7.4 ?g/l	most <2 ?g/l	most <10
Median-		6.8?g/l		

These comparisons suggest that metal loads in dry weather runoff from the study (urban) watersheds could be a contributing factor to dry weather copper and zinc loads measured at Campus Drive. These dry weather discharges do not result in non-compliance of the base flow metal TMDL at Campus (based on the reviewed data only). It is unknown if the elevated

concentrations measured in the dry weather urban runoff result in exceedance of the CTR criteria in the immediate receiving waters. If flow reductions observed in the intervention watershed are attributable to the ET controllers, then these controllers would help to reduce impacts from any potential exceedances of the TMDL because the discharges would be subject to greater dilution by the in-stream flows.

5.4.4.5 Pathogens

Pathogens are agents or organisms that can cause diseases or illnesses, such as bacteria and viruses. Fecal coliform bacteria are typically used as an indicator organism because direct monitoring of human pathogens is generally not practical. Fecal coliform are a group of bacteria that are present in large numbers in the feces and intestinal tracts of humans and animals, and can enter water bodies from human and animal waste. The presence of fecal coliform bacteria implies the water body is potentially contaminated with human and/or animal waste, suggesting the potential presence of associated pathogenic organisms.

Fecal Coliform TMDL **–** The RWQCB has adopted phased TMDL criteria for pathogens, with the initial focus on additional monitoring and assessment to address areas of uncertainty. The goal of the Newport Bay TMDL is compliance with water contact recreational standards by 2014:

- Fecal coliform concentration of not less than five samples per 30 days shall have a geometric mean less than 200 MPN/100 ml, and not more than 10 percent of the samples shall exceed 400 MPN/100ml for any 30-day period.

A second goal is to achieve the shellfish harvesting standards by 2020:

- The monthly median fecal coliform concentration shall be less than 14 MPN/100 ml, and not more than 10 percent of the samples shall exceed 43 MPN/100 ml.

The TMDLs are applicable for all flow regimes.

Study Data Comparison with Fecal Coliform TMDLs **–** Table 5-26 shows the mean and median fecal coliform concentrations measured in the five study watersheds. From 70 percent to 100 percent of all fecal coliform measurements were greater than 400 MPN/ml in all study watersheds. This level of exceedance is substantially greater than the allowable 10 percent. The mean and median fecal coliform concentrations also exceed the 400 MPN/100ml criterion in all study watersheds. There was insufficient data to calculate the 30-day geometric mean (a minimum of 5 samples per 30 days needed). However, the TMDL criterion (30-day geometric < 200 MPN/100 ml) would likely be exceeded, assuming that any additional data would be of the same magnitude as those collected. Exceedance of the TMDL criteria in all study watersheds suggests that urban dry weather runoff is likely a contributing factor to any dry weather exceedance of the TMDL in the receiving waters.

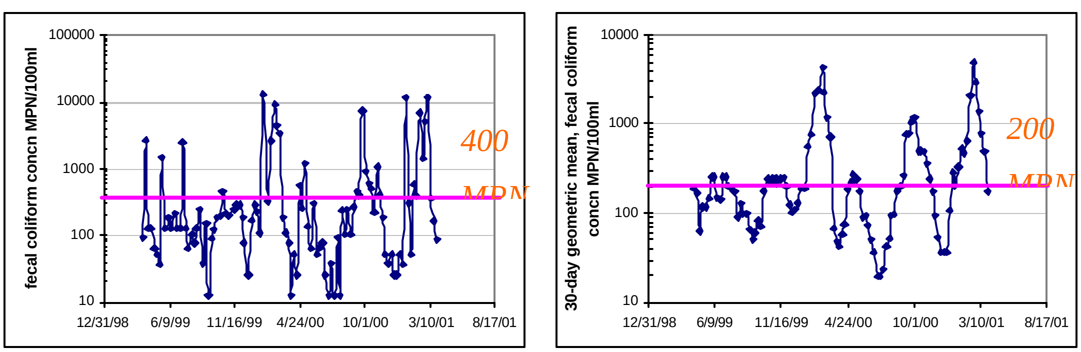
Table 5-26
Mean and Median Fecal Coliform Concentration (MPN/100ml) by Site

	1001		1002		1003		1004		1005	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
All Data										
n	22	24	21	24	23	24	21	24	23	24
Mean	4921	3003	5582	128193	34526	28980	28205	34185	17976	10326
Median	2300	1400	1700	3000	13000	4000	13000	13000	8000	8000
% > 400 MPN/100ml	82%	67%	86%	79%	100%	88%	95%	83%	92%	93%
Subsets[1]										
n	17	14	17	14	18	14	17	14	18	14
Mean	2545	3054	3090	5074	13783	37479	23312	20166	8524	6109
Median	2200	950	1400	1400	8000	2650	8000	6500	4000	2900
% > 400 MPN/100ml	100%	71%	82%	79%	100%	86%	94%	79%	100%	93%

1 – Data subsets with comparable sampling time and seasons. Evening samples were deleted from the pre-intervention data. The post-intervention data include only those data collected in months identical to the pre-intervention period.

Dry weather coliform monitoring information in the Central Irvine Channel was not available. Therefore, it is unknown if elevated fecal coliform concentrations measured in the study watershed contribute to an exceedance of the TMDL in the immediate receiving waters. The OCPFRD has collected dry and wet weather *E. coli* monitoring information in San Diego Creek at Campus Drive (OCPFRD, September 2001), which is considerably downstream from the study watersheds. A plot of the equivalent fecal coliform concentration (assuming an 80 percent *E. coli* content) shows exceedance of the TMDL occurs primarily during the wet season, although dry season exceedances are also evident (see Figure 5-9). This suggests that dry weather urban runoff is potentially a contributing factor to exceedance of the TMDL in dry weather flows at Campus Drive. The ET controllers would reduce the impacts from these potential exceedances if they were determined to be effective in reducing the dry weather runoff volumes.

Figure 5-9
Time Series of Fecal Coliform Levels of San Diego Creek at Campus Drive (converted from measured E. *coli* concentrations)



Median fecal coliform concentrations presented in Table 5-26 may be used to evaluate the influence of the structural and non-structural BMPs. When all monitoring data sets are

considered, the median fecal coliform concentrations are equivalent or increase from pre- to post- intervention conditions in all sites except the 1001 (intervention site) and 1003 (a control site). Based on the Mann-Whitney (rank-sum) test, the reduction in median concentrations at Site 1001 and 1003 is significant at the 95 percent confidence level. Thus the site with the irrigation controllers corresponded to a significant reduction in median fecal coliform concentrations, in comparison to two of the three control sites, while the education only watershed exhibited no discernable reduction in median concentrations.

When subsets of the data with similar seasons and sampling times are considered (Table 5-26), there is a decrease in the median fecal coliform concentration at all sites except 1002. However, because of the smaller sample sizes, the decrease is median concentration is statistically significant only at Site 1003. This suggests that there could be seasonal influences in the monitoring data, but the data is not sufficient to determine if there are statistically significant differences in the median concentrations.

5.5 Conclusions

The initial review of water quality data from the study found virtually no difference in concentrations or pollutant flux over time. The technological and education treatments provided essentially no detectable increase or decrease in water quality following the intervention.

The follow-up review utilizing more robust statistical methods on a sample of study data suggests that the interventions did result in changes in water quality. TN levels in the retrofit neighborhood following intervention were found to be significantly lower than levels before intervention, whereas no detectable differences were noted before and after intervention in the education neighborhood. Relatively large observed reductions in TN flux in the retrofit neighborhood could be influenced by seasonal factors, and the extent to which the ET controller contributed to the reduction is unknown. Similarly, although reductions in TP flux were observed in the retrofit neighborhood, the effect of the ET controllers cannot be determined.

Chapter 6: Public Education

6.1 Overview

This chapter discusses issues pertaining to public acceptance of water conservation and runoff reduction measures. Specific information is provided on:

- Evaluation approach, including development of ET controller + education and education-only BMPs
- Customer interaction
- Evaluation results, as measured through responses to pre- and post-intervention customer surveys

More detailed information is provided in Appendix F.

6.2 Evaluation Approach

The public acceptance evaluation was conducted to compare the effectiveness of proposed BMPs for ET controller technology + education and education only. There were three groups of R3 Study participants: 1) participants who had their home irrigation controllers replaced with an ET controller and who received educational materials, 2) participants who received educational materials only, and 3) control groups, who received no interventions. The retrofit participants were selected through random "cold knocking" and through letter solicitations that explained the study. The education group was self and randomly selected. Some of the education group participants voluntarily chose to participate in the study by replying to a letter. However, the majority was randomly selected through a door-to-door campaign.

6.2.1 ET Technology + Education (Retrofit Group)

For the R3 Study, existing sprinkler timers that are set manually by the homeowner were replaced with the radio controlled ET controller systems. Trained technicians were used to ensure successful installation because ET controllers require programming for each valve including area (size of yard or planter per valve), soil type (clay, sand, etc.), and landscape type (turfgrass, shrubbery, etc.). The remaining irrigation system was unchanged, including piping and sprinkler head configuration.

The participating ET technology retrofit group homes received a site evaluation and installation of an ET controller to manage the irrigation system. Additionally, the residents of these homes received information regarding environmentally sensitive landscape practices. The controllers were installed in 112 residential homes, two condominium associations' landscapes, two HOA landscapes, one pool/park setting, and 12 city street landscapes.

Public education materials were also provided, as described in Section 6.2.2.

6.2.2 Education Only

Educational materials were provided to both the retrofit and education-only groups. Public education consisted of an initial informational packet containing three items. The first item was an introductory letter that described the purpose of the packet. The second item was a booklet with irrigation, fertilization, and weed and pest control information. The centerfold of the booklet was a month-by-month guide to irrigating, fertilizing, and pesticide application suitable for posting near the sprinkler timer. Third, each homeowner was supplied a soil probe for measuring the water content of the landscaped soils. In addition to the initial packet, monthly reminders were mailed to each homeowner including landscape maintenance tips about irrigation system, watering schedule, fertilizing, and weed and insect control. Suggested sprinkler run times (for the non-ET sprinkler neighborhood) and fertilizer or pesticide application usage, including non-toxic alternatives, were also provided in the monthly newsletter. A representative collection of the public information tools used for the R3 Study is provided in Exhibits A through D at the end of this section.

6.2.3 Customer Interaction

Home residents were advised that if they had any problems with the controller or if the controller required any adjustments, they should call the water district for assistance. IRWD's customer service department telephone number was left on a sticker on the ET controller. All calls related to the ET controller were logged in separately and routed to the appropriate staff member for assistance. Table 6-1 shows the number of calls that were received from residential residents during the R3 study period.

Table 6-1
Calls from Residential Customers in R3 Study

April 2001	1	August 2001	13	December 2001	1	April 2002	2
May 2001	12	September 2001	4	January 2002	4	May 2002	3
June 2001	7	October 2001	5	February 2002	9	June 2002	6
July 2001	13	November 2001	3	March 2002	4	July 2002	2

Generally, there were four common types of calls: 1) customer misunderstanding the way the ET controllers were supposed to operate, 2) installation-related issues, 3) maintenance or system design issues, and 4) ET controller malfunctioning. These issues were addressed and resolved. (See Appendix F.)

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6.3 Customer Surveys

This section describes pre-and post-intervention surveys developed to measure public acceptance.

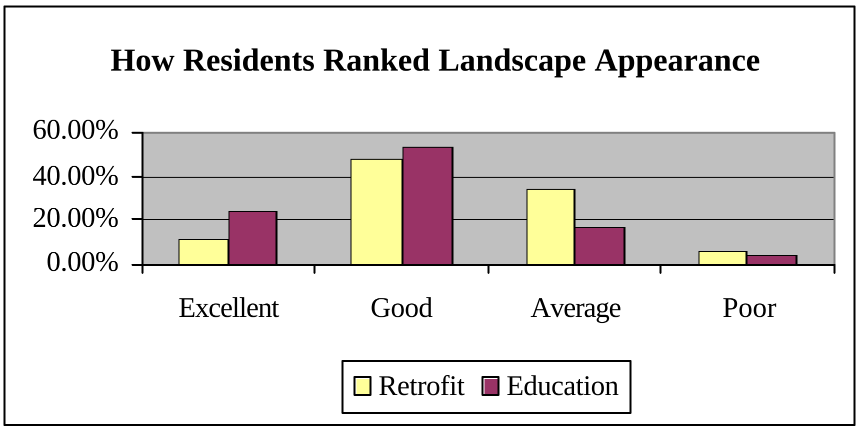
6.3.1 Pre-survey

The purpose of the pre-survey was to determine if the retrofit group and the education group had similar irrigation practices and attitudes. The pre-survey was distributed to the retrofit group while installation of the controller was taking place. Retrofit study participants were asked to fill

out the survey while staff was installing the controller. The education group received their survey as part of the initial educational packet that was randomly distributed to residents. Education group participants were provided a stamped addressed envelope to return their survey to the IRWD. Ninety-seven percent (109/112) of those that received a survey from the retrofit group mailed the survey back. Twenty-four percent (53/225) of residents in the education group mailed back a survey. Pre-survey results are tabulated in Appendix F and summarized below.

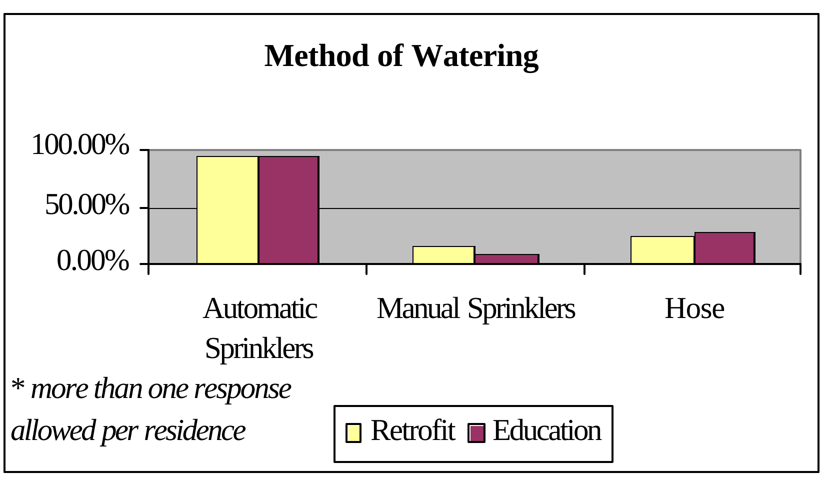
Figure 6-1 shows the responses of both of the groups. Similar responses were given. A majority of the residents in both groups believed that the appearance of the yard is average to good. It should be noted that the "excellent" response was selected by more of the education group than the retrofit group. One possible explanation for this response is that the staff was on-site while people were filling out their survey in the retrofit group.

Figure 6-1



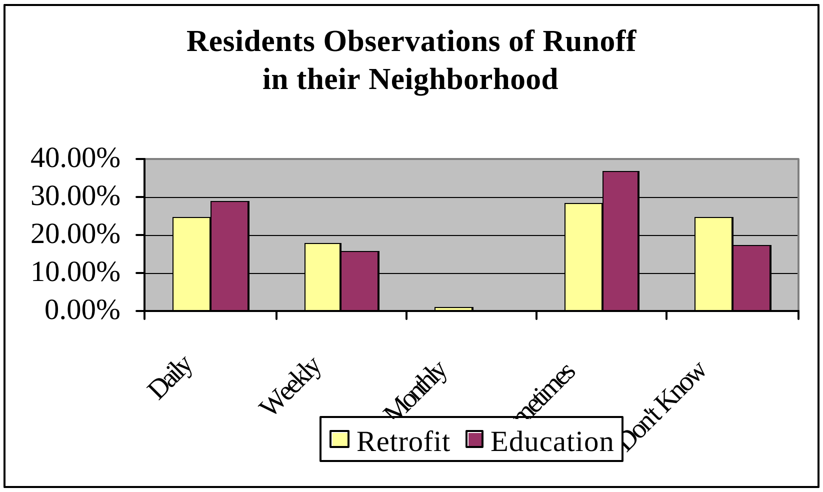
When residents were asked how they watered their lawn, the responses across groups were very similar. The percentage of people in the retrofit and education group that use automatic sprinklers, manual sprinklers, or a hose are similar. The survey shows that the retrofit and education groups have similar watering behaviors. As shown on Figure 6-2, the majority of the participants used automatic sprinklers. This is important because the R3 Study focuses on retrofitting the automatic irrigation controllers as a water management tool.

Figure 6-2



Residents were asked how often they observed runoff in their neighborhood. As presented on Figure 6-3, the data shows that residents in both groups have similar attitudes and views of urban runoff.

Figure 6-3



Residents were asked if they used fertilizers in their landscape, and chemicals to control pests or weeds. As shown on Figure 6-4, fertilizer use in both groups is almost the same. Results for chemical use were also similar for both groups. (See Figure 6-5.)

Figure 6-4

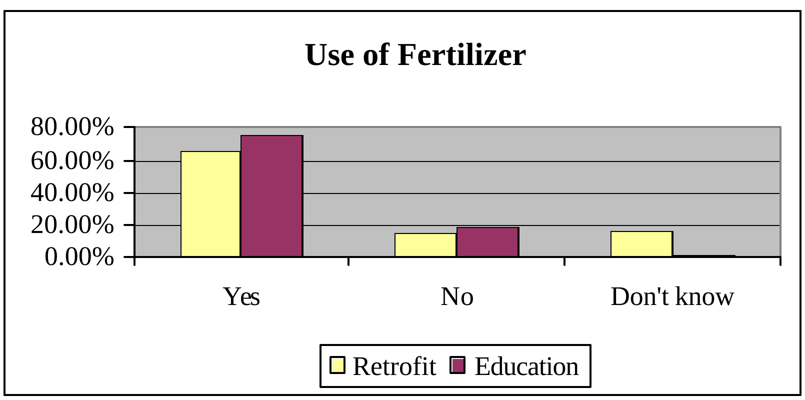
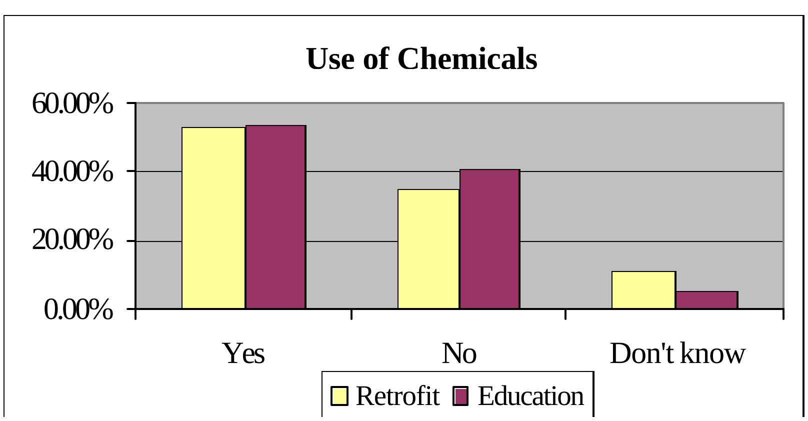


Figure 6-5



The purpose of the post-survey was to determine the attitudes of the study participants towards the ET controller and to determine if the education material had an impact on modifying behavior of the recipients. The post-survey was distributed to both of the groups through the mail. Twenty-three percent (52/225) of the education group participants responded to the survey, and forty-five percent (50/112) of the retrofit group participants responded. Post survey results are tabulated in Appendix F and summarized in the tables and text below.

6.3.2 Post-survey

Table 6-1 summarizes responses of the retrofit group compared to responses from the education group. The majority of the retrofit households acknowledged their satisfaction with the ET controller's performance and agreed that they would recommend the ET controller to their friends. It appears that the residents liked the controller and did not mind having someone else manage their irrigation-watering schedule. Data shows that households accepted the controller as a method of saving water, reducing runoff, and watering their landscapes. The survey shows that twice the number of retrofit households observed a decrease in their water bill than the education households did. A majority of the education households did not observe a change in their water bills. Data appears to show that the appearances of the retrofit landscapes were ranked equally with those landscapes that were part of the education group. It can therefore be concluded that the survey showed that the lower use of water did not create landscapes that were inferior to the education group. The customer's perception of a lower bill is important for the success of any long-term conservation program.

The retrofit and education group were asked if they were willing to pay for an ET controller signal. A majority of the households in both of the groups would not be willing to pay for an ET signal. The ET controller costs approximately $150.00 and the signal fee is $48 per year. The ET controller would be able to save less than 2 ccfs per month, which is a savings of about $14 per year. It appears that the savings in water use per year is not large enough for the water customer to pay for an ET signal.

Table 6-2
ET Controller Selected Responses

Responses to select survey questions	Retrofit group	Education group
Were satisfied with the ET controller	72 percent	n/a
Would recommend use of the ET controller to others	70 percent	n/a
Ranked the appearance of their yard as good to excellent	70 percent	69 percent
Not willing to pay for an ET signal	58 percent	69 percent
Saw decrease in water bills	44 percent	23 percent
Saw water bills unchanged	38 percent	63 percent

6.3.3 Education Only and Retrofit Group Responses

Table 6-3 summarizes the responses to the educational material by the retrofit group compared to the responses by the education group. Samples of these educational materials provided for participants in the R3 Study are presented on the following pages as Exhibit A through Exhibit D. Only half of the education households acknowledged that they sometimes or most of the time would change the settings on their controller according to ET via the monthly letter's (Exhibits A and B) suggested schedule. Monthly mailings also provided monthly landscape maintenance tips (Exhibits C and D). Here, the majority of the households in both of the groups liked the tips on the irrigation checks and fertilization sections. Although most people read these sections, a vast majority (80 percent) of households in both of the groups did not change their use of pesticides, herbicides, or fertilizers.

In addition to the education materials, a soil probe was given to both groups at the beginning of the study. A soil probe is a tool that takes a soil sample and enables the user to see the amount of moisture available to the plants and its depth. This allows the user of the soil probe to determine if the plants require more or less irrigation. More than half of the households in both groups only used the soil probe once or not at all. The majority of the people never used the soil probe at all. From a program point of view, people enjoy the education materials, but they appear to have little effect on modifying behavior.

Table 6-3
Education Material Selected Responses

Responses to select survey questions	**Retrofit group**	**Education group**
Have not changed their use of pesticides and herbicides	82 percent	81 percent
Have not changed their use of fertilizers	80 percent	73 percent
Did not use the soil probe or used it only once	76 percent	62 percent
Believed fertilization checks (part of monthly tips) were helpful	58 percent	44 percent
Believed irrigation checks (part of monthly tips) were helpful	42 percent	58 percent

6.4 Conclusions

While there were some customer service-related issues, the response to the ET controller was generally positive with 72 percent of participants indicating that they liked the controllers. This group also found that the controller irrigation either maintained or improved the appearance of their landscape. This is a classic win-win situation. The water district customers receive a desired benefit of a healthy landscape, and the community receives several important environmental benefits from the conservation of valuable and limited water resources and the reduction in dry season urban runoff.

Exhibit A
Monthly Landscape Maintenance Tips Letter Sent to "retrofit" customers in group 1001

May Landscape Maintenance Tips

The weather is getting warmer, the days are longer, and most of your plants are well into their growth stage. This is also the season for weeds and garden pests.

Irrigation System

- Watch for grass or plant growth that blocks sprinkler heads.
- Look for overspray onto streets and sidewalks and realign the sprinkler head.
- Look for dry spots and find the sprinkler problem to fix, such as a clogged head.
- Look for wet spots and potential sprinkler problems, such as a broken head.

Watering Schedule

- The Run-off Study Controller will adjust watering times as the weather changes.

Fertilizing

- Time to apply a slow release Nitrogen fertilizer to turf (apply only as directed on the bag or container).
- Keep fertilizer off of sidewalks, patio and streets.
- Do not wash fertilizer into drains or gutters.

Weed and Insect Control

- Watch for aphids and whiteflies. Wash insects off of leaves with a hard spray of water or spray with diluted soap solution.
- Apply mulch to control weeds, improve moisture retention and restore nutrients to the soil.
- Pick weeds now while they're still small.
- Use weed and insect chemicals only as directed on the containers.

This is a guide only. This guide does not hold public agencies responsible for the health and appearance of your home landscape.

Exhibit B
Monthly Landscape Maintenance Tips Letter (Sent to "education only" customers in group 1005)

May Landscape Maintenance Tips

The weather is getting warmer, the days are longer, and most of your plants are well into their growth stage. This is also the season for weeds and garden pests.

Irrigation System

- Watch for grass or plant growth that blocks sprinkler heads.
- Look for overspray onto streets and sidewalks and realign the sprinkler head.
- Look for dry spots and find the sprinkler problem to fix, such as a clogged head.
- Look for wet spots and potential sprinkler problems, such as a broken head.

Watering Schedule

- Start with this suggested schedule:
  Turf: 3 days per week, 3 cycles* of 3 minutes
  Shrubs and groundcover: 2 days per week, 3 cycles* of 3 minutes
- Reduce this amount in shaded areas.
- Use the soil probe to check the level of moisture beneath the surface before you water. If the soil is still moist 2 or more inches below the surface, wait another day to water.

Fertilizing

- Time to apply a slow release Nitrogen fertilizer to turf (apply only as directed on the bag or container).
- Keep fertilizer off of sidewalks, patio and streets.
- Do not wash fertilizer into drains or gutters.

Weed and Insect Control

- Watch for aphids and whiteflies. Wash insects off of leaves with a hard spray of water or spray with diluted soap solution.
- Apply mulch to control weeds, improve moisture retention and restore nutrients to the soil.
- Pick weeds now while they're still small.
- Use weed and insect chemicals only as directed on the containers.

This is a guide only. This guide does not hold public agencies responsible for the health and appearance of your home landscape.

*By "cycling" your irrigation timer to turn on for the suggested number of minutes about an hour apart, you reduce runoff and gain deeper watering and healthier root growth.

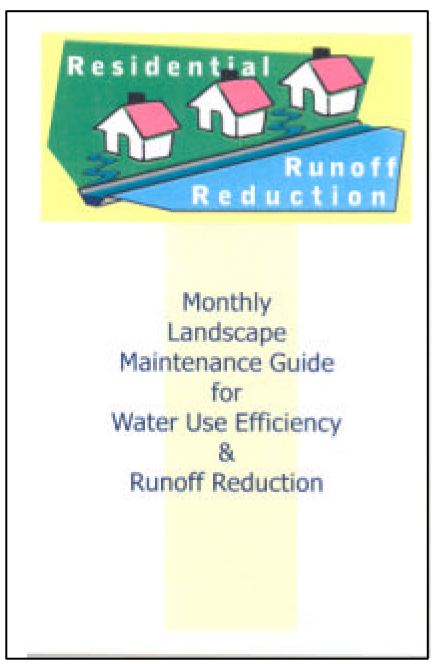
Exhibit C
Monthly Landscape Maintenance Calendar (Provided for "retrofit" and "education only" customers)
(Actual size: 8.5 in. x 11in.)

Residential Runoff Reduction

Monthly Landscape Maintenance Guide for Water Use Efficiency & Runoff Reduction

Seasons	Fall		Winter			Early Spring		Late Spring		Summer		
Month	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**
Irrigation System												
Check for: Runoff, from broken, blocked, clogged heads or overspray	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Check for Misting	✓				✓		✓		✓		✓	
Check for Dry Spots	✓							✓	✓	✓	✓	✓
Watering Schedule If two numbers are shown (i.e. 3 ▶ 2) adjust the number of days as indicated sometime during the month.												
Turf (grass) or Annuals Days to water per week	3 ▶ 2	2 ▶ 1	1	1	1 ▶ 2	2 ▶ 3	3	3	4	4 ▶ 5	4	4 ▶ 3
Trees, Shrubs Groundcovers	2 ▶ 1	1	1	1	1	1 ▶ 2	2	2	2	2	2	2
Deep Watering (trees) ●									●	●	●	●
Root zone watering: Use the soil probe any time you think there is too much or too little water in the yard. If soil is moist in the plant root zone, irrigation level is OK. If the soil is very wet, reduce your watering.												
Rain potential: Turn controllers to "rain pause" or off. Use a soil probe to determine when to turn controllers back on.	✓	✓	✓	✓	✓	✓	✓					
Fertilizing (specialty plants like roses or annuals may have different fertilizer requirements)												
Turf	✓ Balanced slow release					✓ Nitrogen slow release		✓ Nitrogen slow Release			✓ Nitrogen slow release	
Groundcovers	✓ Balanced slow release					✓ Balanced slow release			✓ Balanced slow release			
Shrubs							✓ Balanced slow release					✓ Balanced slow release
Trees						✓ Balanced slow release						✓ Balanced slow release
Weed/Insect Control												
Mulch	✓							✓				
Pesticides (insects)						✓	✓		✓			✓
Herbicides (weeds)					✓		✓				✓ Optional	

Exhibit D
Monthly Landscape Maintenance Guide Provided for "retrofit" and "education only" customers
(Actual size 5.5 in. x 8.5 in)



Chapter 7: Findings, Conclusions, and Recommendations

7.1 Overview

The previous chapters of this report evaluate changes in water usage, dry weather runoff, water quality, and customer attitudes and awareness related to irrigation practices associated with the R3 Study. The intent of this chapter is to "integrate" these findings and outline their context as they relate to the interests and goals of the study participants and provide guidance for future efforts to improve water quality in the San Diego Creek watershed and in other areas of the county and state. Information is provided on:

- Findings and conclusions related to study methods for the water conservation, runoff reduction, water quality, and customer acceptance evaluations
- Findings and conclusions related to key results from the four study evaluations
- Recommendations related to future planning and policy

7.2 Study Methods

As noted in Chapters 3 through 6 of this report, study assumptions and methods demonstrated varying degrees of success. This section presents findings and conclusions regarding the degree of reliability of certain evaluation approaches and provides a foundation for future studies to build upon.

7.2.1 Water Conservation

Findings and conclusions regarding the study method for the water conservation evaluation portion of the R3 Study focused on three major areas.

First, the empirical effort used in the study quantified the change in mean water consumption and the shift in seasonal consumption. The models were not extended to document how water savings vary across households, for example, how savings are decreased/increased among lower/higher water use households. Such information could be useful in future studies.

Second, the study evaluated only about one year of post installation data. Thus, the statistical models can say little about the persistence of water savings. Additional follow-up quantification of water savings in subsequent years would be desirable.

Third, the modeling effort did not estimate the effect of self-selection by the participants in the education-only group. Thus, no attempt was made to extend the inference from the existing sample of participants to: 1) the rest of the service area; or 2) other service areas. The error component of the estimated models could be improved by specifying a function form to explain the variance. This should only be attempted after all major data issues have been resolved.

7.2.2 Runoff Reduction

As discussed in Chapters 2 and 4, significant measurement and data quality issues were associated with the enacted real-time measurement of urban runoff. The technology employed involved custom configurations and numerous needed calibration adjustments. Debris build-up was an early, ongoing, and possibly unavoidable issue that interfered with the calibration of the flow meters. Some of the original locations selected were more prone to this type of problem, and the flow meters were necessarily relocated. Although flow-monitoring problems required data from two of the three control sites to be discarded, the data from the other three sites (two treatments and one control) was sufficiently accurate to allow for the determination of meaningful statistical results.

To minimize the data collection issues experienced during the R3 Study, it would be helpful to install a V-notch weir in the storm drain. (See figure 7-1.) This would enable low flows to be captured and measured more precisely. It should be noted, however, that installation in an underground drain (as opposed to the surface drain shown on the figure) would require protective gear to be worn by the data collectors. Full gear (breathing apparatus) could become cost prohibitive for an aggressive (bi-weekly) monitoring program.

Figure 7-1
Detail of Diversion V-notch Design of Weir Installed in Large Drainage Pipe
(Note: Black sonic sensor hanging directly over V-notch to measure water flow levels.)

7.2.3 Water Quality

As discussed in Chapter 5, two independent reviews of water quality measurements were conducted as part of the R3 Study. Because of the variability of the data and limitations in sample quantities, the first review, which used parametric statistical techniques, provided less definitive results that the second review, which used more robust data analysis techniques. For

some of the parameters reviewed, the robust analytical techniques were able to identify and measure differences in water quality across time and between study treatments.

7.2.4 Public Acceptance

As discussed in Chapter 6, pre- and post- intervention surveys were given to both the retrofit group and the education group. The pre-intervention survey was given to assess and document the prevailing landscape maintenance attitudes and behaviors of both participating groups. The post- intervention survey was given to determine 1) whether or not there was an acceptance of the ET controller as a way of managing landscape irrigation and 2) if exposure to the educational materials and monthly landscape maintenance tips had led to a change in irrigation practices and landscape management behaviors in either study group.

The survey responses indicate that, while 82 to 90 percent of the retrofit and education-only group reported to have read the educational materials, reading these materials did not cause their landscape maintenance habits to change. These responses suggest that future surveys should be designed to capture a measurement of the changes in the study subjects' consumer attitudes and behaviors in greater detail.

Future projects could benefit from using a marketing research firm specializing in the use of polls and surveys to measure residential consumers' attitudes and behaviors. The wording of each pre- and post- intervention survey question can be very carefully crafted in order to target, capture, and quantify each specific pre- and post- intervention behavioral change that is being measured. Identical or one-to-one correspondence between the pre- and post- survey questions is another effective marketing research technique. By documenting customers' changing responses, over time, to identical questions, behavioral shifts can be tracked and quantified.

7.3 Study Results

Key results of the four R3 Study evaluations are summarized below. Because the water conservation and runoff reduction evaluations were interrelated, the results from these evaluations are discussed together below.

7.3.1 Water Conservation and Runoff Reduction

As discussed in Chapter 3, water consumption by residential customers in the retrofit group was reduced by 41.2 gallons per day per household, with a reduction for the education group of 25.6 gallons per day per household. In contrast, whereas the runoff flows for the retrofit group were reduced during the study, flows in the education group increased (Chapter 4). There are three related explanations for this dichotomy: 1) the inclusion of small to medium size "common area" landscapes in the retrofit group and the exclusion of this group from the education group; 2) differences in irrigation scheduling between the residential homes in the two groups; and 3) proximity and relative flow volumes of the landscapes to the storm drain system.

7.3.1.1 Dedicated Landscapes

The retrofit group common areas averaged 0.8 acres in size and encompassed 15 sites/irrigation controllers including city landscape medians, HOA greenbelts, and a park. It is estimated that these sites account for more than 75 percent of the total area under treatment in the Site 1001 area. More specifically, these 15 sites totaled about 12 acres. The remaining 112 irrigation controllers installed on single-family residential lots are estimated to encompass 3.5 to 4 acres. The proportion of residences receiving educational materials including irrigation scheduling information was chosen to match the number receiving retrofit treatment. However, the total treated acres for the two groups varied considerably.

As was the protocol for all retrofit sites, irrigation schedules for these sites were established based on valve-by-valve evaluations of plant, soil, and irrigation system parameters. These schedules resulted in significantly more start times and shorter run times than that observed in these areas prior to the study.

More specifically, prior to installation of the retrofit treatment, each valve was turned on for two minutes to determine the flow. In this brief period, runoff was observed for many of the valves. This relates to the predominant clay soils, where runoff can exceed 90 percent of applied water after short periods due to the low infiltration rates. It is believed that the more frequent, short duration irrigation schedules developed by the treatment irrigation technology is the primary mechanism to reduce runoff from irrigation sites. In addition, these sites were closely monitored and incorporated suggested BMPs such as weekly meter readings. These sites were also used to develop the protocol for the midweek scheduling changes for all of the retrofit area and when to terminate a rain pause for the region.

In contrast to the retrofit group, the controllers on comparable common area landscapes in the education group are assumed to have continued with typical irrigation schedules that likely result in higher levels of runoff. If this is the case, and the common areas account for a similar percentage of irrigated area, this could explain the observed differences in runoff between the retrofit and education groups.

7.3.1.2 Differences in Irrigation Schedules

In addition to the runoff differences likely stemming from the inclusion of the nonresidential landscapes in the retrofit group, irrigation scheduling differences also existed for the residential homes between the retrofit and education groups. The education group households received a suggested irrigation schedule that provided the number of days per week to run the irrigation system, the number of minutes per cycle (start time), and a maximum of three start times. As noted above, short run times and multiple start times are believed to be the key element in reducing irrigation runoff.

Although the post-study survey indicated that about 60 percent of those in the education group changed their controller's irrigation schedule at least "sometimes," it is not clear how closely they followed the suggested schedule, including the recommendation on start times. Inasmuch as programming many controllers for multiple start times can be challenging, it is possible these

instructions were generally overlooked. In contrast, the weather-based irrigation controller used on the retrofit homes automatically reduced the run time for slope, soil, and sprinkler precipitation rate. This will likely reduce runoff even in the absence of direct water savings. This difference may also be a consideration in the dissimilar runoff results in the two treatment sites.

7.3.1.3 Proximity to Storm Drains and Flow Volumes

The final consideration is the location and relative flow volumes of the common area landscapes relative to location and flow volumes of the residences. The common area landscapes were typically located closer to storm drain catch basins (and the study flow monitors) than most residential lots and also had much higher flow volumes on the individual irrigation valves. Runoff from most residential lots had to travel a signficant distance through surface street gutters before reaching catch basins and were subject to both evaporation and seepage in route. In addition, the limited drainage associated with many residential back yards could have further reduced the quantity of water reaching the storm drain from these areas in both the retrofit and education groups. Consequently, the reduction in runoff from treated retrofit common area landscapes and the presumed lack of similar reductions for the education group common areas, combined with the high valve flow volumes, likely explain the differences in observed runoff for the two treatment groups.

7.3.2 Water Quality

As described in Chapter 5, water quality samples were taken twice per month, resulting in a total of 39 samples over an 18-month period. One of the simplest and most straightforward methods to review these samples is to compare them to established water quality objectives for the San Diego Creek watershed. The subsections below address water quality and flow, and runoff water quality.

7.3.2.1 Water Quality and Flow

Chapter 5 of this report also describes issues with the reliability of study flow data during certain study periods and with certain monitoring locations. Because of the temporal relationship of these issues, integrating the water quality and flow data to determine changes in the mass loading of water quality constituents is difficult from a statistical standpoint. However, certainly, the water quality and flow data from the study provide some useful qualitative insight into the impacts of the interventions and may be instructive for future water quality improvement efforts.

7.3.2.2 Runoff Water Quality

Analyses utilizing ore robust statistical methods suggest that the intervention did result in changes in water quality. TN levels in the retrofit neighborhood following intervention were found to be significantly lower than levels before intervention, whereas no detectable differences were noted before and after intervention in the education neighborhood. Relatively large observed reduction in TN flux in the retrofit neighborhood could be influenced by seasonal factors, and the extent to which the ET controller contributed to the reduction is unknown.

7.3.3 Public Education

Data issues discussed previously make it difficult to quantify the impact of public education on reduced water usage and reduced dry season runoff. However, pre- and post-surveys of the retrofit + education and education only groups showed a positive response to the concepts of the irrigation tips. More than 70 percent of the retrofit group participants indicated that they liked the ET controllers, and the group also found that controller irrigation either maintained or improved the landscape. However, it appears that the savings in water use per year is not large enough for the water customers to be willing to pay for an ET signal.

7.4 Recommendations

The application of data from this study will influence future programs and efforts to improve water quality. The application of the irrigation management program focusing on using automatic real-time weather-based irrigation scheduling not only resulted in reductions in onsite/customer water use, but also reduced runoff. With the quality of runoff essentially unchanged, this reduction in runoff should result in a decrease in the total mass of non-point source pollutant loading to the watershed. The relative cost-effectiveness of this program should be evaluated in comparison to other existing or proposed BMPs to improve watershed water quality.

Although not directly determined from the study, the results suggest that the common area landscape sites will provide the most cost-effective application of the water management program. Additional empirical verification of this relative cost-effectiveness supposition is likely warranted.

An additional issue related to the water management program is the availability and viability of the irrigation controllers tested as a part of the study. Although the tested controllers operated reasonably well, occasionally glitches occurred, which necessitated either telephone or onsite intervention by study personnel. For the number of controllers installed for the study, these maintenance issues were manageable. However, the wide-scale use of these controllers would require a significant commitment from the water purveyor or the controller manufacturer to address maintenance issues. At this time, it is not believed that the controller manufacturer has established infrastructure to support a large number of controllers. In addition, the viability of the tested water management program is completely dependent on the regular transmission of data signals from the controller manufacturer to adjust irrigation schedules. Assurances on the long-term viability of signal transmission are imperative to the expansion of the tested program.

In contrast to the water management program, the educational program implemented as a part of the R3 Study reduced customer water use, but did not reduce measured runoff from the study area. Consequently, again assuming no change in runoff quality, this treatment would not appear to provide pollutant mass loading benefits to the watershed. However, the relationship between the observed water savings for the treated portion of the study area and increased runoff for the entire study area is unclear. Because of the clear relative cost advantages of educational programs, additional and more focused studies should be conducted to more fully understand this

relationship and determine the viability of educational programs in reducing non-point source pollution.

Appendix A: References

The Residential Runoff Reduction Study

Appendix A: References

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Appendix B: Study Design

The Residential Runoff Reduction Study

Appendix B: Study Design

Introduction

In 1999, the Municipal Water District of Orange County (MWDOC) and Irvine Ranch Water District (IRWD), in partnership with other national, state, and local agencies and organizations began developing a project to accomplish two goals:

1) Measure changes in the dry weather volume and pollutant content of residential runoff associated with improved irrigation management practices.
2) Confirm residential irrigation water savings identified in a previous study evaluating an automated residential irrigation controller system (the "Westpark Study").

This Appendix presents detailed information on the general study design framework described in Chapter 2. Subjects discussed include watershed selection, flow monitoring, water quality sampling, ET controller operation and selection process, and controller installation and operation.

Watershed Selection

Five watersheds were selected for the study area, based on five criteria: 1) Isolation from other watersheds, 2) climate, 3) land use, 4) development age, 5) irrigation water management techniques.

Isolation from Other Watersheds:

A watershed consists of a region of land, which drains through a single point. The five study watersheds were located in the Northwood Village subdivision in the IRWD service area. Each watershed drains through a single point and is isolated from other sources of runoff. This enabled the runoff flow and water quality to be free of interference from other sources.

Climate

While most of Southern California and Northwood Village have a similar climate, the five watersheds share the same ET zone. They are located within 5 miles of CIMIS station #75, which provides local ET_o information. The ET_o (reference evapotranspiration, the amount of water utilized by plants and lost to evaporation) is the same throughout the Northwood region and most of the central section of the IRWD service area. The plant water requirements of ET_g, which is the standard of turfgrass for cool season turfgrass and is often referred to as simply ET, are the same for all five watersheds.

Due to the close proximity of the all the homes and the lack of any physical or geographical separation of the five watersheds, the study team relied on the CIMIS station #75 for ET_o data.

Land Use

The Northwood section of IRWD's service area was selected because the predominant land use is single-family residence. There are also local parks, common city streetscapes, two condominium associations and one homeowners association (HOA). Several of the watersheds contained townhouses, apartments or condominiums. However, these types of multi-family units were limited in each of the watersheds; no single watershed had a large number of multi-family units.

Development Age

Northwood's neighborhoods were created during two distinct periods of home development. The first phase of development began in the late 1970s and finished in the early 1980s. The second phase started in 2000 and continues to the present. The study excluded the newer section of Northwood for two reasons. First, the newer homes and their HOA are not typical of Southern California. Second, IRWD has monthly water bill information dating back to the late 1980s on homes in the older section of Northwood.

Irrigation Water Management Factors

In addition to ET_o, other basic factors of irrigation water management are precipitation rate, soil type, and plant type. This study implemented real time ET scheduling through a commercially-available signal and distributed educational material to improve water management. Other water management factors are described below.

Precipitation rates vary from irrigation valve to irrigation valve, and most of the homes applied the water with spray heads operating off the pressure provided by IRWD. The individual homeowners installed most of the irrigation systems after the purchase of their houses. The technology used in these irrigation systems was of the same approximate age and featured similar types of equipment. The irrigation systems installed in the study area were also representative of a common irrigation set-up presently in use in Southern California. .

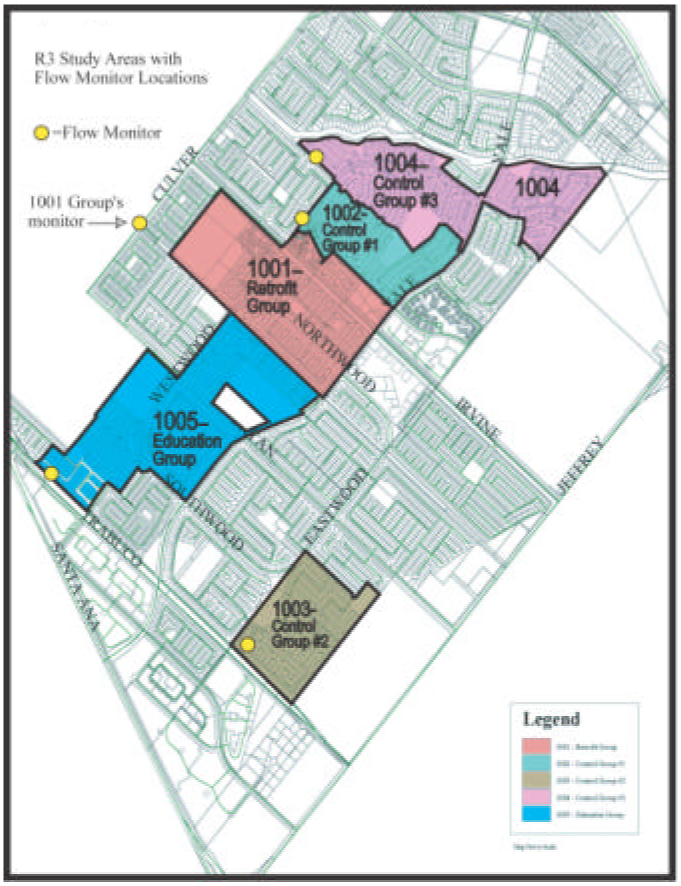
The soil type in the study area is not typical of Southern California and consists of heavy clay. Clay has the lowest infiltration rate and requires the highest level of water management.

The landscapes have sufficiently similar plant material. Although there was no data available to perform a numerical comparison, the study team field surveyed each of the potential watersheds. The majority of landscaping of all homes in the study area consisted of turfgrass. To varying extent, the outside edges, fence, building and walkways areas were lined with shrubs and plant materials other than turfgrass. The best estimate of the ratio of turfgrass to other landscaping is approximately 70 percent. While some of the homes in each of the watersheds may not have followed this construct, the vast majority of landscapes were laid out in this fashion, which allowed the study team to determine which plant materials were mostly consistently found throughout the five watersheds.

Results

After determining that large sections of Northwood were similar and after locating safe monitoring sites, the study team traced the storm drains. The selection of the monitoring site determined the shape and contents of the watershed. The study was able to isolate five watersheds with similar characteristics. The areas of the five watersheds are outlined and labeled in Figure B-1 below.

Figure B-1
Five watershed areas and their corresponding Control groups



Flow Monitoring

The two main criteria for the study's flow monitoring equipment were: 1) the monitor could not alter the pipe or channel and 2) the monitoring must be able to distinguish the seasonal flow changes and any flow change that resulted from the three different treatments (i.e., retrofit group treatment, education-only group treatment, and control group treatment).

Two technologies were suitable for this application: Manning's equation plus a level sensor, or velocity sensor and level monitor (area-velocity). The area-velocity method was chosen due to lack of slope information for the storm drain system. The selected equipment was a Sigma 950, manufactured by Hach. The equipment was battery operated, could record data every minute, and included an ultrasonic transmitter and a velocity sensor located in the storm drain. The ultrasonic transmitter established the water surface level and area, while the velocity sensor determined the velocity of the water in the pipe.

Flow was calculated by the equation: Flow = Area x Velocity. Because four of the five monitoring locations (see Figure B-1 above) were located in pipes, several variations on the ultrasonic transmitter / velocity sensor were tested before the combination of sonic and velocity wafer were selected.

Water Quality Sampling

The water quality sampling program quantified constituents found in residential runoff flows. Because a typical residential neighbor includes more than single-family lots, the concept of water management through an ET signal technology expanded to include common area landscapes.

The water quality sampling program consisted of two phases: 1) pre-study and 2) dry weather sampling.

Pre-study

Based on water level elevation provided by the flow monitors, the study team developed a plan for sampling water quality during dry weather runoff periods. In the early evening (7 to 10 pm) and again in the early morning (3 to 6 am), the water level would rise, indicating an increase in runoff flow. While the amount of change varied by location and date, the pattern was common to all of the watersheds.

The study team performed a weeklong test to determine the most representative sampling time. The team sampled all five study areas every day at 4 am and 7 pm. The constituents sampled were fecal coliform, nutrients, and trace metals.

The test results showed neither differences nor patterns in concentrations between sites, days, and sample times.

Dry Weather Sampling Duration

The final sampling program consisted of bi-weekly sampling of all five sites. During sampling weeks, all five sites were sampled for all analyses listed in Table B-1 on Tuesday, and three sites were sampled for pesticides two additional days. Toxicity samples were collected once per month at all five sites.

Table B-1
Routine Water Quality Analysis Responsibilities

Responsible Lab	Water Quality Parameter	Bottle Type
IRWD	NO_2, NO_3, NH_3, T-PO_4, TKN, O-PO_4, EC, pH, Trace Metals, Total / Fecal Coliform	(2) 1-L Cubitainer (1) 250 ml Sterile
SCCWRP	Toxicity (Sea Urchin Fertilization)	
SCCWRP	Pesticides	
MWL	MS-2 Phage	(1) 1-L (from MWL)
MWL	Enterococcus	(1) 250 mL (from MWL)

The study team collected the biweekly Tuesday samples beginning in January of 2001 and continuing through the next 18 months. The first months of sampling occurred before or during the installation of the ET controllers in the residences and the common landscape. The last 12 months, starting in July 2001 and finishing in June 2002, became the post retrofit samplings. The pesticide sampling continued for an additional six months through December 2002. Table B-2 provides outlines the water quality and data collection schedule for each group in the study.

Table B-2. Water Quality and Data Collection Schedule					
Sample Site	**Site ID**	**Cross Streets**	**Atlas Page**	**Parameter**	**Frequency**
Group A Education Site Control Site	1005 1003	Shadwell/Westmoreland Carver/Carver	84w – C1 105w – A1	Flow WQ	Weekly Bi-weekly
Group B Control Site Control Site Retrofit Site	1004 1002 1001	Hicks Canyon/Park Place La Paloma/Park Place Culver/Florence	83w – D2 83w - D1 84n – A3	Flow WQ	Weekly Bi-weekly

ET Irrigation Controller Operation and Selection Process

To meet the R3 Study objectives, it was necessary to install as many ET controllers as possible in the retrofit group. Providing the fullest coverage of the watershed with proper irrigation water management generated the best chance of changing the runoff flows. Since residential areas include landscapes other than those of the homeowners, these landscape areas were included in the water management component of the R3 Study. This represents a 3 to 1 ratio of medium-size landscapes to residential landscapes. A description of the installation process for both residential and medium-size landscapes follows:

<u>Residential Landscapes</u>

The IRWD staff attempted to reach as many of the 334 residences in the retrofit watershed as possible. These targeted residents received three letters which informed them of the following:

1) If selected to participate in the study, they would receive a free controller that would automatically adjust the landscape watering.
2) Their participation would be part of an environmental study aimed at preventing runoff from reaching the ocean.
3) They would be saving water without having to program an irrigation controller.
4) They were provided instructions for participating in the study along with a phone number to call to sign-up, as well as a form with a stamped and addressed envelope (for returning the form).

Additionally, IRWD staff hosted a function for the HOA in which staff demonstrated the ET controller to the residents and helped them to complete the sign-up form. Lastly, IRWD staff walked the Northwood neighborhood and hung flyers on the study candidates' front doors. These flyers contained statements from the homeowners in Westpark that had participated in the original ET Controller study. The flyers also described the ET controllers' overall customer satisfaction and ease with which the irrigation system worked.

In all, 137 residents responded to the various communication efforts by agreeing to participate in the study and installing the ET controller on their property. Of the 137 positive responses, 112 homes were equipped with proper automatic valves.

The installation of controllers began in April 2001 and continued through June 2001. A full team of IRWD staff worked weekdays, Saturdays and evenings to complete the installations. Additionally, educational materials were distributed to the retrofit group during installations.

Medium-size Landscapes

In addition to the single-family residences, the retrofit watershed contains 2 condominium complexes, and one HOA with three distinct land use types. The area also contained 12 city streetscapes. The City of Irvine agreed to change out the existing manual controllers with the ET controllers. All of the HOAs agreed to change out their controllers for the ET controllers.

The only major landscape not replacing its existing controller with an ET controller was the park-playground area of the school. The school landscape area consisted of a single meter with two separate controllers and more than 50 valves. This would require at least six ET controllers. Given the limitation in the controller and the high number of cycles that would be required to correctly irrigate the school site, IRWD was not confident that the ET controllers could be programmed in a manner that would avoid conflicting runtimes.

Controller Installation and Operation

The study evaluated the performance of the engineering of irrigation management techniques to reduce the consumption and residential runoff while maintaining the quality of the landscape. A typical irrigation controller is difficult to program and limited in the scope of the scheduling ability. Proper scheduling requires calculations based on real time ET data, landscape topography, and plant type, which are beyond the capabilities of typical controllers. The landscaper in the field is left to guess or rely on past experience as to the correct amount of water, the correct runtime to prevent runoff, and the correct days of the week to water.

The operation of the ET controller in this study was optimized by: 1) weekly maintenance, and 2) proper irrigation scheduling. IRWD staff programmed the controllers, which were operated by a combination of IRWD staff and HydroPoint consultants. (HydroPoint Data Systems, also known as HydroPoint, developed and supplied the ET controllers used in the R3 Study.)

During the prior study in Westpark, the programming was calculated based on a design precipitation rate suggested for spray heads. That study received numerous complaints that too much water was being applied and an effort was undertaken to conduct an area/flow measurement to determine the actual precipitation rate. These measurements indicated an average precipitation rate of 3.98 inches per hour while the design precipitation rate for the spray heads was 1.80 inches per hour. The measured rates varied from as low as 1.4 inches per hour to as high as 9 inches per hour. This suggested that standard settings in which a homeowner would program the controller are unlikely to efficiently run the irrigation. Because of this and other important factors, trained staff preformed the installations

Appendix C: Statistical Analysis of Water Savings

The Residential Runoff Reduction Study

Appendix C - Statistical Analysis of Water Savings

Prepared for
Municipal Water District of Orange County and
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February 2002

DRAFT FINAL

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Summary

Findings

$ **Single Family Residences:** Households receiving an evapotranspiration (ET) controller and education were found to save approximately 41.2 gallons per day on average (33.2 gpd – 49.2 gpd is the 95 percent confidence level). Households receiving the education treatment alone were found to save approximately 25.6 gallons per day on average (20.1 gpd – 31.1 gpd is the 95 percent confidence level). This sample compared 93 ET controller/education participants and 192 education-only participants to 1236 nonparticipating single family customers.

A secondary finding in this sample related to seasonal shape in this average savings effect. For the one year of post-intervention consumption data within our sample, the water savings was not constant. The ET controller/education intervention, in particular, saved more water in the autumn and less in the spring growing season.

$ **Landscape-Only Accounts:** Among a smaller sample of 21 landscape-only accounts, significant water savings (16 percent) were obtained from the use of ET controllers. A sample of 76 matched sites (similar in landscaped area and type of use) also showed the effects of City water efficiency improvements. Since both of these samples contain a large number of medians and streetscapes, it is possible that each gallon saved from irrigation-only sites contributes more to runoff

reduction than a gallon saved at a single family site. Since the runoff reduction was not measured by customer account, this study will not be able to confirm or deny this hypothesis.

Introduction

The purpose of this work is a statistical analysis of water savings among customers who installed evapotranspiration (ET) controllers and customers given irrigation education in the Irvine Ranch Water District. This report documents a careful statistical analysis of historical water consumption data to derive estimates of the net water savings from these interventions.

Approach

Historical water consumption records (July 1997 to August 2002) for a sample of participants and for a sample of nonparticipating customers were examined statistically. The hypothesis was that installation of new irrigation technology or better management of existing equipment would reduce the observed water consumption of customers participating in this program. This study empirically estimates the water savings that resulted from both types of interventions—(1) customers receiving both ET controllers and follow-up education and (2) customers receiving an education-only intervention.

Since installation of ET controllers required the voluntary agreement of the customer to participate, this sample of customers can be termed "self-selected." Customers were randomly chosen to receive the education-only treatment. While this analysis does quantitatively estimate the reduction of participant's water consumption, one may not directly extrapolate this finding to nonparticipants. This is because self-selected participant can differ from customers that decided not to participate.

The explanatory variables in these models include

- Deterministic functions of calendar time, including
    - The seasonal shape of demand
- Weather conditions
    - measures of air temperature
    - measures of precipitation, contemporaneous and lagged
- Customer-specific mean water consumption
- "Intervention" measures of the date of participation and the type of intervention

Data and Methods

Consumption records were compiled from the IRWD customer billing system for customers in the study areas. Billing histories were obtained from meter reads between July 1997 and August 2002. It is important to note that a meter read on August 1 will largely represent water consumption in July. Since the ET controllers were installed in May and June of 2001, the derived sample will only contain slightly more than one year of data for each participant. Table 1 presents descriptive statistics on the sample.

Table 1: Single Family Residential Sample Descriptive Statistics

	Site 1001		Site 1004	Site 1005	
	ET Controller Participant	Non-Participant	Control	Education Participant	Non-Participant
Number of Usable Accounts	97	213	264	196	346
Pre-period: July 1997-May 2001					
Mean Use (gpd)	375	371	405	390	418
No. of observations	4,504	9,860	12,452	9,251	16,364
Post-period: June 2001-August2002					
Mean Use (gpd)	366	379	427	395	421
No. of observations	1,358	2,982	3,694	2,744	4,856

The landscape-only customers (21 accounts) were handled separately. Two control groups were developed for these irrigation accounts: A matched control group was selected by IRWD staff by visual inspection, finding 3-5 similar control sites for each participating site. Similarity was judged by irrigated area and type of use (Home Owner Association, Median, Park, or Streetscape). Since the City of Irvine was improving irrigation efficiency on the City-owned sites during the post-intervention period, this matched control group also had potential water savings. A second control group was developed where the selection was done solely located by geographic area. In this way, the statistical models can separately estimate the water savings effects for each group.

Table 2: Landscape Accounts
Descriptive Statistics

	Participant	**Matched Control**	**Unmatched Control**
Number of Usable Accounts	21	76	895
Acres per Account	0.93	0.92	0.96
Type of Account (if known)			
HOA	3	13	
Median	3	11	
Park	1	6	
Streetscape	14	47	
Pre-period: July 1997-June 2001			
Mean Use (gpd)	2,948	2,768	3,042
Mean Use per Acre (inches/day)	0.11702	0.11823	0.12893
No. of observations	967	3,503	39,352
Post-period: July 2001-August2002			
Mean Use (gpd)	2,845	2,990	3,271
Mean Use per Acre (inches/day)	0.10813	0.12012	0.13013
No. of observations	293	1,052	12,121

The first major issue with using meter-read consumption data is the level and magnitude of noise in the data. The second major issue is that records of metered water consumption can also embed non-ignorable meter mis-measurement. To keep either type of data inconsistencies from corrupting statistical estimates of model parameters, this modeling effort employed a sophisticated range of outlier-detection methods and models. These are described in the next section.

Daily weather measurements—daily precipitation, maximum air temperature, and evapotranspiration—were collected from the CIMIS weather station located in Irvine. The daily weather histories were collected as far back as were available (January 1, 1948) to provide the best possible estimates for "normal" weather through the year. Thus we have at least 54 observations upon which to judge what "normal" rainfall and temperature for January 1^{rst} of any given year.

Robust regression techniques were used to detect which observations are potentially data quality errors. This methodology determines the relative level of inconsistency of each observation with a given model form. A measure is constructed to depict the level of inconsistency between zero and one; this measure is then used as a weight in subsequent regressions. Less consistent observations are down-weighted. Other model-based outlier diagnostics were also employed to screen the data for any egregious data quality issues.

Specification

A Model of Water Demand

The model for customer water demand seeks to separate several important driving forces. In the short run, changes in weather can make demand increase or decrease in a given year. These models are estimated at a household level and, as such, should be interpreted as a condensation of many types of relationships—meteorological, physical, behavioral, managerial, legal, and chronological. Nonetheless, these models depict key short-run and long-run relationships and should serve as a solid point of departure for improved quantification of these linkages.

Systematic Effects

This section specifies a water demand function that has several unique features. First, it models seasonal and climatic effects as continuous (as opposed to discrete monthly, semi-annual, or annual) function of time. Thus, the seasonal component in the water demand model can be specified on a continuous basis, then aggregated to a level comparable to measured water use (e.g. monthly). Second, the climatic component is specified in different form as a similar continuous function of time. The weather measures are thereby made independent of the seasonal component. Third, the model permits interactions of the seasonal component and the climatic component. Thus, the season-specific response of water demand can be specific to the season of the year.

The general form of the model is:

Equation 1

$$Use = \mu_i + S_t + W_t + E_{i,t}$$

where ***Use*** is the quantity of water demand within time *t*, the parameter $\boldsymbol{\mu_i}$ represents mean water consumption per meter *i*, $\boldsymbol{S_t}$ is a seasonal component, $\boldsymbol{W_t}$ is the weather component, $\boldsymbol{E_{i,t}}$ is the effect the landscape interventions for meter *i* at time period *t*. Each of these components is described below.

Seasonal Component : A monthly seasonal component can be formed using monthly dummy variables to represent a seasonal step function. Equivalently, one may form a combination of sine and cosine terms in a Fourier series to define the seasonal component as a continuous function of time.[1] The following harmonics are defined for a given day *T*, ignoring the slight complication of leap years:

Equation 2

$$S_t \equiv \sum_{1}^{6} \left[\beta_{i,j} \cdot \sin\left(\frac{2\pi \cdot jT}{365} \right) + \beta_{i,j} \cdot \cos\left(\frac{2\pi \cdot jT}{365} \right) \right] = Z \cdot \beta_S$$

[1] The use of a harmonic representation for a seasonal component in a regression context dates back to *Hannan* [1960]. *Jorgenson* [1964] extended these results to include least squares estimation of both trend and seasonal components.

where T = (1,...365) and j represents the frequency of each harmonic.[2] Because the lower frequencies tend to explain most of the seasonal fluctuation, the higher frequencies can often be omitted with little predictive loss.

To compute the seasonal component one simply sums the multiplication of the seasonal coefficient with its respective value. This number will explain how demand changes due to seasonal fluctuation.

Weather Component: The model incorporates two types of weather measures into the weather component–maximum daily air temperature and rainfall.[3] The measures of temperature and rainfall are then logarithmically transformed to yield:

Equation 3

$$R_t \equiv \ln\left[1+\sum_{t=T}^{T_d} Rain_t\right], A_t \equiv \ln\left[\sum_{t=T}^{T_d} \frac{AirTemp_t}{d}\right]$$

where d is the number of days in the time period. For monthly aggregations, d takes on the values 31, 30, or 28, ignoring leap years; for daily models, d takes on the value of one. Because weather exhibits strong seasonal patterns, climatic measures are strongly correlated with the seasonal measures. In addition, the occurrence of rainfall can reduce expected air temperatures. To obtain valid estimates of a constant seasonal effect, the seasonal component is removed from the weather measures by construction.

---

[2] If measures of water demand are available on a daily basis, the harmonics defined by Equation 2 can be directly applied. When measures of water demand are only observed on a monthly basis, two steps must be taken to ensure comparability. First, water demand should be divided by the number of days in the month to give a measure of average daily use. Otherwise, the estimated seasonal component will be distorted by the differing number of days in a month. The comparable measures of the seasonal component are given by averaging each harmonic measure for the number of days in a given time period.

[3] Specifically it uses the maximum daily air temperature and the total daily precipitation at the Irvine weather station. This station was selected due to its proximity to the study area.

Specifically, the weather measures are constructed as a departure from their "normal" or expected value at a given time of the year. The expected value for rainfall during the year, for example, is derived from regression against the seasonal harmonics. The expected value of the weather measures ($\hat{\boldsymbol{A}} = \boldsymbol{Z} \bullet$) is subtracted from the original weather measures:

Equation 4

$$W_t \equiv (R_t - \widehat{R}_t) \cdot b_R + (A_t - \widehat{A}_t) \cdot b_A$$

The weather measures in this deviation-from-mean form are thereby separated from the constant seasonal effect. Thus, the seasonal component of the model captures all constant seasonal effects, as it should, even if these constant effects are due to normal weather conditions. The remaining weather measures capture the effect of weather departing from its normal pattern.

The model can also specify a richer texture in the temporal effect of weather than the usual fixed contemporaneous effect. Seasonally-varying weather effects can be created by interacting the weather measures with the harmonic terms. In addition, the measures can be constructed to detect lagged effects of weather, such as the effect of rainfall one month ago on this month's water demand.

Effect of Landscape Interventions: Information was compiled on the timing and location of each ET controller installation and education-only customer participation. The account numbers from these data were matched to meter consumption histories going back to 1997. All raw meter reads were converted to average daily consumption by dividing by the number of days in the read cycle. Using these data, relatively simple

“intervention analysis” models[4] were statistically estimated where, in this case, the intervention is ET controller installation and/or participation in the landscape education program. The form of the intervention is:

Equation 5

$$E_{i,t} \equiv I_{ET} \cdot b_{ET} + I_{Ed} \cdot b_{Ed}$$

The indicator variable I_{ET} takes on the value one to indicate the presence of a working ET controller and is zero otherwise. The indicator variable I_{Ed} takes on the value one if a household agreed to participate in the education program and is zero otherwise.

The parameter $\hat{b}_{ET}$ represents the mean effect of installing an ET controller and is expected to be negative (installing an ET controller reduces water consumption.) The parameter $\hat{b}_{Ed}$ has a similar interpretation for the education-only participants.

This formulation also permits formal testing of the hypothesis that landscape interventions can affect the seasonal shape of water consumption within the year. Since numerous studies have identified a tendency of customers to irrigate more than ET requirements in the fall and somewhat less in the spring, it will be informative to examine the effect of ET controllers designed to irrigate in accord with ET requirements. The formal test is enacted by interacting the participation indicators with the sine and cosine harmonics.

[4]See Box and Tiao, “Intervention Analysis with Applications to Economic and Environmental Problems” *Journal of the American Statistical Association*, Vol 70,No. 349, March 1975, pp. 70-70.

Stochastic Effects

To complete the model, we must account for the fact that not every data point will lie on the plane defined by **Equation 1**. This fundamental characteristic of all systematic models can impose large inferential costs if ignored. Misspecification of this “error component” can lead to inefficient estimation of the coefficients defining the systematic forces, incorrect estimates of coefficient standard errors, and an invalid basis for inference about forecast uncertainty. The specification of the error component involves defining what departures from pure randomness are allowed. What is the functional form of model error? Just as the model of systematic forces can be thought of as an estimate of a function for the “mean” or expected value, so too can a model be developed to explain departures from the mean—i.e., a “variance function” If the vertical distance from any observation to the plane defined by **Equation 1** is the quantity **e**, then the error component is added to **Equation 1**:

Equation 6

$$Use = \mathbf{f}\left(\mathbf{S}_t, \mathbf{C}_t, \mathbf{T}_t\right) + e$$

The error structure is assumed to be of the form:

Equation 7

$$\begin{aligned} &e_{it} = m_i + x_{it} \\ &where \\ &m_i \sim N(0, s_m^2) \\ &x_{it} \sim N(0, s_x^2) \end{aligned}$$

The *X* and *?* are assumed to be independent of each other and of *μ*. The individual component *μ* represents the effects of unmeasured household characteristics on household water use. An example of such an unmeasured characteristic might be the water use behavior of household members. This effect is assumed to persist over the estimation period. The second component *?* represents random error. Because *μ* and *?* are independent, the error variance can be decomposed into two components:

Equation 8

$$s_e^2 = T \cdot s_m^2 + s_x^2$$

This model specification is accordingly called an error components or variance components model. The model was estimated using maximum likelihood methods.

Estimation Results

Estimated Landscape Customer Water Demand Model

Table 3 presents the estimation results for the model of landscape (irrigation-only) customer water demand in the R3 study sites. This sample represents water consumption among 992 accounts between June 1997 and August 2002. This sample contains 21 ET controller accounts, 76 matched control accounts, and 895 unmatched control accounts.

The constant term (1) describes the intercept for this equation. The independent variables 2 to 9—made up of the sines and cosines of the Fourier series described in Equation 2—are used to depict the seasonal shape of water demand. The estimated weather effect is specified in "departure-from-normal" form. Variable 10 is the departure of monthly temperature from the average temperature for that month in the season. (Average seasonal temperature is derived from a regression of daily temperature on the seasonal harmonics.) Rainfall is treated similarly (Variable 11). One month lagged rainfall deviation is also included in the model (Variables 12). The next variable accounts for the amount of irrigated acreage on the site. (Note that while measured acreage is available for all irrigation-only accounts, this is not true for single family accounts.)

The effect of the landscape conservation program interventions is captured in the following rows. The parameter on the indicator for ET controllers (15) suggests that the mean change in water consumption is 472 gallons per day, approximately 16 percent of the pre-intervention water use. The matched control group (17) did experience water savings, approximately 241 gallons per day or 8.7 percent of their pre-intervention water use. The variables testing for differences in pre-intervention use cannot distinguish any differences between the different types of accounts.

Table 3: Landscape Customer Water Demand Model **Dependent Variable: Average Daily Metered Water Consumption (in gallons per day)**		
Independent Variable	**Coefficient**	**Std. Error**
1. Constant (Mean intercept)	2619.0670	234.8112
2. First Sine harmonic, 12 month (annual) frequency	-811.6864	26.3271
3. First Cosine harmonic, 12 month (annual) frequency	-1984.6310	25.9776
4. Second Sine harmonic, 6 month (semi-annual) frequency	104.1141	26.5769
5. Second Cosine harmonic, 6 month (semi-annual) frequency	-18.5088	26.9614
6. Third Sine harmonic, 4 month frequency	-124.1069	28.1396
7. Third Cosine harmonic, 4 month frequency	107.1129	28.4812
8. Fourth Sine harmonic, 3 month (quarterly) frequency	39.5420	30.5372
9. Fourth Cosine harmonic, 3 month (quarterly) frequency	-62.1012	30.7453
10. Deviation from logarithm of 31 or 61 day moving average of maximum daily air temperature	6306.4130	562.5547
11. Deviation from logarithm of 31 or 61 day moving sum of rainfall	-747.0860	51.9108
12. Monthly lag from rain deviation	-209.8997	46.2994
13. Irrigated Acreage (in acres)	490.5891	139.6673
14. ET controller sites, test for difference in pre-intervention use	-46.2624	1278.0470
15. Average Effect of ET controller (21 accounts)	-472.1763	279.4630
16. Matched accounts, test for difference in pre-intervention use	-166.3042	691.8883
17. Average Effect of city efficiency improvements (76 accounts)	-240.9208	148.0551
Number of observations		57017
Number of customer accounts		983
Standard Error of Individual Constant Terms		5749.64
Standard Error of White Noise Error		4179.81
Time period of Consumption	June 1997 - July 2002	

Estimated Single Family Residential Water Demand Model

Table 4 presents the estimation results for the model of single family water demand in the R3 study sites. This sample represents water consumption among 1,525 single family households between June 1997 and July 2002. This sample contains 97 ET

controller/education participants (in Site 1001) and 192 education-only participants (in Site 1005).

The constant term (1) describes the mean intercept for this equation. (A separate intercept is estimated for each of the 1,525 households but these are not displayed in Table 4 for reasons of brevity.) The independent variables 2 to 8—made up of the sines and cosines of the Fourier series described in Equation 2—are used to depict the seasonal shape of water demand. The predicted seasonal effect (that is, $Z \cdot \widehat{b}_S$) is the shape of demand in a normal weather year. This seasonal shape is important in that it represents the point of departure for the estimated weather effects (expressed as departure from normal). We will also test to see if the landscape interventions have any effect on this seasonal shape.

The estimated weather effect is specified in "departure-from-normal" form. Variable 11 is the departure of monthly temperature from the average temperature for that month in the season. (Average seasonal temperature is derived from a regression of daily temperature on the seasonal harmonics.) Rainfall is treated in an analogous fashion (Variable 14). One month lagged rainfall deviation is also included in the model (Variables 15). The reader should also note that the contemporaneous weather effect is interacted with the harmonics to capture any seasonal shape to both the rainfall (Variables 12 and 13) and the temperature (Variables 9 and 10) elasticities. Thus, departures of temperature from normal produce the largest percentage effect in the spring growing season. Similarly, an inch of rainfall produces a larger effect upon demand in the summer than in the winter.

The effect of the landscape conservation program interventions is captured in the following rows. The parameter on the indicator for ET controllers/education (16) suggests that the mean change in water consumption is 41.2 gallons per day while the education only participants (19) saved approximately 25.6 gallons per day. The model cannot say whether education-only participants saved this water through improved irrigation management or by also reducing indoor water consumption. Since the sample includes only one year of post-intervention date, the model cannot say how persistent either effect will be in future years.

Table 4: Single Family Residential Water Demand Model

Dependent Variable: Average Daily Metered Water Consumption (in gallons per day)

Independent Variable	Coefficient	Std. Error
1. Constant (Mean intercept)	405.6593	3.1660
2. First Sine harmonic, 12 month (annual) frequency	-45.4215	0.9636
3. First Cosine harmonic, 12 month (annual) frequency	-89.1494	0.9629
4. Second Sine harmonic, 6 month (semi-annual) frequency	3.6549	0.6798
5. Second Cosine harmonic, 6 month (semi-annual) frequency	1.0709	0.6733
6. Third Cosine harmonic, 4 month frequency	1.7312	0.7151
7. Fourth Sine harmonic, 3 month (quarterly) frequency	4.4016	0.7403
8. Fourth Cosine harmonic, 3 month (quarterly) frequency	3.3491	0.7865
9. Interaction of contemporaneous temperature with annual sine harmonic	48.7897	17.1559
10. Interaction of contemporaneous temperature with annual cosine harmonic	-72.4672	22.3626
11. Deviation from logarithm of 31 or 61 day moving average of maximum daily air temperature	284.7163	13.542
12. Interaction of contemporaneous rain with annual sine harmonic	10.1102	1.8546
13. Interaction of contemporaneous rain with annual cosine harmonic	5.9969	2.6904
14. Deviation from logarithm of 31 or 61 day moving sum of rainfall	-34.0117	1.8931
15. Monthly lag from rain deviation	-13.3173	1.0549
16. Average Effect of ET controller/Education (97 participants)	-41.2266	4.0772
17. Interaction of ET intervention with annual sine harmonic	38.9989	5.3327
18. Interaction of ET intervention with annual cosine harmonic	-6.3723	4.8980
19. Average Effect of Education-only intervention (192 participants)	-25.5878	2.8081
20. Interaction of Ed.-only intervention with annual sine harmonic	6.0357	3.5870
21. Interaction of Ed.-only intervention with annual cosine harmonic	-3.0703	3.3826
Number of observations	94,655	
Number of customer accounts	1,525	
Standard Error of Individual Constant Terms		120.85
Standard Error of White Noise Error		129.81
Time period of Consumption	June 1997 - July 2002	

How ET Controllers Affect Peak Demand

The question of how these programs affected the seasonal shape of water demand can be interpreted from the remaining interactive effects—the indicators interacted with the first sine and cosine harmonics. For example, the seasonal shape of demand can be derived before and after ET controller/education participation:

$$\text{Pre\_Intervention}: S_t = Z \cdot \hat{b}_S \approx -45.4 \cdot \sin_1 - 89.1 \cdot \cos_1 + 3.6 \cdot \sin_2 + 1.1 \cdot \cos_2 + \ldots + 3.4 \cos_4$$

$$\text{Post\_ETIntervention}: S_t^{'} \approx Z \cdot \hat{b}_S + 39 \cdot I_{ET} \cdot \sin_1 - 6.4 \cdot I_{ET} \cdot \cos_1$$

When the pre/post seasonal patterns are combined with their pre/post mean water consumption, the following before and after picture can be seen throughout the year.

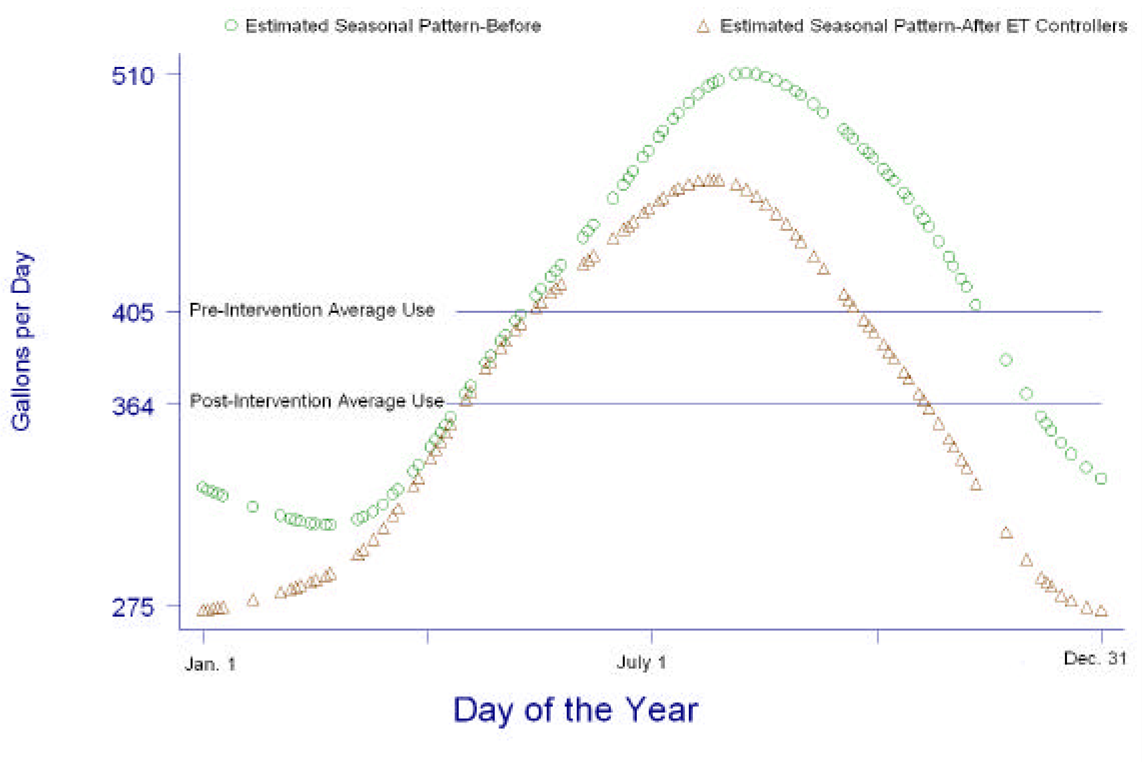

Figure 1-Effect of ET intervention on Water Demand

In Figure 1, several observations should be made. First, the difference between the two horizontal lines corresponds to the estimated mean reduction of approximately 41 gallons

per day. Second, the assumption of a constant 41 gallon per day effect does not hold true throughout the year. The reduction is barely noticeable in the spring growing season and is much larger in the fall.

The reduction in peak demand—though dependent upon how the seasonal peak is defined[5]—is greater than the average reduction. The estimated peak day demand, occurring on August 8, is reduced by approximately 51 gallons. This “load-shaping” effect of the ET controller intervention can translate into an additional benefit to water agencies. The benefits from peak reduction derive from the avoided costs of those water system costs driven by peak load and not average load—the costs for new treatment, conveyance, and distribution all contain cost components driven by peak capacity requirements.

Figure 2 plots the corresponding estimates for the Education-only intervention. The reduction in average demand is less—approximately 25 gallons per day. The effect upon the estimated seasonal shape of demand is much more muted. In fact, the change to the estimated seasonal shape of demand induced by the education-only intervention is not significantly different from zero at classical levels of significance.

[5] This is the issues of “coincident” versus “noncoincident” peak demand: the extent to which the peak load of a customer coincides with the system peak. Water systems by their nature have a strong and predictable tendency to peak seasonally—for Southern California, this occurs in the summer. Given the predictability of system peaks, and the attendant costs, the empirical case for the contribution of ET controller load shaping to the reduction of systems cost is relatively straightforward. The additional value of peak reduction--over and beyond reductions in average consumption--require careful specification of the additional incremental costs necessitated by peak flow requirements.

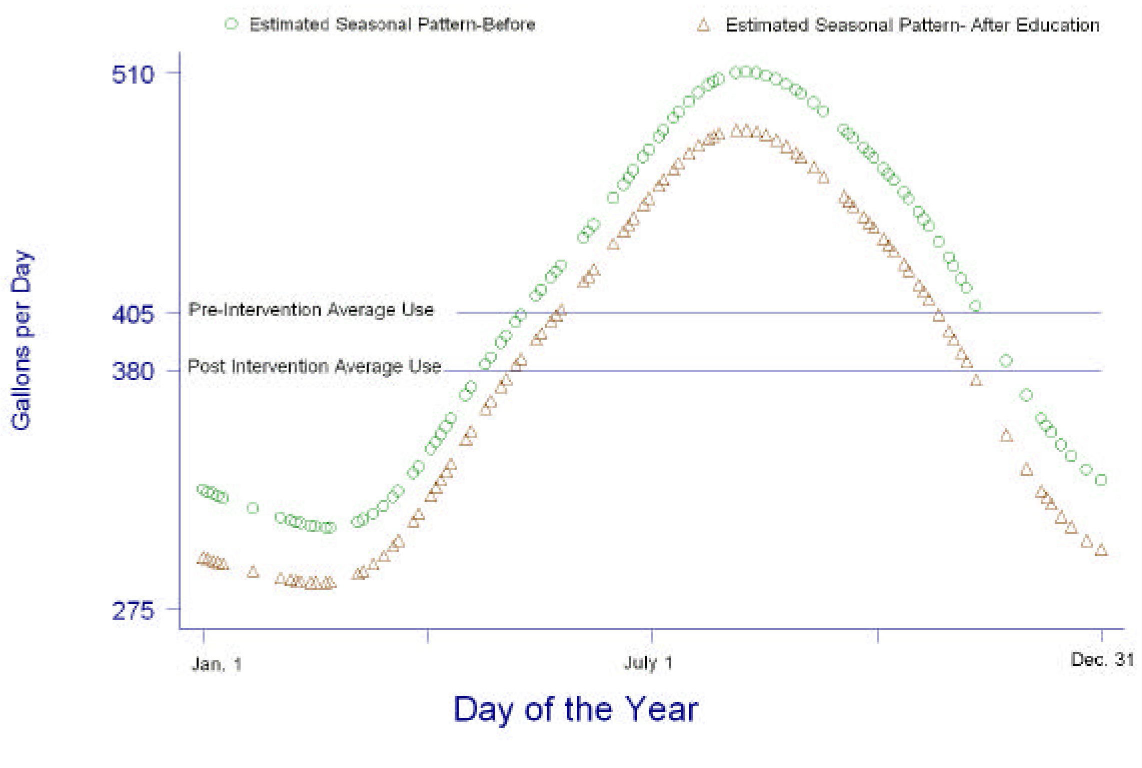

Figure 2-Estimated Effect of Education-only on Water Demand

Caveats and Additional Work

This modeling effort focused on developing the best depiction of net changes in water consumption due to the landscape interventions of ET controllers and/or education. Much of the modeling effort was expended on data cleaning, diagnosis, and validation. We believe that the most serious data issues were identified and appropriately handled. To the extent that future data quality can be improved, future work could provide several statistical refinements in model specification:

- The empirical effort has quantified the change in mean water consumption and the shift in seasonal consumption. The models have not been extended to document how water savings vary across households—how are savings decreased/increased among lower/higher water use households?
- Since the sample only contains about one year of post installation data, the statistical models can say little about the persistence of water savings. Additional follow-up quantification of water savings in subsequent years is required.
- The modeling effort to date has *not* attempted to estimate the effect of self-selection. Thus, we make no attempt to extend the inference from the existing sample of participants to (1) the rest of the service area or (2) to other service areas.
- The error component of the estimated models could be improved by specifying a function form to explain the variance. This should only be attempted after all major data issues have been resolved.

Conclusion

This report documents the shape of water savings achieved by the landscape interventions of ET controllers and/or education. Households participating in these programs saved significant amounts of water. The education-only program showed less water savings than the ET controller/education program, but were still significant. The ET controller/education program changed both the level and shape of water demand.

Appendix D1: Statistical Analysis of Urban Runoff Reduction

The Residential Runoff Reduction Study

Appendix D1 - Statistical Analysis of Urban Runoff Reduction

Prepared for
Municipal Water District of Orange County and
The Irvine Ranch Water District

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February 2002

DRAFT FINAL

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Summary

$ **Data Reliability and Validity:** There were significant measurement and data quality issues with the enacted real-time measurement of urban runoff. The technology employed involved custom configurations and numerous needed calibration adjustments. Debris build-up was an early, ongoing, and possibly unavoidable issue that interfered with the calibration of the flow meters. Some of the original locations selected were more prone to this type of problem and the flow meters were necessarily relocated. Careful attention was paid to documenting data quality issues in ways that did allow for quantitative evaluation of runoff. Nonetheless, the intrinsic data reliability constrains the inference that can be drawn.

$ **Control Study Sites 1002 and 1003:** The measured runoff for the study sites 1002 and 1003—potential control sites—had recurring measurement issues that produced generally unreliable runoff data. We were unable to use the runoff data from either of these sites to serve as a match to either of the sites receiving landscape interventions (ET controllers and/or education).

$ **Control Site (1004):** The unadjusted runoff flow at Site 1004 contained some elevated and likely invalid flow recordings in the pre-intervention period; that is prior to May 2001. Using robust statistical modeling methods, the spurious flow observations were identified and "quarantined." It is possible that these high flow

measures were completely accurate measures of real runoff within Site 1004; perhaps one or more customers experienced undetected leaks. If this is the case, then Site 1004 could not serve as a good “matched” control site. The runoff in the post-intervention period for the Control Site 1004 increased 63 percent from the pre-intervention period.

$ **Effect of Education-only Intervention (Site 1005):** Study site 1005 contained approximately 565 single-family residences. Of these, 225 residential customers agreed to participate in the irrigation education program. Study site 1005 was found to have post-intervention runoff (after May 2001) that was 36 percent higher than pre-intervention runoff (May 2001 and before). The question of how much higher runoff might have been without the education intervention necessitates comparisons to comparable sites that did not receive any intervention.

Comparison across sites can, in theory, control for time-varying covariance in runoff. That is, measured runoff from a matched control group could be used to estimate how runoff increases in the summer period. Comparing across sites, however, will also require standardizing for the different areas across sites and testing for how well matched the sites are in the pre-intervention period. These results are presented in the body of this chapter. If one is willing to accept the Control Site as a matched control, Site 1005's post-intervention runoff is 21 percent less than expected.

$ **Effect of Evapotranspiration Controller/Education Intervention:** Study site 1001 contained 565 single-family residences. Of these, 114 agreed to participate in the evapotranspiration (ET) controller/education program. In addition, approximately 26 landscape sites (HOA, City median, parks, and school sites) also received ET controllers.

Study site 1001 was found to have post-intervention runoff (after May 2001) that was approximately 49 percent less than pre-intervention runoff (May 2001 and before). These two time periods are not equivalent as valid pre-intervention measures include less than four months of data. Since urban runoff derives from outdoor water use, it generally increases in the spring and summer and declines in the autumn and winter. Hence, the 49 percent runoff reduction is likely to be an underestimate of the level of runoff reduction that would be estimated on comparable time periods.

Using either Site 1005 or 1004 as matched controls implies that the observed post-intervention runoff was 64 to 71 percent less than expected.

Introduction

The purpose of this work is a statistical analysis of the reduction of runoff induced by Evapotranspiration (ET) controllers and irrigation education in the Irvine Ranch Water District. This report documents a careful statistical analysis of measured runoff in residential areas to derive estimates of the runoff reduction from these interventions.

Methods

Robust regressions techniques were used to detect which observations are potentially data quality errors. This methodology determines the relative level of inconsistency of each observation with a given model form. A measure is constructed to depict the level of inconsistency between zero and one; this measure is then used as a weight in subsequent regressions. Less consistent observations are down-weighted. Other model-based outlier diagnostics (Cook's distance, DFBETA statistics, and residual diagnostics) were also employed to screen the data for any egregious data quality issues.

Results

Descriptive Statistics

Raw flow rates

After screening for the known data quality problems, using the "rank" indicator, all raw meter reads were first converted to average hourly values. These were then aggregated by date to convert to daily runoff—the runoff measures are available in both mean hourly flow and total daily volume. Precipitation taken from the Irvine weather station was matched to the daily data and used to separate wet from dry days. Wet weather storm

flow can be a more complicated phenomenon to predict, as it depends on the timing and magnitude of the rainfall event, the moisture deficit of soils, and other factors. The relative lack of large storm events in the post-intervention period precluded examination of these more complicated forces and the effect that the landscape interventions might have on wet day runoff.

Standardizing for area

Area-standardized measures of site runoff were also created for dry/wet days, where total daily volume was divided by the estimated permeable/total area. Estimates of area for the study sites were derived from the IRWD GIS system. The GIS system was queried to produce estimates of the number of lots and total area for the different land use classifications (single family residence, condo, HOA, school, landscape, street, and unknown). The GIS system also provided an estimate of the number of buildings, and building area. The area taken up by buildings is treated as impermeable. The remaining area was separated into permeable and impermeable area using a land use classification-specific assumption of impermeability. Table 1 provides the raw data used to construct the estimated site area. (Due to lack of usable flow measures, Sites 1002 and 1003 are not separately reported.) Table 2 aggregates these data by site.

Table 1: Estimated Area of Study Sites by Land Use

R3 GROUP	#Lots	Classification	Total Area	Building Area	Assumed Impermeable Coefficient	Estimated Impermeable Area	Estimated Permeable Area
1001	64	?	499885		0	0	499885
1001	565	SFR	2911227	976574	0.5	1943900	967326
1001	109	Condo	447096	189721	0.9	421358	25738
1001	4	HOA	255208		0.75	191406	63802
1001	2	School	198676		0.9	178808	19868
1001	10	Landscape	845529		0	0	845529
1001	97	Street	2163105		1	2163104	0
1004	61	?	307556		0.0	0	307556
1004	417	SFR	2081636	719485	0.5	1400560	681076
1004	1	HOA	40165		0.8	30123	10041
1004	1	School	348739		0.9	313865	34874
1004	2	Landscape	1136		0.0	0	1136
1004	42	Street	1089143		1.0	1089143	0
1005	8	?	118370		0.0	0	118370
1005	559	SFR	2957363	1033197	0.5	1995280	962083
1005	1	HOA	66421		0.8	49816	16605
1005	1	School	264236		0.9	237812	26424
1005	1	School	261089		0.9	234980	26109
1005	2	Landscape	773206		0.0	0	773206
1005	45	Street	1736098		1.0	1736098	0

Table 2: Estimated Area of Study Sites (in sq. ft.)

R3 Group	Estimated Impermeable Area	Estimated Permeable Area	Total Area
1001	4,898,578	4,246,905	7,320,726
1004	2,833,692	572,686	3,868,375
1005	4,253,986	1,194,553	6,176,782

Robust Analysis of Runoff

Form of the Model

Using the runoff flow data, regression models were used to estimate mean runoff by site. A regression framework allows for (1) hypothesis testing within or across sites and (2) use of robust modeling techniques to identify and minimize the influence of spurious or outlying observations. Sites 1002 and 1003 contained too few valid observations to be included in this analysis. The form of the model is specified to have a single pre-intervention mean (μ_1) and to allow for tests of changes in this mean over time and across sites:

Equation 1

$$\frac{RunoffVolume_{i,t}}{SiteArea_i} \equiv m_1 + I_{4,\mathrm{Pre}} \cdot d_{4,\mathrm{Pre}} + I_{5,\mathrm{Pre}} \cdot d_{5,\mathrm{Pre}} + I_{1,Post} \cdot d_{1,Post} + I_{4,Post} \cdot d_{4,Post} + I_{5,Post} \cdot d_{5,Post}$$

The indicator variable $I_{i,\,t}$ takes on the value one to indicate that an observation comes from site *i* and the time period *t* (pre/post). Thus, the indicator variable $I_{4,Pre}$ takes on the value one for Site 1004 in the pre-period (Feb.2001-May 2001) and is zero otherwise. The parameter $d_{4,\mathrm{Pre}}$ is the estimate of how runoff in Site 1004 differs from the common mean μ_1 in the pre-period. The parameter $d_{5,\mathrm{Pre}}$ has a similar interpretation for Site 1005. The common intercept will, by construction, pick up the estimate of Site 1001 pre-period mean runoff, since the parameters $d_{4,\mathrm{Pre}}$ and $d_{5,\mathrm{Pre}}$ absorb any differences in the other sites.[1] The indicator variable $I_{,1Post}$ takes on the value one for Site 1001 in the post-period (June 2001 -June 2002); its parameter is interpreted as the estimated change to the pre-

period mean runoff. The parameters $d_{4,Post}$ and $d_{5,Post}$ have similar interpretations for Site 1004 and Site 1005.

Table 3: Robust Regression Estimates of Mean Dry Day Runoff

Dependent Variable: Dry Day Runoff Height (in inches per unit area) (Height=Runoff Volume/Site Area)

Variable	Coefficient	Std. Error	t	Prob.>|t|
Mean Runoff: Feb-May 2001				
1. Intercept (1001 mean runoff)	0.898563	0.120838	7.44	0
2. Difference of Site1004 in pre-period	0.143721	0.157245	0.91	0.361
3. Difference of Site1005 in pre-period	-0.092260	0.151479	-0.61	0.543
Change in Runoff: June 2001-June2002				
4. Change of Site 1001 in post-period	-0.445390	0.134540	-3.31	0.001
5. Change of Site 1004 in post period	0.878089	0.113737	7.72	0
6. Change of Site 1005 in post period	0.202553	0.106973	1.89	0.059
Number of observations	950			
F (5, 944)	74.92			
Prob. > F	0			
Quasi-R-Squared	0.35			

Robust Regression Results

Table 2 presents the robust regression estimation results for the model of dry day runoff in R3 study Site 1001 (containing some customers receiving the ET controller/education intervention), Site 1004 (whose customers received no treatment), and Site 1005 (containing some customers receiving the education-only treatment). This sample represents metered dry day runoff, standardized by estimated site permeable area, between Feb. 2001 and June 2002.

[1] The choice of Site 1001 as the reference site—implied by excluding a Site 1001 change indicator—is not required. Choosing another site would generate an essentially equivalent model that is one that generates identical predictions, but would change the interpretation of the coefficients.

Differences among Sites in the Pre-Intervention Period. The constant term (1) defines the intercept for this equation and can be interpreted as the mean daily runoff in Site 1001—about 0.898 hundredths of an inch per permeable acre. The following two variables (2) and (3), the indicators for Sites 1004 and 1005 in the pre-period, suggest that estimated difference in mean runoff is not statistically distinguishable from zero; The standard errors of the estimated coefficients are larger than the estimated coefficients. The estimated pre-period site mean runoff for these sites can also be inferred from these coefficients: $m_{4,\mathrm{Pre}} \equiv m_1 + d_{4,\mathrm{Pre}} \approx 0.89 + 0.14 = 1.03$ hundredths of an inch and

$m_{5,\mathrm{Pre}} \equiv m_1 + d_{5,\mathrm{Pre}} \approx 0.89 - 0.09 = 0.80$.

Change in Runoff in the Post-Intervention Period: The formal test for the change in runoff in the post-intervention period (June 2001-June 2002) can be found in the following three site-specific terms: variables 4, 5 and 6 as shown in Table 3. The estimated change in dry day runoff for Site 1001 (4) is -0.44 hundredths of an inch. In relative terms, this works out to approximately a 49 percent reduction. The implied mean post-intervention dry day runoff for Site 1001 is 0.89-0.44˜0.45 hundredths of an inch. This reduction in runoff is statistically distinguishable from zero at classical levels of confidence.

The reader should be careful in interpreting this result as the pre- and post- periods are not comparable. The post-intervention period, June 2001 to June 2002, includes 13

months but would be fairly close to an annual average. The period of time covered by the pre-intervention period for all sites, February to May 2001, includes at most 4 months. For Site 1001, the pre-intervention period only includes the months of April and May in 2001, because the flow meter produced enough invalid reads in February and March to necessitate its relocation to a new site in April. Since these are not the highest months for urban runoff, it would be reasonable to expect runoff in the post-intervention period to increase. For this reason, the reduction of 49 percent from the pre-intervention period would be a lower bound on the true estimate of runoff reduction. We can examine the other two valid sites for insight into how much runoff would have increased in the post-intervention period.

The estimated change in dry day runoff for Site 1004 (5) is +0.88 hundredths of an inch. This increase in runoff is statistically distinguishable from zero at classical levels of confidence. The implied mean post-intervention dry day runoff for Site 1004, is (0.89+0.88˜) 1.77 hundredths of an inch. In relative terms, this works out to a fairly large (1-{1.77-1.03}/1.03=) 72 percent increase in the post-intervention period.

The estimated change in dry day runoff for Site 1005 (6) is +0.20 hundredths of an inch. This increase in runoff is statistically distinguishable from zero at close to classical levels of confidence. The implied mean post-intervention dry day runoff for Site 1005, is (0.89+0.20˜) 1.09 hundredths of an inch. In relative terms, this works out to a more modest (1-{1.09-0.80}/0.80=) 36 percent increase in the post-intervention period.

Comparing Post-Intervention Change in Runoff across Sites. The last and potentially most vulnerable inference compares the time change in runoff across sites. If Site 1001 had experienced the same change in runoff as its neighbor sites 1005 or 1004, then dry day runoff would have increased from 36 to 72 percent in the post-intervention period. In absolute terms, this would imply a prediction of non-intervention runoff of 1.24 to 1.53 inches per acre. Compared to the realized 0.45 inches of runoff in the post-intervention period, this reduction would translate to 64 to 71 percent reduction in runoff.

A similar counterfactual exercise for Site 1005 would require assuming that Site 1004 is a good matched control site. Then dry weather runoff in Site 1005 would have increased by 72 percent in the post-intervention period, a level of 1.38 inches per acre. Compared to the realized 01.09 inches of runoff in the post-intervention period, the reduction would translate into a modest but non-ignorable 21 percent decrease in runoff.

Both of these exercises require use of Site 1004 as a control site. While the unadjusted flow measures for Sites 1001 and 1005 are fairly close in the pre-intervention period, the same cannot be said for the flow measures from Site 1004. Perhaps the question would be best put, “Given the three estimates of reduction runoff for Site 1001, which should be used?” The direct within-site estimate of a 49 percent runoff reduction is likely biased low; runoff in the post-intervention period should have increased. The estimate of 64 percent, based on Site 1005 as a control site, may also be biased on the low side. Though Site 1005 did have pre-intervention runoff that reasonably matched Site 1001, Site 1005 also contained more than 200 homes that participated in the education-only intervention

with monthly follow-up. These homes did have quantified water savings, some of which is likely to have resulted from reduced runoff. Site 1004 did not receive any treatment but did have measurement issues. Thus the estimate of a 71 percent reduction, using Site 1004 as a control site, has an unknown bias.

The bigger inferential uncertainties lie in how these conservation interventions will work as they are scaled in a larger program or in how other implementations of these programs would work in other areas.

Caveats and Additional Work

- The difficulties encountered in calibrating custom configured equipment to measure runoff limited the amount of pre-intervention data. This in turn precluded simple before and after comparisons of mean runoff flow. Nonetheless, a sufficient length of baseline data was collected to allow quantitative estimates of runoff reduction. If additional flow data can be collected, additional analysis would be possible: (1) the runoff reduction under wet conditions could be examined and (2) an estimate of the seasonal shape of runoff could be included in the models to improve the precision of the estimated runoff reduction.

- Because the runoff measurement is not at a customer level, we cannot distinguish the relative contribution of different customers to urban runoff reduction. Thus, for Site 1001, we cannot state how much the single family ET

controller/education contributed relative to the ET controller intervention with landscape customers.

Appendix D2: Residential Runoff Reduction Study Update – 2003 Runoff Data

The Residential Runoff Reduction Study

Memorandum

To: Dick Diamond, IRWD

From: Thomas W. Chesnutt, Ph.D.

Date: August 31, 2004

Re: Residential Runoff Reduction Study Update – 2003 Runoff Data

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Finding

The 2003 measures of runoff from the Residential Runoff Reduction Sites 1001, 1004, 1005 support the findings of the earlier data: Site 1001 has a consistently lower mean level of urban runoff *and* a smaller variation in runoff.

Approach

A & N Technical Services performed data manipulation, collation, and validation on 2003 flow data collected in the R3 Study. The raw flow measures were provided in spreadsheet form. First, the spreadsheets of flow data from three study sites were incorporated into database form. This entailed the writing of a program for each site to convert the spreadsheets that also accounted for variations of form. Second, we performed validation checks on the estimated flow rates to check for consistency problems. Where correctable, revisions will be performed to the flow estimates. Last, these raw data exhibit an inconsistent time step, varying from 5-30 minutes. The raw data for each site was converted into their consistent daily basis—mean flow and total daily volume. The consistent time series version of flow data in the three study sites was then combined into a single consistent database with a consistent time series across sites. A consistent time-step, in term, allows valid comparisons across sites.

An attached spreadsheet contains the raw estimated daily runoff data–mean daily flow, total daily volume, and an indicator measure of data quality. As was experienced with the earlier data, there were considerable measurement issues that the IRWD team had to overcome to obtain consistent measures of flow. The project team coded a data quality indicator ("rank") for each subcomponent of the flow measure—instantaneous velocity and flow height. A combined indicator was also developed. The data quality indictor was set to 2 for measures that were known to be bad (rank=2). The data quality indictor was set to 1 for measures of questionable data quality (rank=1). Thus, the data quality indicator rank would take on the value 222 if all three measures (velocity, height, and estimated flow) were known to be bad and would take on the value 111 if all three were of questionable data quality. A value of zero was assigned to measures having no known or suspected data quality issues.

The data are summarized in two ways. First, the descriptive statistics of the mean daily flow volume (adjusted by site area) at each of the three sites in this post-installation period are examined. The

estimated mean daily runoff flow is expressed in inches per acre. Second, a graph of 2003 runoff data is developed for each site that displays the raw data and a lowess-smoothed line of central tendency. (Lowess smoothers are a robust data analytic technique that can convey a sense of the level of runoff.)

Table 1 provides the descriptive statistics of mean dry day runoff height at the three sites. (Note that the number of observations per site are reduced due to the exclusion of flow measures on wet days and exclusion of flow measures due to data quality concerns.) The 2003 flow data were also graphed for the three sites. These figures follow. Site 1001 that received the ET controller and education intervention consistently displays both lower levels of runoff and lower variability in runoff. Site 1004 displays very large variability in runoff; this level of variability is the norm rather than the exception. The months of May and June in 2003 did experience wetter than normal (May) and cooler than normal (June) weather patterns.

Table 1: Estimated Mean Dry Day Runoff Height

January 2003 – August 2003

(in inches per unit area)

(Height=Runoff Volume/Site Permeable Area)

Site	Obs	Mean	Std. Dev.	Min	Max
Site 1001 (ET controllers +ed.) Runoff Height	136	1.03	0.72	0	3.90
Site 1005 (Education only) Runoff Height	160	1.79	2.75	0	27.29
Site 1004 ("Control") Runoff Height	136	2.29	2.83	0	14.25

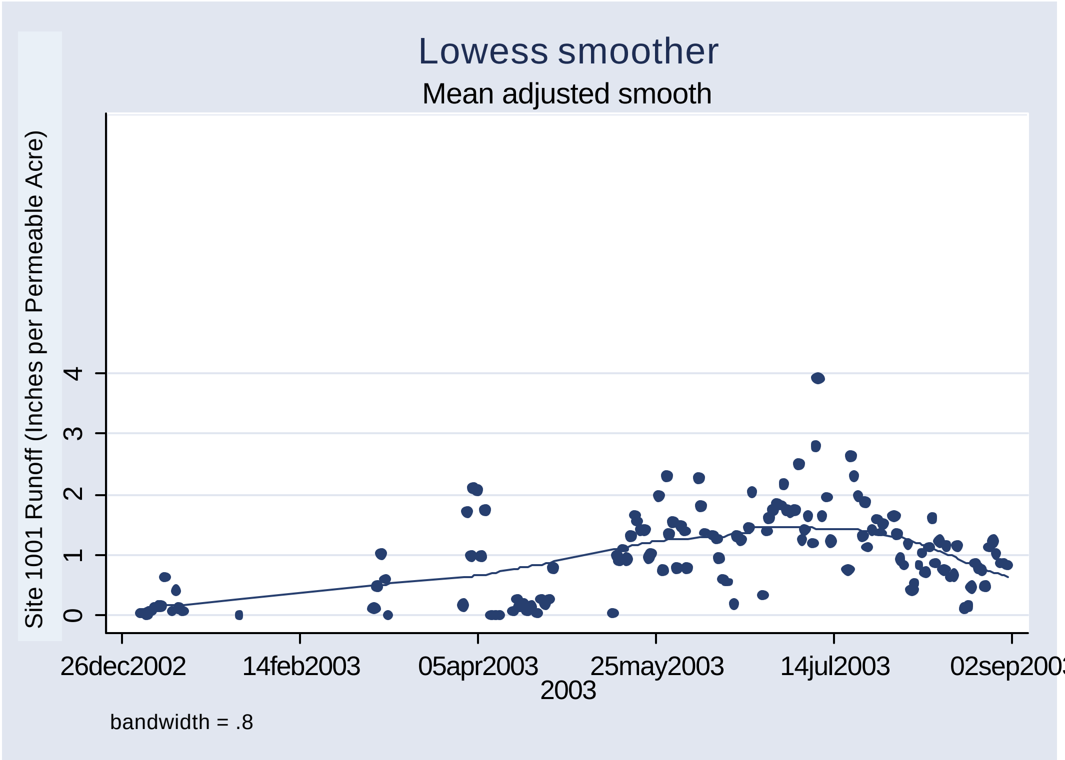

Figure 1: Site 1001 ET Control and Education Intervention

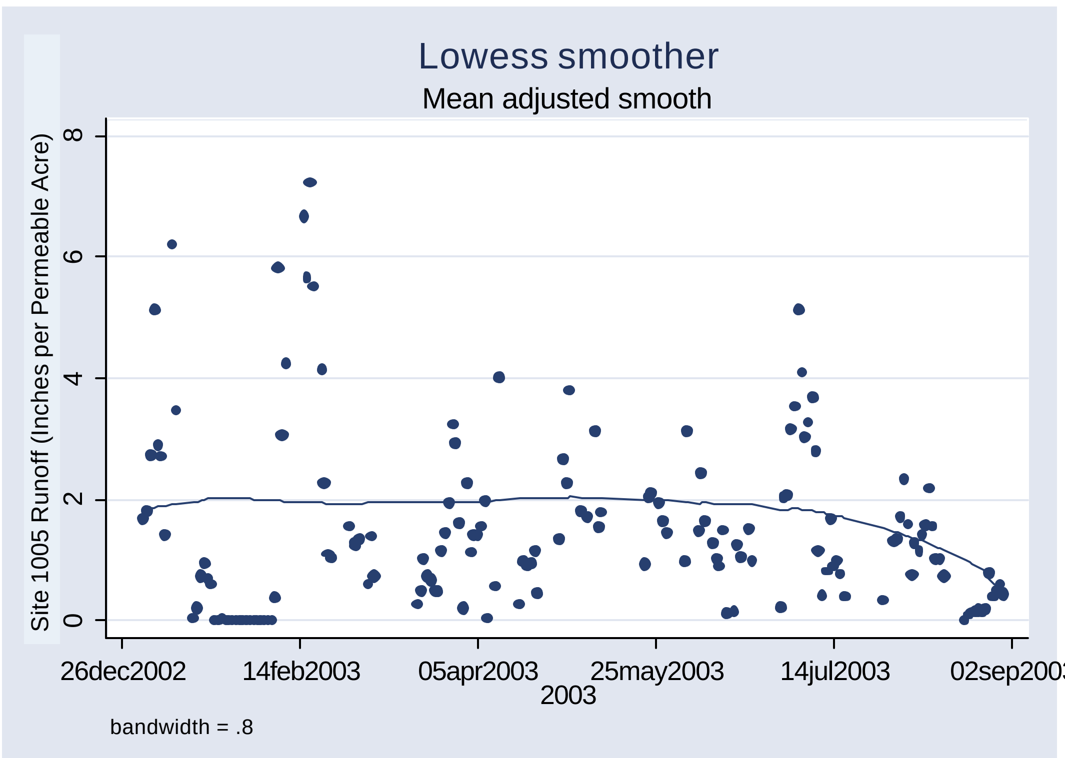

Figure 2: Site 1005 Education Only Site

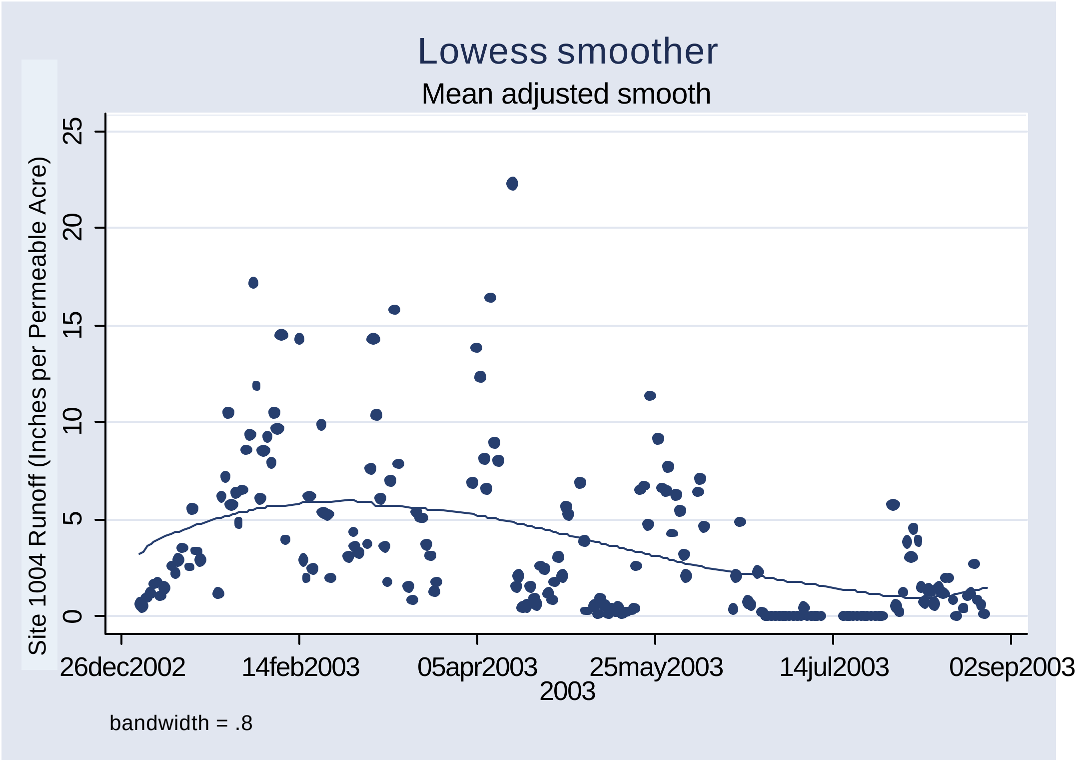

Figure 3: Site 1004 "Control" site

Appendix E1: The Effect of Technology and Public Education on the Water Quality of Dry Weather Runoff from Residential Neighborhoods

The Residential Runoff Reduction Study

Appendix E1

The Effect of Technology and Public Education on the Water Quality of Dry Weather Runoff from Residential Neighborhoods

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ABSTRACT

Urban runoff is one of the largest contributors of pollutants to impaired surface waters in the United States, however little is known about effectiveness of potential best management actions (BMPs) to improve water quality. The goal of this study was to quantify the effectiveness of a technological BMP compared to public education as a BMP. The technological BMP consisted of a new evapotranspiration (ET) sprinkler controller that automatically changes sprinkler timing based on weather conditions using remotely controlled radio signals at a nearby weather station. Water quality (nutrients, trace metals, bacteria, pesticides, toxicity) was measured every two weeks for six months at five similar residential neighborhoods, then the technology plus education or education only treatments were applied to one neighborhood each, and measurements continued for another year. At the end of one year post intervention, there was virtually no difference in concentrations or pollutant flux over time. The technological and education treatments provided essentially no detectable increase or decrease in water quality following the intervention. The lack of detectable differences in water quality was a result of a combination of factors including large variability among measurements within a neighborhood and insufficient sample sizes to detect small changes in concentration or pollutant flux.

INTRODUCTION

Urban runoff has been identified as a major contributor to water quality problems throughout the United States (EPA 2000). Runoff from urban areas contains numerous potential pollutants including nutrients, trace metals, pesticides, and/or bacteria (US EPA 1987, Wong et al 1997, Smullen et al 1999, Ackerman and Schiff in press). These discharges have resulted in water quality impairments such as excessive blooms of algae (Bricker et al 1999), toxicity to aquatic organisms (deVlaming et al 2000, Bay et al 1996, closures of recreational shoreline for protection of human health (Noble et al 2000).

As managers become aware of the environmental concerns resulting from discharges of urban runoff, they are seeking methods and technologies for reducing or eliminating these discharges. Best management practices (BMPs) come in a variety of forms, including structural and non-structural control measures. Structural BMPs typically include technologically driven management actions that either reduce or eliminate runoff volume and/or attempt treatment of runoff prior to discharge. Non-structural BMPs typically are aimed at changing peoples attitudes or behavior that reduce the use of potential pollutants or limit their entry into the storm drainage systems. The most commonly cited form of non-structural BMPs is public education, which often consists of advertising campaigns, mailers, and other widely distributed educational materials.

The problem with both structural and nonstructural BMPs is that the efficiency and effectiveness of these BMPs are largely unknown. There is no uniform manner or standard method for independently testing these BMPs. Manufacturer information is occasionally available for some structural BMPs, but these data are looked upon suspiciously by most urban runoff managers as a result of their potential conflict of interest. Nonstructural BMPs, such as public education, are almost entirely without rigorous evaluation of their effectiveness. Hence, managers struggle with which BMPs to select, and in which environmental application, to achieve the greatest reduction in pollutant concentrations or mass emissions. At the same time, regulatory mechanisms like National Pollutant Discharge Elimination System (NPDES) Permits for municipal

separate storm sewer systems or total maximum daily loads (TMDLs) continue to push the regulatory obligation of urban runoff managers to reduce concentrations and mass emissions of many potential pollutants.

The goal of this study is to compare the effectiveness of technological BMPs versus public education for reducing concentrations or mass emissions of potential pollutants in dry weather discharges. The technological BMP consisted of evapotranspiration (ET) controllers that communicate with landscape irrigation systems of individual households. This technology is designed to optimize watering times for landscaped areas, hence reducing overwatering and resultant runoff. The public education campaign focused on not just appropriate watering times, but also minimization of pesticide, herbicide, and fertilizer usage. These two types of BMPs were tested in residential neighborhoods, typically the most common land use in urban watersheds (Wong et al. 1997). Our goal was to determine if technology or education provides more pollutant reduction so that urban runoff managers can select optimal runoff pollutant minimization strategies.

METHODS

We used a before-after, control-impact (BACI) design for evaluating the effectiveness of both the sprinkler technology and public education. Each neighborhood was sampled every other week between December 2000 and June 2001. In June 2001, homes in one of the neighborhoods were outfitted with the ET sprinkler controllers. Since homeowners with the retrofitted sprinkler controllers were simultaneously being educated, a well-defined public education campaign was also begun with these homeowners. To ascertain the difference between education and ET sprinkler technology, homeowners in a second neighborhood were targeted with an identical public education campaign, but without effect of the ET sprinkler retrofit technology. There was no education or technology intervention in the remaining three neighborhoods, which served as control neighborhoods to document the effect of no treatment. Sampling at the five neighborhoods continued every other week from June 2001 to June 2002.

ET Sprinkler Controller and Public Education

The ET controller is described in detail elsewhere (*see Chapter 2 – Study Methods*). It is similar to any automatic sprinkler timer available at most home improvement stores and nurseries, but with the capacity to receive radio signals that will alter sprinkler timing based on current weather conditions. If weather is hot and dry, the radio signals call for longer or more frequent irrigation. If the weather is cool and moist, such as recent precipitation, the radio signals call for shorter or less frequent irrigation. For this study, the existing sprinkler timers that are set manually by the homeowner were replaced with the radio controlled ET controller systems. Trained technicians were used to ensure successful installation; ET controller requires programming for each valve including area (size of yard or planter per valve), soil type (clay, sand, etc.), and landscape type (turfgrass, shrubbery, etc.). The remaining irrigation system was unchanged, including piping and sprinkler head configuration.

Public education consisted of an initial informational packet containing three items. The first item was an introductory letter that described the purpose of the packet. The second item was a booklet with irrigation, fertilization and weed and pest control information. The centerfold of the booklet was a month-by-month guide to irrigating, fertilizing and pesticide application suitable for posting near their sprinkler timer. Third, each homeowner was supplied a soil probe for measuring the water content of their landscaped soils. In addition to the initial packet, monthly reminders were mailed to each homeowner including landscape maintenance tips such as irrigation system, water schedule, fertilizing, and weed and insect control. Suggested sprinkler run times (for the non-ET sprinkler neighborhood) and fertilizer or pesticide application usage, including non-toxic alternatives, were also provided in the monthly newsletter.

Treatment Neighborhoods

The five neighborhoods were located within a three mile radius in Irvine, CA. The selection criteria for the neighborhoods included similarity in: 1) age of neighborhood (approximately 20 years old); 2) primary land use (single family residential); 3) irrigation management factors (precipitation rate, soil type, plant type, slope and sun exposure); 4) proximity to radio signal for ET controller (all neighborhoods used the same signal). The five neighborhoods were designated 1001 (sprinkler retrofit + education), 1002 (control), 1003 (control), 1004 (control), and 1005 (education only). Although each of the five neighborhoods met the selection criteria, there were some differences worth noting (Table WQ1). First, the two treatment neighborhoods were larger, up to twice as large as the control neighborhoods. Second, the two treatment neighborhoods were more impervious, up to two twice as much impervious area, as the control neighborhoods. Third, the two treatment neighborhoods had greater proportions of landscaped common areas than any of the control neighborhoods.

The treatments were not uniformly applied to all homeowners in either the 1001 or 1005 neighborhoods. In the case of sprinkler + retrofit neighborhood (1001), roughly one third of the pervious area actually retrofit their sprinkler systems. These homeowners, condominium complexes, school and city landscaped areas were recruited by trained personnel. In order to keep the relative percentages approximately the same between treatment neighborhoods, homeowners representing roughly 30% of the pervious area were selected to receive the education materials in the education only neighborhood (1005). These homeowners were selected at random.

Sampling and Laboratory Analysis

Each of the five neighborhoods were hydrologically self-contained and drained to a single underground pipe unique to each neighborhood. At each of these five locations, samples were collected for flow and water quality. Stage (water depth) and velocity were recorded at 5 min intervals using an ultrasonic height sensor mounted at the pipe invert and a velocity sensor mounted on the floor of the pipe. Flow was calculated as the

product of velocity and wetted cross-sectional area as defined by the stage and pipe circumference. Despite the relatively continuous measurement of flow, many of the flow measurements were excluded due to faulty readings. Synoptic flow and water quality measurements were only available for two sites over the course of the entire study (i.e. before and after intervention), including the sprinkler + education and education only sites. Flow measurements at the time of water quality sampling for the three control sites were considered faulty and discarded.

Grab samples for water quality, collected just downstream of the flow sensors in the early morning, were collected using peristaltic pumps and pre-cleaned Teflon tubing. Samples were placed in individual pre-cleaned jars, placed on ice, and transported to the laboratory within one hour. Each sample was analyzed for 19 target analytes, five microbiological parameters, and four toxicity endpoints (Table WQ2). Target analytes included trace metals, nutrients, and organophosphorus (OP) pesticides. Microbiological parameters included fecal indicator bacteria and bacteriophage. Toxicity was evaluated using two marine species, the purple sea urchin *Strongylocentrotus purpuratus* and the mysid *Americamysis bahia*. Toxicity endpoints included the median effects concentration that estimates the concentration at which 50% of the sample population is affected (EC50) and the no effect concentration that estimates the highest concentration at which no effect is observed (NOEC). All of the laboratory methodologies followed standard protocols developed by the US EPA (1995, 1993, 1983) or Standard Methods (APHA 2001).

Data Analysis

Data analysis consisted of five steps. These steps included: 1) comparison of water quality among the five neighborhoods prior to intervention; 2) comparison of water quality concentrations over time by neighborhood; 3) comparison of water quality concentrations before and after intervention by treatment type; 4) comparison of pollutant flux before and after intervention by treatment type; and 5) correlation of toxicity measures with potential toxicants in dry weather runoff.

Comparison of water quality concentrations among the five neighborhoods prior to intervention was conducted to assess if there were inherent differences among treatment sites for each constituent. This analysis was conducted using an analysis of variance (ANOVA) using Tukey's post hoc test for identifying the significantly different neighborhoods. All data were tested for normality and homogeneous variance prior to testing. Only the microbiological data were determined to be non-normally distributed, so these results were log transformed prior to data analysis

Comparison of water quality concentrations over time was accomplished by creating temporal plots of monthly mean concentration. Comparisons of water quality concentration before and after intervention by treatment type were accomplished using a standard t-test of the mean concentration before versus mean concentration after intervention. The mean concentrations for sprinkler+education, education only, and sprinkler+education – education only for each sampling event were normalized by the grand mean of the control sites for the same sampling event.

Pollutant flux estimates were calculated by the product of the concentration and volume at the time of sampling and then normalized to the area of the sampled neighborhood. Pollutant flux before and after treatment was compared somewhat differently since the lack of flow data at the control sites did not permit an estimate of flux for these neighborhoods. Mean pollutant flux before and after intervention was compared using standard t-tests at the sprinkler+education and education only neighborhoods without normalization to control values.

Correlation of toxicity with toxicant concentrations was accomplished using a Pearson product moment correlation. These correlations are inferential only and do not presume resulting correlations automatically identify the responsible toxicants. In order to help identify potential causative toxic agents, concentrations of the correlated constituents were compared to concentrations known to induce toxicity in the respective test organisms.

RESULTS

There were significant differences in water quality among sites prior to intervention (Table WQ3). Site 1004, the control site, had the greatest mean concentrations for 15 of the 24 constituents evaluated prior to the sprinkler intervention. Mean concentrations for seven of the 15 constituents were significantly greater at site 1004 than mean concentrations at least one other site (ANOVA, $p<0.05$). In particular, all of the mean nutrient concentrations were greater at site 1004 than the other sites. Mean ammonia, nitrate/nitrite, and TKN were a factor of 13, 11, and 2.5-fold greater at site 1004 than the mean concentrations at the next greatest site, respectively. On the other hand, sites 1001 and 1002 generally had the lowest average concentrations prior to the sprinkler intervention. Cumulatively, these sites had the lowest mean concentrations for 17 of the 24 constituents evaluated. Site 1002 also had the least toxicity, on average, of all five sites. Finally, site 1003 had an intermediate status. Mean concentrations of enterococcus and fecal coliforms at this site were greater than any other site (fecal coliforms significantly greater than sites 1001 and 1002), but the mean concentrations of five trace metals (chromium, copper, cobalt, nickel, selenium) were lowest at this site.

Water quality concentrations and toxicity were highly variable over time during the study period (Figure WQ1). Temporal plots of concentrations and toxicity for each site demonstrated that there was no seasonal trend and no overall trend with time. There were, however, occasional spikes in concentrations for many constituents that appeared to fall into one of two categories. The first category was recurring spikes in concentration that were unpredictable in timing and location. For example, both fecal coliform and enterococcus consistently varied by more than an order of magnitude from month to month during the study period and there was no similarity in pattern between the sites. The second category of concentration spike was single or infrequent peaks. Occasionally these spikes would occur across multiple sites, such as the peak in both lead and zinc at all three control sites (1002, 1003, and 1004) in October 2001, without

commensurate changes in concentration at the treatment sites (1001 or 1005). More often, infrequent spikes were isolated to a single site. For example, concentrations of chlorpyrifos climbed to over 10,000 ng/L in July 2001, but averaged near 50 ng/L the remainder of the year at site 1005. Similarly, concentrations of ammonia and total phosphorus spiked 10 and 25-fold prior to June 2001 at the control site (1004) with less variability and overall lower concentrations the remainder of the study.

There were few significant differences that resulted from the intervention of education, sprinkler retrofit and education, or sprinkler retrofit minus education, relative to control sites (Table WQ4). Only six of the 24 constituents evaluated showed a significant difference between pre and post-intervention concentrations after normalizing to mean control values. These significant differences were a net increase in concentrations of ammonia, nitrate/nitrite, total phosphorus, chlorpyrifos, diazinon, and fecal coliforms. These statistical analyses were the result of one of two circumstances. In the first circumstance, there were individual large spikes in concentration at treatment sites, but not at control sites following intervention (i.e. chlorpyrifos and diazinon at sites 1001 and 1005). Therefore, the net difference in concentrations between controls and treatments increased following the intervention. In these cases, removal of the outlier samples resulted in no significant difference among treatment effects relative to controls before intervention compared to after intervention. In the second circumstance, there were large spikes in concentrations at control site(s) prior to the intervention (i.e. ammonia, nitrate/nitrite, and total phosphorus at site 1004) that later subsided while treatment site concentrations and variability remained steady. Therefore, the difference between treatments and controls changed following interventions, although it was not a result of the education or technology.

Although there were no significant differences in pollutant flux as a result of the intervention, there were significant differences in pollutant flux among sites prior to intervention (Table W5). Mean flux did not change at either site from before to after the installation of technology or initiation of education. Site 1001 however, the sprinkler+education site, had the greatest mean flux for 22 of the 24 constituents

evaluated prior to the sprinkler intervention. The mean flux for 20 of these 22 constituents was significantly greater at site 1001 than the mean flux at site 1005 (t-test, $p<0.05$). Site 1005 had greater mean fluxes only for MS2 phage and ammonia. The differences among the fluxes prior to (and after) intervention was the result of two factors; greater flow and, at times, greater concentrations at site 1001 compared to site 1005. Mean dry weather flow at the time of water quality sampling was nearly three times greater at site 1001 than 1005.

Toxicity was inconsistently found at all five of the sampling sites (Table WQ3, Figure WQ4) and there was no change in toxicity as a result of the intervention (Table WQ4). The two species tested did not respond similarly either among sites, among treatments, or over time. Correlation of toxicity with constituent concentrations yielded few significant relationships for either species (Table WQ6). Mysid toxicity was correlated with diazinon and several trace metals, but the strongest relationship was with diazinon concentration. Moreover, the concentrations of diazinon were well above the levels known to cause adverse effects in this species while trace metals were not (Table WQ7). Sea urchin fertilization toxicity was only correlated with concentrations of zinc. The concentrations of zinc were well above the level known to induce adverse effects in this species (Table WQ7).

DISCUSSION

This study was unable to find large, significant reductions in concentration or pollutant flux as a result of education and/or sprinkler retrofit technology. This may indicate that the technology and/or education are inefficient for improvements in water quality. Equally as important, however, was the absence of meaningful increases in concentrations. Of the small number of concentrations that showed significant increases, most could be explained by highly variable spikes in concentrations reminiscent of

isolated entries to the storm drain system as opposed to ongoing chronic inputs or the effects of best management practices evaluated in this study.

If significant changes did occur, our study design may not have detected these changes due to two factors. First, the variability in concentrations within and between sites are naturally high and our study simply collected too few samples. After taking into account the variability and relative differences in mean concentrations, we used zinc as an example constituent to determine what sample sizes would be required to detect meaningful differences. Assuming that our sampling yielded the true mean and variance structure that actually existed at the five sites, power analysis indicated that a minimum sample size of no less than five-fold would have been required to detect the differences we observed in zinc concentrations during this study.

The second factor that could have hindered our ability to detect meaningful differences in water quality is that the technology and education treatments were applied at the spatial scale of individual homes, while our study design sampled at the neighborhood scale. This problem was exacerbated in this study because only a fraction (approximately one-third) of the homes within the neighborhoods we sampled had the technological or educational treatments. Therefore, the treatments were effectively diluted, decreasing our ability to detect differences in water quality.

It appears that residential dry weather flows measured in our study may contribute significant proportions of some constituents to overall watershed discharges. Our study sites were located within the San Diego Creek watershed, the largest tributary to Newport Bay. San Diego Creek is routinely monitored to provide environmental managers the information they need to properly manage the Bay (OCPFRD 2002). We compiled the dry weather monitoring data at the mouth of San Diego Creek from OCPFRD during 2001-2002 and compared the concentrations to our results from residential neighborhoods (Table wq5). Mean concentrations of chlorpyrifos, diazinon, copper and zinc were much higher in upstream residential neighborhoods, than concentrations measured at the mouth of San Diego Creek. These residential dry weather contributions

are amplified by the fact that the San Diego Creek watershed is primarily composed of residential land uses. In contrast, concentrations of selenium, arsenic, and total phosphorus in the residential dry weather discharges were much lower than the cumulative dry weather discharges from San Diego Creek, indicating that residential areas may not be the primary source of these constituents.

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Table WQ1. Characteristics of the five treatment[a] study neighborhoods.

	Neighborhood				
	1001	1002	1003	1004	1005
Total Area (ft^2)	5,174,861	2,145,864	2,426,731	3,868,375	6,176,782
Impervious Area (%)	64.3	30.3	33.6	54.8	82.2
Land Use (%)					
Single Family Res	34.4	52.8	65.4	53.8	47.9
Condo	7.7	2.2	0.0	0.0	1.1
Homeowners Assoc	1.6	8.1	0.0	1.0	4.3
School	3.8	0.0	0.0	9.0	4.2
Landscape	16.3	0.1	6.6	0.0	12.5
Street	29.2	30.4	28.1	28.2	28.1
Unknown	7.0	6.5	0.0	8.0	1.9

[a] 1002, 1003, 1004=control, 1005=education, 1001=education + sprinkler retrofit

Table WQ2. Reporting level and method for target analytes.

	Reporting Level	Method
Metals (ug/L)		
Antimony	0.2	EPA 200.8
Arsenic	1.5	EPA 200.8
Barium	0.2	EPA 200.8
Cadmium	0.2	EPA 200.8
Chromium	0.3	EPA 200.8
Cobalt	0.1	EPA 200.8
Copper	1.5	EPA 200.8
Lead	0.3	EPA 200.8
Nickel	0.2	EPA 200.8
Selenium	5.0	EPA 200.8
Silver	0.4	EPA 200.8
Zinc	5.0	EPA 200.8
Microbiology		
Enterococcus (MPN/100 mL)	2	SM9230B
Fecal Coliform (MPN/100 mL)	2	SM9221B
Total Coliform (MPN/100 mL)	2	SM9221B
MS2 Phage (PFU/100 mL)	2	EPA 1602
Somatic Phage (PFU/100 mL)	2	EPA 1602
Nutrients (mg/L)		
Ammonia as N	5.0	EPA 350.1
Nitrate/Nitrite as N	5.0	EPA 353.2
Total Kjeldahl Nitrogen	10.0	EPA 351.2
Ortho-Phosphate as P	0.5	EPA 365.1
Total Phosphorus	1.0	EPA 365.4
OP Pesticides (ng/L)		
Chlorpyrifos	20.0	IonTrap GCMS
Diazinon	20.0	IonTrap GCMS
Toxicity (% effluent)		
Sea Urchin Fertilization EC50	NA	EPA 1995
Sea Urchin Fertilization NOEC	NA	EPA 1995
Mysid EC50	NA	EPA 1993
Mysid NOEC	NA	EPA 1993

Table WQ3. Mean concentration (and 95% confidence interval) of constituents in dry weather discharges collected before and after intervention[a] at five residential neighborhoods in Orange County, CA.

Parameter	Site 1001				Site 1002				Site 1003				Site 1004				Site 1005			
	Pre-Intervention		Post-Intervention		Pre-Intervention		Post-Intervention		Pre-Intervention		Post-Intervention		Pre-Intervention		Post-Inter vention		Pre-Intervention		Post-Intervention	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Metals (ug/L)																				
Antimony	3.28	0.52	3.09	0.51	2.90	0.29	3.49	0.73	3.33	0.60	3.71	0.72	2.98	0.33	3.46	0.51	2.66	0.30	3.11	0.58
Arsenic	2.19	0.64	2.61	0.95	1.99	0.41	2.87	1.25	1.58	0.35	2.38	0.94	4.06	0.85	3.07	0.95	2.44	0.60	3.02	0.97
Barium	80.91	11.61	93.04	10.97	87.39	9.00	105.12	23.99	88.34	6.09	80.12	11.72	79.22	21.23	82.01	13.16	94.36	13.93	104.55	17.74
Cadmium	0.26	0.09	0.15	0.07	0.26	0.11	0.42	0.38	0.25	0.12	0.23	0.18	0.37	0.14	0.21	0.12	0.28	0.12	0.28	0.18
Chromium	2.49	0.98	1.97	0.59	3.74	1.53	4.72	3.35	1.96	0.41	2.70	1.25	3.31	1.41	2.44	0.82	4.01	2.79	3.89	2.01
Cobalt	0.43	0.11	0.50	0.21	0.65	0.28	1.19	0.81	0.40	0.11	0.53	0.26	0.97	0.49	0.73	0.25	0.64	0.19	1.08	0.54
Copper	13.91	4.31	16.14	7.27	31.50	30.24	27.12	17.30	11.82	2.57	24.30	15.41	24.02	12.64	16.81	6.71	33.98	39.62	29.67	14.38
Lead	0.57	0.18	1.63	1.15	6.95	9.32	4.23	2.90	0.88	0.40	1.45	0.88	4.09	4.84	1.34	0.69	0.79	0.23	3.09	1.98
Nickel	9.28	0.91	9.32	1.87	9.40	1.58	10.94	4.14	7.76	0.72	7.87	2.06	11.18	1.94	9.11	1.60	9.97	1.46	10.23	2.33
Selenium	2.43	0.13	2.50	0.00	2.43	0.13	2.50	0.00	2.30	0.26	2.50	0.00	2.43	0.13	2.50	0.00	2.30	0.26	2.50	0.00
Silver	0.13	0.05	0.14	0.07	0.11	0.02	0.18	0.10	0.17	0.09	0.17	0.15	0.12	0.03	0.16	0.17	0.16	0.09	0.17	0.15
Zinc	58.75	7.13	40.57	10.49	130.25	115.77	65.28	29.77	59.33	14.92	53.58	16.10	93.40	50.30	40.80	12.22	73.08	31.52	75.74	35.18
Microbiology (Log)																				
Enterococcus (MPN/100 mL)	3.95	0.43	3.24	0.18	3.80	0.38	4.16	0.35	4.36	0.68	4.22	0.24	4.49	0.61	4.35	0.25	4.34	0.31	4.37	0.29
Fecal Coliform (MPN/100 mL)	3.45	0.31	2.94	0.27	3.15	0.37	3.50	0.45	4.13	0.33	3.67	0.32	4.08	0.35	3.84	0.32	3.88	0.33	3.67	0.23
Total Coliform (MPN/100 mL)	4.16	0.27	3.82	0.24	4.30	0.30	4.51	0.46	4.70	0.33	4.36	0.26	5.04	0.39	4.50	0.27	4.53	0.34	4.51	0.24
MS2 Phage (PFU/100 mL)	-0.30	0.00	0.02	0.55	-0.30	0.00	-0.09	0.52	-0.19	0.14	0.02	0.53	0.30	0.44	0.05	0.52	0.05	0.43	0.33	0.54
Somatic Phage (PFU/100 mL)	2.00	0.35	2.02	0.49	1.84	0.42	1.81	0.69	2.59	0.40	2.24	0.62	2.88	0.32	2.52	0.54	2.16	0.46	2.37	0.47
Nutrients (mg/L)																				
Ammonia as N	0.17	0.15	0.08	0.03	0.17	0.07	0.39	0.51	0.23	0.11	0.28	0.23	7.32	4.93	0.31	0.26	0.65	0.32	0.42	0.24
Nitrate/Nitrite as N	2.72	0.50	1.48	0.28	3.00	1.14	1.00	0.33	2.35	0.96	1.63	0.78	38.71	18.21	9.29	6.58	2.94	0.61	3.70	4.48
Total Kjeldahl Nitrogen	1.62	0.51	1.87	1.20	1.75	0.62	2.38	0.92	1.96	1.33	2.61	1.75	11.18	5.71	3.60	2.03	4.49	2.64	3.51	1.65
Ortho-Phosphate as P	0.65	0.15	0.64	0.12	0.80	0.25	0.73	0.14	0.79	0.39	1.21	0.75	2.93	0.90	1.55	0.57	0.87	0.25	1.00	0.22
Total Phosphorus	0.79	0.21	0.63	0.16	0.78	0.25	0.82	0.23	1.22	0.83	1.19	1.07	3.30	1.37	1.46	0.73	0.96	0.39	1.16	0.40
OP Pesticides (ng/L)																				
Chlorpyrifos	22.66	9.27	442.78	827.29									45.54	33.48	11.34	6.31	75.27	64.41	803.44	1433.34
Diazinon	1680.45	1379.39	829.56	338.72									3265.38	3277.20	1650.50	1540.87	1159.12	553.01	1738.58	721.44
Toxicity (% effluent)																				
Fertilization EC50	47.26	8.89	53.73	6.17	57.37	3.48	51.94	9.85	41.60	8.94	49.58	10.17	49.79	8.96	55.91	6.48	43.81	9.26	58.35	2.98
Fertilization NOEC	25.36	8.61	44.62	10.32	35.00	8.54	46.23	11.11	32.07	13.27	37.69	11.15	32.50	9.66	51.92	7.67	22.00	9.31	42.88	9.76
Mysid EC50	46.76	25.04	60.00	0.00	56.32	10.22	39.04	35.71	39.10	24.16	51.94	22.38	54.28	15.88	49.36	25.33	39.32	25.25	60.00	0.00
Mysid NOEC	90.71	17.23	104.00	9.49	82.14	18.13	95.00	16.20	95.71	12.20	77.50	17.53	64.29	16.73	68.50	22.30	53.86	14.81	83.00	17.96

[a] 1002, 1003, 1004=control, 1005=education, 1001=education + sprinkler retrofit

Table WQ4. Significance of ANOVA results for the effect of sprinkler + education, education alone, and the difference between sprinkler + education and education alone relative to control concentrations. No data indicates $p > 0.05$

	Effect of Sprinkler + Education	Effect of Education Alone	Difference Between Sprinkler + Education and Education Alone
Metals			
Antimony			
Arsenic			
Barium			
Cadmium			
Chromium			
Cobalt			
Copper			
Lead			
Nickel			
Selenium			
Silver			
Zinc			
Microbiology			
Enterococcus			
Fecal Coliform	0.04		
Total Coliform			
MS2 Phage			
Somatic Phage			
Nutrients			
Ammonia as N	0.03	0.02	
Nitrate/Nitrite as N	0.02		
Total Kjeldahl Nitrogen			
Ortho-Phosphate as P			
Total Phosphorus		0.03	
OP Pesticides			
Chlorpyrifos	<0.01	<0.01	<0.01
Diazinon		<0.01	
Toxicity			
Fertilization EC50			
Fertilization NOEC			
Mysid EC50			
Mysid NOEC			

Table WQ5. Mean flux (and 95% confidence interval) of constituents in dry weather discharges collected before and after intervention[a] at two residential neighborhoods in Orange County, CA.

Parameter	Site 1001				Site 1005			
	Pre-Intervention		Post-Intervention		Pre-Intervention		Post-Intervention	
	Mean Flux	95% CI	Mean Flux	95% CI	Mean Flux	95% CI	Mean Flux	95% CI
Metals (ug/hr/km^2)								
Antimony	1564	740	920	410	167	99	1756	1666
Arsenic	1476	1006	741	427	164	107	2610	2425
Barium	41644	18423	29241	11384	6537	4624	83266	71121
Beryllium	43	17	36	15	7	5	94	79
Cadmium	157	97	40	17	13	5	207	189
Chromium	880	474	562	264	155	86	3199	2810
Cobalt	273	166	131	57	41	21	958	854
Copper	4738	2383	3600	1587	2233	1178	13717	11137
Lead	1149	861	253	133	81	52	1475	1270
Nickel	4287	2096	2743	1249	636	465	7319	6221
Selenium	1075	420	910	367	177	132	2045	1894
Silver	58	19	49	35	13	8	64	73
Zinc	28968	13481	11264	9171	5589	3276	39966	39179
Microbiology (Log)								
Enterococcus (MPN/hr/km^2)	1771	768	1437	624	281	208	1822	1464
Fecal Coliform (MPN/hr/km^2))	1254	567	955	418	234	170	3393	3251
Total Coliform (MPN/hr/km^2)	1628	607	1264	489	284	193	3902	3687
Somatic Phage (PFU/hr/km^2)	976	480	650	282	57	32	748	550
Nutrients (mg/hr/km^2)								
Ammonia as N	584	324	339	260	1145	1236	2466	2475
Nitrate/Nitrite as N	12981	6366	4316	2174	1849	1706	12102	9812
Total Kjeldahl Nitrogen	8144	4881	3621	1893	3083	2614	18149	13628
Ortho-Phosphate as P	4822	2535	1516	679	504	279	6735	6634
Total Phosphorus	4875	2573	1645	657	477	308	7782	8007
Pesticides (ng/hr/km^2)								
Chlorpyrifos	8	8	7	4	3	5	26	20
Diazinon	467	606	234	185	56	36	822	579

[a] 1005=education, 1001=education + sprinkler retrofit

Table WQ6. Correlation coefficients (and p value) of constituent concentrations with toxicity endpoints (No Observed Effect Concentration, NOEC and Median Effect Concentration, EC50) in dry weather discharges from residential neighborhoods in Orange County, CA. No data indicates p > 0.05

	Sea Urchin Fertilization NOEC	Mysid Survival NOEC	Sea Urchin Fertilization EC50	Mysid Survival EC50
Antimony		-0.273 (0.009)		
Arsenic		-0.3396 (0.001)		
Barium				
Cadmium				
Chromium		-0.244 (0.021)		-0.219 (0.044)
Cobalt		-0.330 (0.002)		-0.279 (0.010)
Copper				
Lead		-0.215 (0.042)		
Nickel				
Silver		-0.260 (0.013)		-0.229 (0.035)
Zinc	-0.277 (0.005)		-0.274 (0.006)	
Chlorpyrifos				
Diazinon		-0.426 (0.001)		-0.468 (0.001)
Ammonia				

Table WQ7. Comparison of median effect concentrations for the mysid survival (*Americamysis bahia*) and sea urchin (*Strongylocentrotus purpuratus*) fertilization tests.

Constituent (µg/L)	Mysid Survival (EC50)	Sea Urchin Fertilization (EC50)
Antimony	>4150	-
Arsenic	1390-2725	-
Barium	>500,000	>1500
Cadmium	16.5-90.2	1,272
Chromium	1560-2450	-
Cobalt	-	-
Copper	267	30
Lead	3130	>4,000
Nickel	387-635	-
Silver	220-283	-
Zinc	400	29
Chlorpyrifos	0.04	-
Diazinon	4.5	>1,000
Ammonia	-	69

- indicates no data available

Table WQ8. Comparison of mean concentrations (95% confidence intervals) in residential dry weather discharges from this study compared to concentrations in dry weather discharges from San Diego Creek at Campus during 2001-2002 (Data from OCPFRD).

	San Diego Creek	Residential
Parameter	Mean(95% CI)	Mean(95% CI)
Nitrate	5.16(0.72)	4.76(1.96)
Phosphate	1.98(0.07)	1.16(0.20)
Diazinon	0.13(0.07)	1.52(0.52)
Chlorpyrifos	0.05(0.01)	0.35(0.44)
Copper	11.59(2.83)	23.59(5.65)
Arsenic	6.58(0.40)	2.68(0.26)
Selenium	21.22(2.65)	2.46(0.03)
Zinc	22.08(2.75)	60.09(8.26)

Figure WQ1. Monthly average concentrations in dry weather discharges from five residential neighborhoods in Orange ounty, CA.

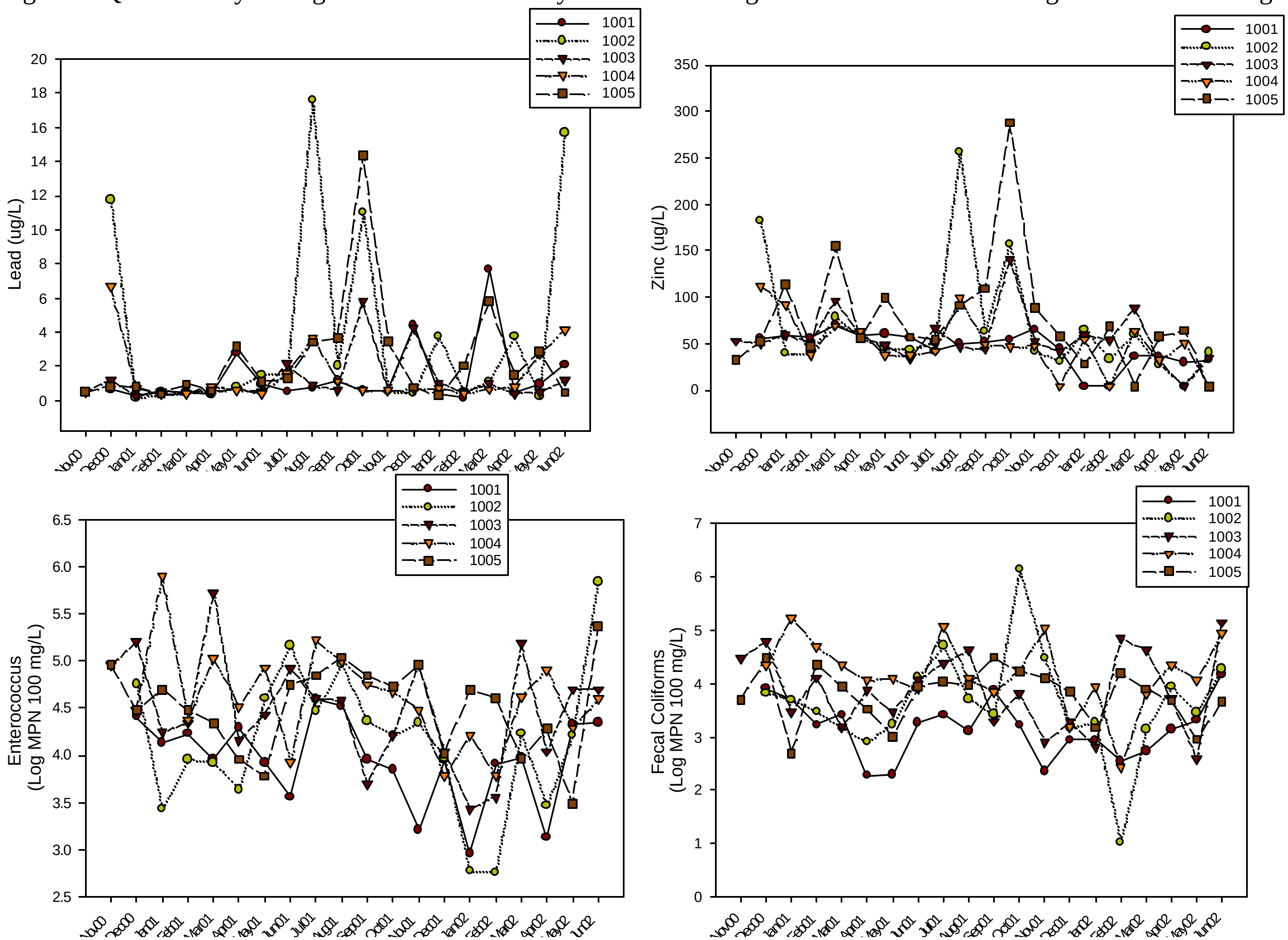


Figure WQ1 continued.

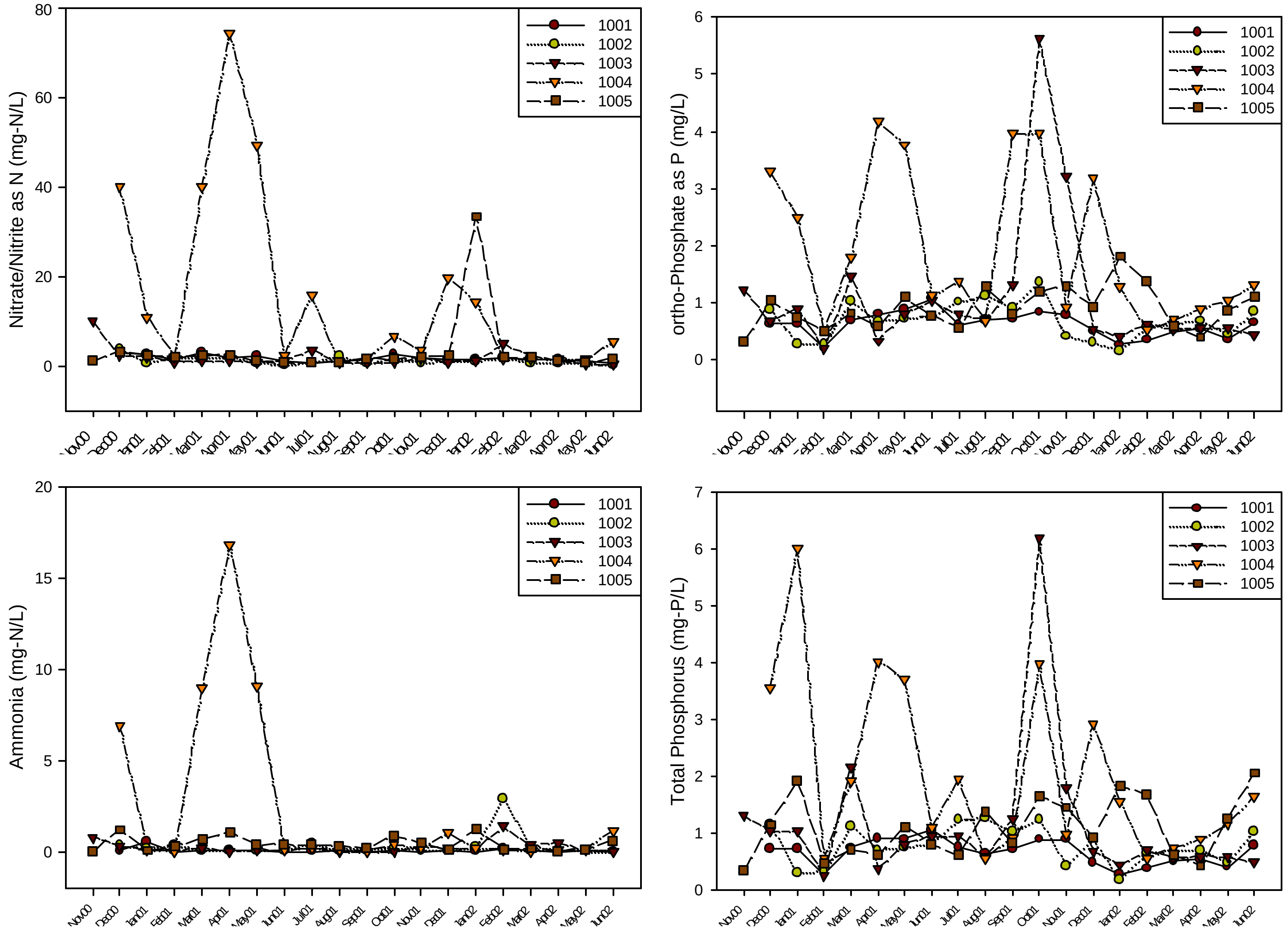
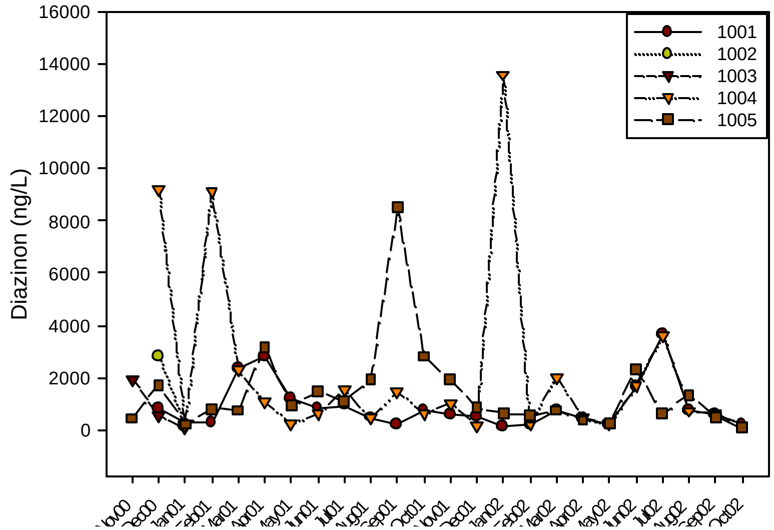


Figure WQ1 continued



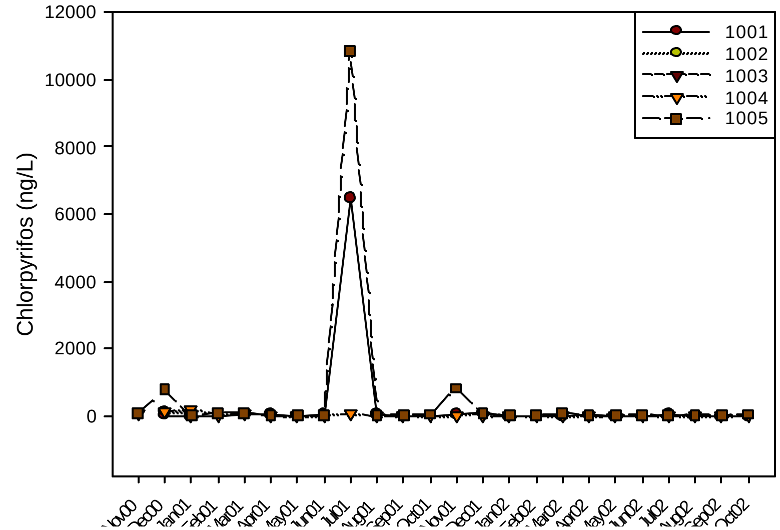
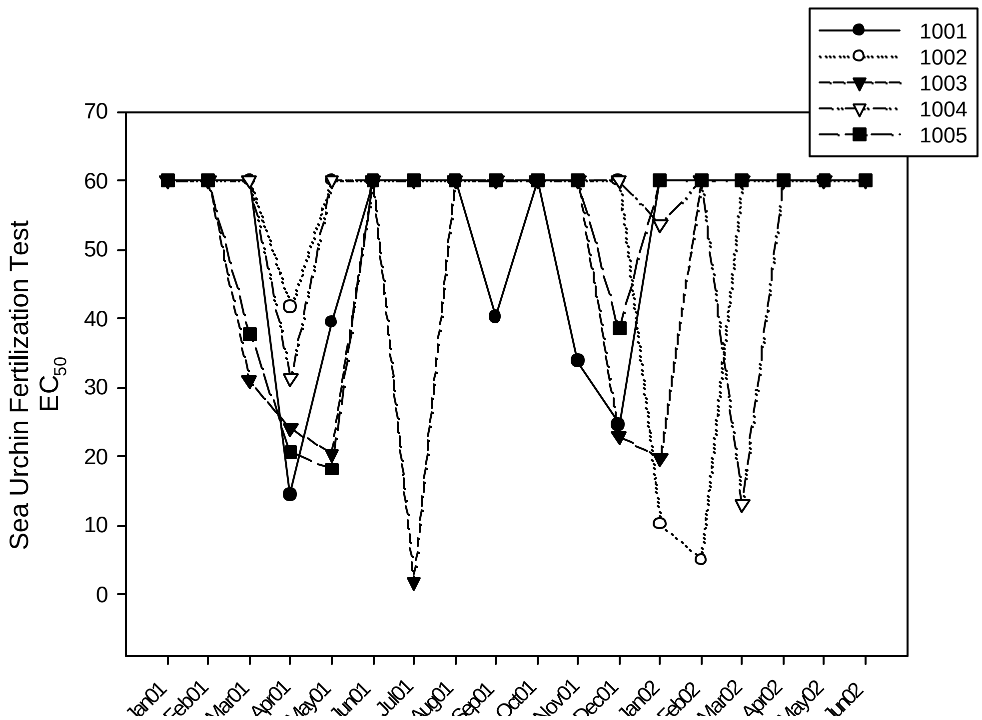
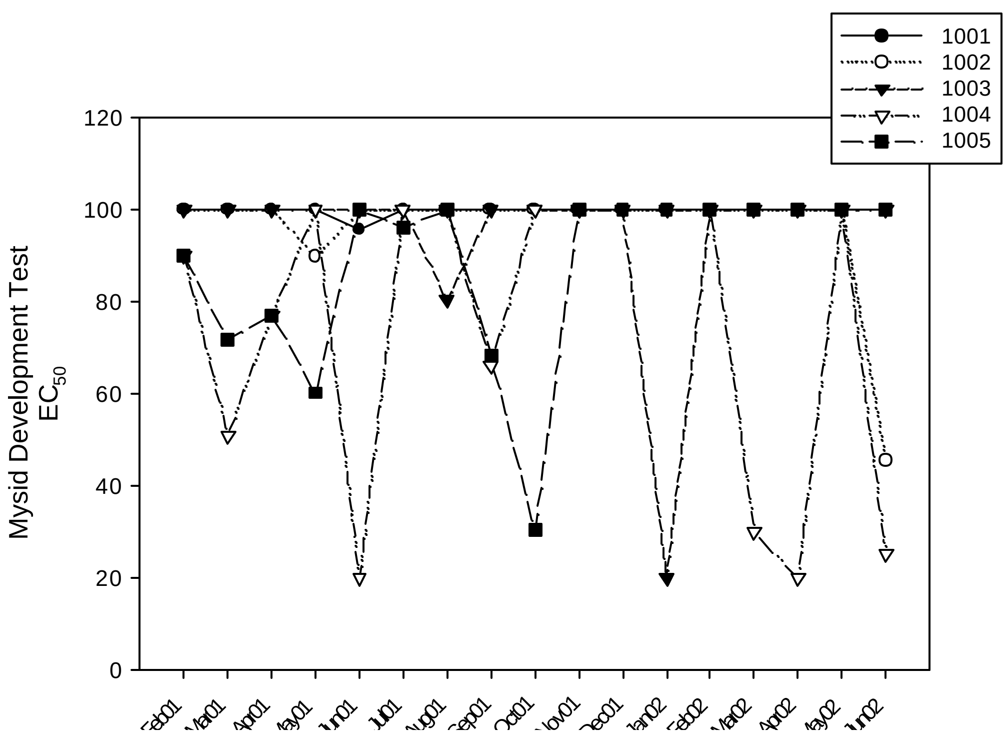


Figure WQ2. Toxicity of dry weather discharges from five residential neighborhoods in Orange County, CA





Appendix E2:
Technical Assistance

The Residential Runoff Reduction Study

Appendix E2: Technical Assistance for the Residential Runoff Reduction (R3) Report

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1. Introduction

This report describes analyses and results of work conducted by GeoSyntec Consultants for the Irvine Ranch Water District (IRWD) to assist in the completion of the Residential Reduction Runoff (R3) Study. The R3 Study is an ambitious investigation to quantify the effectiveness of BMPs in reducing dry weather discharges and associated pollutants.

GeoSyntec Consultants completed the following tasks:

1. Review and Analysis of Water Quality Data. We reviewed the analyses described in Chapter 5 of the R3 report and conducted additional analyses of the water quality data and flux calculations to explore and potentially enhance the interpretation of the monitoring results.
2. Evaluation of Possible Implications on TMDL Compliance. We reviewed and summarized applicable TMDLs in the San Diego Creek Watershed. Results from Task 1 were compared with the TMDLs to evaluate whether the BMPs are beneficial to achieving the TMDL objectives.

2. GeoSyntec Review of Section 5 of the R3 Study Report

Section 5 in the R3 report describes the water quality monitoring data and analyses. The following are GeoSyntec review comments of Section 5.

- **Abstract and Introduction**. The abstract and introduction section provides a recap of the entire study, including a description of the study motivation and objectives. This suggests that this section of the report was originally written as a stand-alone report. In the final report we recommend that most of this information should be integrated into an earlier overall report introductory chapter. The introduction of Section 5 should be limited to a recap of the water quality and flow data, and to present the purpose/goals of the data analysis described in this section.
- **Methods**. The methods section similarly presents much of the study details (watershed descriptions, intervention description-BMPs applied-, etc). We recommend this information be presented in an earlier chapter in the report that describes the study design and procedures in a high degree of detail. This study description chapter could then be referenced as needed throughout the report.
- **Data Analysis and Results**. The 5 data analysis steps are logical and reasonable, however, the procedures, assumptions made, and results are, in some cases, unclear as discussed below. Additional details of the procedures and assumptions made, as well as the use of alternative, possibly more appropriate statistical procedures could enhance the interpretation and usefulness of the monitoring data. Some specific suggestions and comments are discussed below:

1. **Comparison of water quality data prior to intervention**. ANOVA tests were used to test for differences among the treatment sites for each constituent prior to intervention. ANOVA is a parametric test, which is identical to the t-test when comparing only two groups of data. This test assumes that all data sets are normally distributed and have equal variance. The t-test has limitedpower todetect small differences among data sets if they are not normally distributed. Currently the report states that the "data were tested for normality and homogeneous variance prior to testing...[and] only the microbiological data were determined to be non-normally distributed..." However, the results of the normality tests were not included, nor were any descriptive statistics that may indicate normality. Our analyses suggest that many of the data groups are not normally distributed. In addition the mean is not considered a good measure of central tendency for many of R3 data, because mean values can be strongly influenced by outlier values, which were frequently observed. Much of our analyses, therefore, are based on the evaluation of median concentrations. Median values are resistant to the influence of outlier values, and may therefore be a more appropriate measure of central tendency in the R3 data.

   Table WQ3 includes means and 95% confidence intervals for the water quality data before and after intervention (BMPs applied). These descriptive statistics only show part of the story. At the very least, other parametric descriptive statistics, such as the standard deviation and the coefficient of skewness should be included, as well as non-parametric (i.e., resistant to outliers) descriptive statistics, such as the median, interquartile range, and the quartile skew. These will aid in interpreting the central tendency, variation, and skewness of the data. A test on the coefficient of skewness will indicate whether the data are symmetric or not. If the null hypothesis that the data are symmetric cannot be rejected, normality tests are warranted. Otherwise, it can be safely assumed that the data do not come from a normal distribution and alternative non-parametric statistical procedures that do not require normality should to be used.

   The standard methods for calculating the 95% confidence interval about the mean (based on t-distribution) are symmetric confidence intervals that require normality, especially with small data sets. While the report does not state the method used for calculating the 95% confidence intervals, it is likely that the standard method was employed since normality was assumed for the ANOVA analysis. When data are non-normal, alternative methods for calculating the 95% confidence intervals could be used, such as the non-parametric interval estimate for the median (no specific data distribution assumed) or an asymmetric confidence interval about the mean (a specific distribution is assumed, such as the lognormal distribution). However, it should be noted that 95% confidence intervals, are appropriate, but not necessary for testing whether there are significant differences between data sets. Hypothesis tests can be used to detect differences. It is recommended that confidence intervals be reserved for showing the uncertainty in an estimate of central tendency (e.g. mean or median) to determine the likelihood for a threshold to be exceeded, such as a water quality criterion.

If one or more of the pre-intervention data sets are determined to be non-normal or unequal in variance, alternatives to the single-factor ANOVA test can be used, such as the Kruskal-Wallis (K-W) test. The K-W test will determine if all of the data sets have the same distribution and if the medians are equivalent within a specified level of confidence.

2. **Comparison of water quality concentrations over time.** Monthly mean concentrations over time were included in the report. While this is a valid approach to analyzing data, it has a tendency to mask the data's true variability, and since there were generally only two samples per month, there is no apparent advantage to averaging for this exploratory data analysis. Also, Site 1004 had large spikes in the nutrient values that when plotted on the same graph as the other sites tends to dampen and make less apparent the variability in monitoring results from the other sites. It is recommended that all data are initially plotted on separate time-series graphs to identify seasonal periodicity, step-trends, or monotonic trends for each sampling site. Time series plots are an excellent approach for presenting the data and an appropriate first step for understanding the characteristics of the data. Note that unless there are obvious trends (step or monotonic), the time-series plots should probably be placed in an appendix rather than the main body of the report, as there will be a number of them and the information provided is primarily to aid the investigator in determining the next step in the analysis.

   In addition to time series plots, other plotting procedures are available that can be useful in the visual inspection of the data. Plots that should be considered for inclusion in the report include box plots that show side-by-side comparisons of central tendency and variability, and side-by-side quantile (cumulative probability distribution) plots that give an indication of the underlying distribution and any apparent differences in those distributions. These should be included in the main body of the report.

3. **Comparison of water quality data before and after intervention.** Standard t-tests were used to compare mean concentrations before and after intervention. The report states that only 6 out of 24 constituents showed significant differences, and the differences showed a net increase from pre- to post treatment. Removing the outlier points did not affect this result. As stated above, the t-test assumes that both groups of data are normally distributed about their respective means and that they have constant variance. There is no indication that the data meet these strict requirements (water resources data rarely do). The report also states that the data were "normalized" to the grand mean of the control sites, but there is no justifiable reason for doing so, especially since the control sites varied greatly amongst themselves.

   A limitation in the comparison of mean concentrations, such as through the use of the t-test, is that the mean of the concentration data is heavily influenced by outlier values. Given that outlier values were identified and recognized to influence the results, alternative measures of central tendency that are more resistant to the influence of the outliers (e.g. median) should be investigated and presented in the report. The rank-sum test, or Mann-Whitney test, is a non-parametric test that tests whether the median of one

group is significantly different from the median of another group. The rank-sum test does not assume any particular distribution or even that the two data sets come from the same distribution. Also, it has the power to detect small differences among data sets and will even work on censored data (data only known to be below the detection limit) as long as less than 50% of the data are censored. The rank-sum test is equivalent to the Kruskal-Wallis test discussed above, but applied to only two data sets. Based on the relative strengths of the rank-sum test as compared to the t-test, and for consistency in the data analysis (as it is highly unlikely the assumptions of the t-test could be met for all, if any of the data sets), it is recommended that the rank-sum (or Krsuskal-Wallis) tests be performed on all data sets.

Once it is determined that a significant difference in the medians exists, the magnitude of the difference can be calculated using the Hodges-Lehmann estimator, which is the median of all possible pair-wise differences between the two data sets. Note that this is often significantly different than the simple difference in medians. A confidence interval about the Hodges-Lehmann estimator can then be calculated to illustrate the variability of the estimate.

4. **Comparison of constituent fluxes (Mass loadings per time) before and after intervention.** Similar to the analysis of concentration data discussed above, mean fluxes for the pre- and post-intervention cases were compared using standard t-tests (for 2 sites only). In general, no difference in the mean flux was found between the pre- and post-intervention data.

   Similar to the analysis of the concentration data, the mean of the flux data is heavily influenced by outliers. Therefore, alternative measures of the central tendency should be calculated and compared. The rank-sum test could be used here as well.

5. **Correlation of toxicity measures with potential toxicants in dry weather runoff**. Correlations between toxicity data and concentration data were investigated using a Pearson product moment correlation. Based on this analysis, no correlations were found to be significant. The first and foremost step in investigating whether one variable is associated with another is to plot the two variables on opposite axes (scatterplot). This step was presented in the report and should be included. A scatterplot matrix helps to identify the nature of the correlation between several variables in one concise graph. A scatterplot will also indicate whether the use of Pearson's correlation coefficient is even appropriate, as it only tests whether there is a linear association between two variables. Due to the nature and complexity of biotic systems, the relationship between toxicity and constituent concentration are likely to be nonlinear. Therefore, an alternative measure of association should be used such as Kendall's Tau or Spearmans Rho. Both of these statistics measure the strength of the monotonic relationship between two variables.

- **Discussion and General Review Comments**. The primary conclusions drawn from the investigation were that there is no statistically significant reductions in pollutant concentration or flux (loadings) as a result of the education and/or sprinkler retrofit

technology. While this may be the case, the data analysis described and presented may have had limited ability to detect differences for the particular data sets. The discussion section included two possible explanations for not being able to detect changes between pre- and post-intervention: 1) the data had too much variability and not enough samples were taken, and 2) the treatments were applied at only about one-third of the individual homes within the test watersheds, which effectively diluted the effects of the intervention. Both of these are logical explanations and should be considered in the design of future studies. A helpful assessment would be to evaluate how much data would be needed to detect levels of differences desired to be detected. This information would be valuable for planning of future studies.

Another possible explanation for having difficulty in detecting differences that was not mentioned in the report is the difference in time periods for the pre-intervention and the post-intervention. The pre-intervention period was from December 2000 to June 2001 and the post-intervention period was from July 2001 to June 2002. In other words, the post-intervention period includes summer and fall data, while the pre-intervention period does not. Moreover, there was considerably more rainfall during the pre-intervention wet season than the post intervention wet season (see Table 1).

Based on this it may be desirable to analyze differences using a truncated post-intervention data set with only winter and spring data. The downside of this approach is that it reduces the number of data points to include in the analysis. However, it is justifiable in that in the summer and fall the observed dry-weather flows are likely more associated with irrigation practices and in the winter and spring the observed dry-weather flows are likely more associated with the leaching of saturated soils. We recommend that the use of a truncated data set should be considered if additional analyses of the data using the approaches recommended above do not reveal statistically significant differences.

Table 1: Daily Rainfall Data at the Tustin-Irvine Rain Gauge (100th of inches)

		2001											2002												
	Dec 00	Jan 01	Feb 01	Mar 01	Apr 01	May 01	Jun 01	Jul 01	Aug 01	Sep 01	Oct 01	Nov 01	Dec 01	Jan 02	Feb 03	Mar 02	Apr 02	May 02	Jun 02	Jul 02	Aug 02	Sep 02	Oct 02	Nov 02	Dec 02
1																									
2							5						15												
3																									
4				47	7							6		5											
5																									
6				3	61												12								
7																22									
8		47																							
9				33	5																				
10													10											163	
11		184										4													
12		105	36									36													
13		8	295																						
14			14																						
15																	7								
16																									99
17															40	29									8
18			3																						
19																		7							
20			9															10							85
21					52								28												
22													8												
23			29													4									9
24		32	12									46					9								
25			85																						
26		57	90	3		8											7						5		
27		13	42											46			3								
28			32											5										3	
29												18	10												13
30													35											54	
31																									
total	0	446	647	86	125	8	5	0	0	0	0	110	106	56	40	55	38	17	0	0	0	0	5	220	214

Pre-intervention period (13.2 inches from12/00-6/01) Post-intervention period (3.1 inches from12/01-6/02)

3. Examples of Recommended Approaches to Data Analysis for Chapter 5

These example analyses focus on TMDL constituents: nutrients (total nitrogen and total phosphorus), metals (copper, lead, zinc, cadmium), pesticides, and pathogens (fecal coliform). The analyses also focus on dry weather flows, as reduction of these flows was the objective of the R3 study.

Recommended Data Analysis Methods

Exploratory Data Analysis

Visual inspection of data and exploration of factors that could potentially influence data (e.g. seasonal trends, rain events)

1. Divide data into pre and post- intervention groups.
2. Construct time series plots to visually inspect data and visually examine for seasonal trends. Overlay storm event markers to identify any relation to rainfall volume or antecedent dry period (ADP).
3. Investigate normality or log normality of data sets. Select appropriate statistical tests.
4. Construct probability plots for pre-intervention and post-intervention periods.
5. Prepare quantile plots.
6. Prepare side-by-side box plots.
7. Calculate descriptive statistics

Hypothesis Testing

Test data for skewness, normality, and statistically significant differences. Note that the skewness and normality tests are only needed if parametric approaches are conducted. It is our recommendation to use non-parametric approaches for consistency because normality will not be met in all cases. Nonetheless examples have been provided to show that several of the data sets do not come from a normal distribution.

1. Skewness hypothesis test for symmetry.
2. Shipiro-Wilkes normality test.
3. Mann-Whitney rank-sum test.
4. For the data sets that have greater than 50% censored data (i.e. data only known to be less than the detection limit), hypothesis tests for differences in proportions.

Example Results

The first step in the data analysis is to construct time-series plots. Time-series plots are constructed to identify seasonal periodicity, step-trends, and monotonic trends. The original report included monthly average time-series plots with all sites included per plot. The authors noted that periodicity and trends were not apparent. However, plotting all sites on one graph tends to hide much of the information. For instance, Site 1004 had much higher nutrient concentrations than the other sites, so by including this site, the minor fluctuations in data from

the other stations are less apparent. Individually plotting the time-series plots reveals more information. Also, by overlaying storm events the role of rainfall volumes and the antecedent dry period (ADP) may be more apparent and may indicate whether additional analyses are warranted (e.g., correlating ADP with concentration). Figure 1 is an example time-series plot with storm event markers overlain for total phosphorus for Site 1001. Notice the pre-intervention period had much more rainfall, which likely added to the variability in runoff concentrations and fluxes. However, it is apparent that the winter and spring concentrations appear to be lower and less variable during the post-intervention period. The irrigation controllers may have had an affect on the runoff concentrations by reducing the amount of irrigation during moister weather conditions (i.e. high soil moisture). Notice a similar effect for total nitrogen in Figure 2. Additional time-series plots are provided in Appendix A.

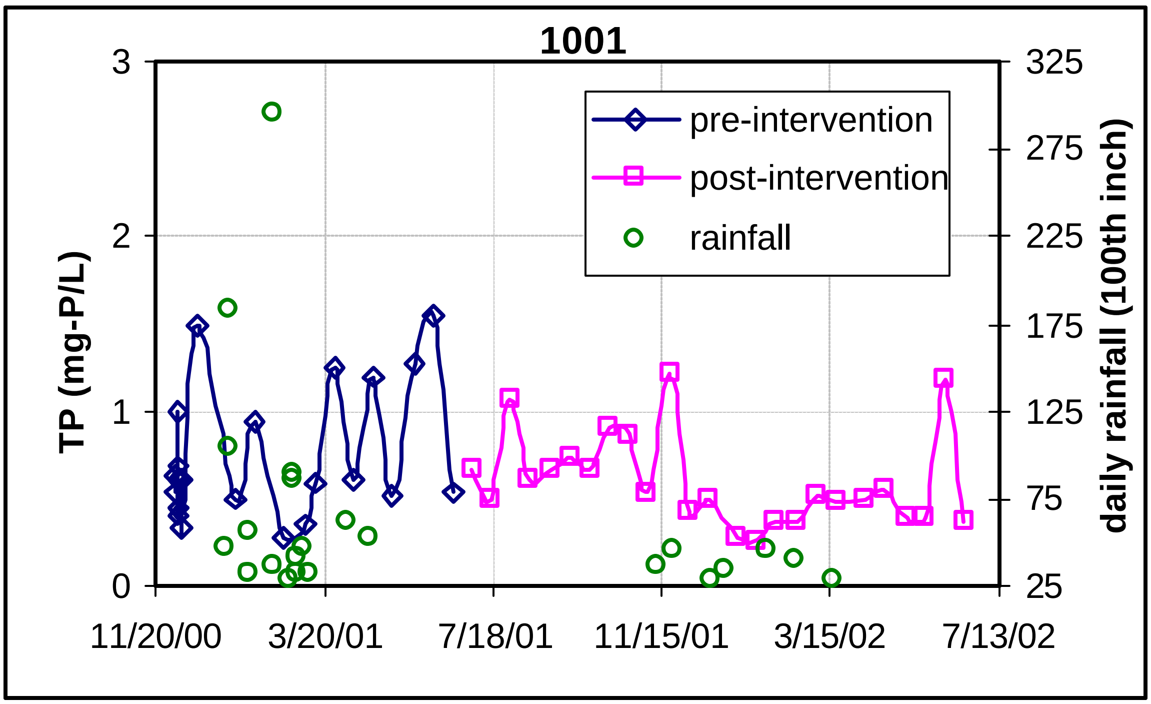


Figure 1. Example time-series plot of total phosphorus with storm event markers.

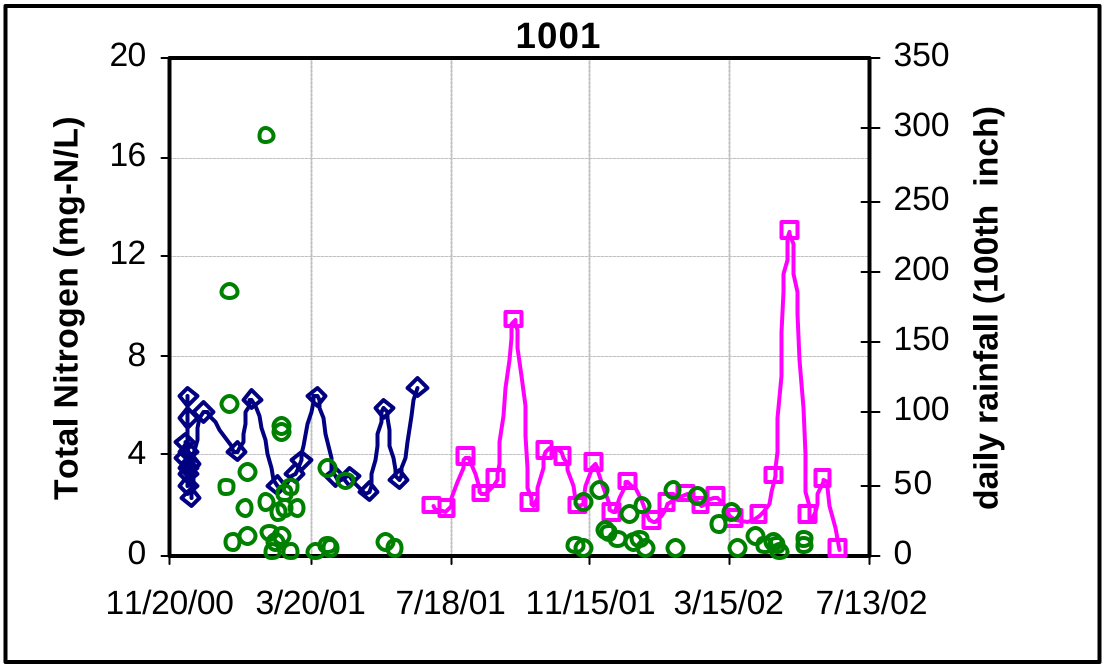


Figure 2. Example time-series plot of total nitrogen with storm event markers.

Comparison of Water Quality Data Prior to Intervention

To visually investigate whether the test sites have similar runoff characteristics, probability plots should be constructed. Figure 3 is an example of a probability plot for total phosphorus for all of the test sites. Notice that all of the sites have a similar distribution except for Site 1004. This suggests that Site 1004 should not be used for "normalizing" of the intervention sites (other information in the report indicating an unknown connection to a nursery further suggests the exclusion of site 1004). However, as mentioned above there is no advantage to normalizing the data using the control sites even if all of the sites had similar distributions.

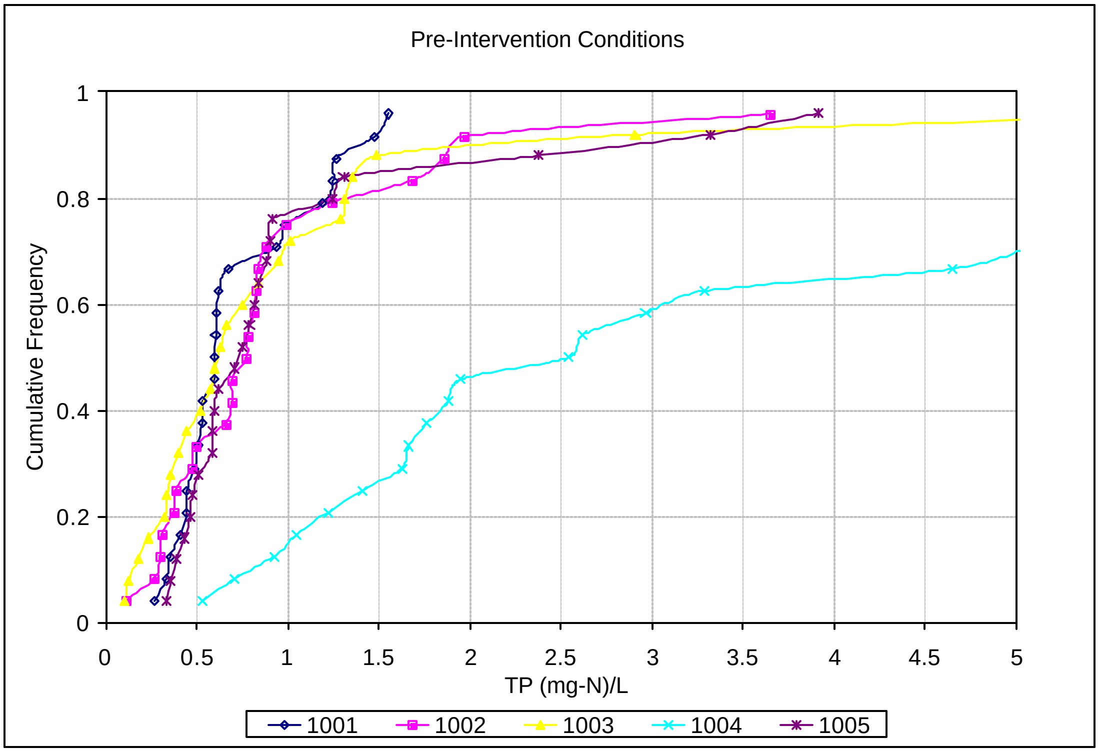


Figure 3. Example probability plot of total phosphorus for all sites prior to intervention.

The next step in the data analysis is to calculate parametric and non-parametric descriptive statistics. Table 2 is an example table of descriptive statistics for total nitrogen for all sites for both the pre- and post-intervention periods. (Additional descriptive statistics are included in Appendix B.) Table 2 includes the number of data points (n), the detection percent (%>MDL/RL), the mean, median, 25% trimmed mean, min, max, 25th percentile, 75th percentile, standard deviation, interquartile range (IQR), and the coefficient of skewness (g_s). Also included in the table are critical skewness coefficients (g_{cr}), which are readily available in statistics texts. If the coefficients of skewness are less than these critical values, then the data are symmetric. Notice that the measures of central tendency (mean and median) and variability (standard deviation) of the sites during the pre-intervention period are quite different, indicating the data arise from different distributions. The median values are consistently smaller than the mean (in some cases substantially smaller) demonstrating the influence of the outliers on the measure of central tendency. Also note that only three pre-intervention data sets are symmetric and none of the post-intervention data sets are. Failure to pass the symmetry test indicates the data are not normal. However, passing the symmetry test does not indicate the data are normal; this requires a normality test. The symmetry test, which is easier to conduct than normality tests, serves as an initial screen for normality to reduce the number of data sets needing further investigation.

Table 2. Example table of descriptive statistics for total nitrogen for each site for pre- and post-intervention.

		1001		1002		1003		1004		1005	
Parameter	**Statistic**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
TN (calculated)	**n**	23	25	23	25	23	25	23	25	23	25
(mg-N/L)	**% > MDL/RL**	100%	80%	98%	90%	98%	96%	98%	96%	100%	98%
	Mean	4.24	3.09	5.31	3.44	3.66	4.42	48.00	10.18	6.89	7.74
	Median	3.84	2.27	3.95	2.55	2.66	2.50	19.01	5.57	5.06	4.36
	Trimmed mean	3.94	2.40	4.53	2.76	2.93	3.01	33.11	6.47	5.08	4.42
	min	2.30	0.30	1.50	0.78	1.46	0.45	3.28	0.74	2.48	1.07
	max	6.76	12.99	13.83	11.40	12.12	19.91	141.06	40.80	20.41	67.12
	25th percentile	3.20	1.79	2.27	2.10	2.11	2.04	9.05	2.71	3.52	3.47
	75th percentile	5.68	3.13	8.02	4.36	4.81	5.17	94.79	19.18	7.07	5.62
	St Dev	1.41	2.67	3.56	2.51	2.48	4.39	49.17	10.73	5.29	12.85
	IQR	2.48	1.34	5.75	2.26	2.70	3.13	85.74	16.47	3.55	2.15
	Skewness, g_s	0.55	2.82	0.84	1.87	2.13	2.27	0.74	1.37	1.88	4.46
	g_{cr}	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	Symmetric ($g_s < g_{cr}$)?	Y	N	Y	N	N	N	Y	N	N	N

Non-parametric tests are recommended for all data analyses for consistency since all data sets do not meet the required assumptions for parametric tests (i.e. normality and constant variance). Non-parametric tests are not based on the assumption of normally distribution; therefore, normality tests were not warranted. It is important to note that if the data sets that passed the initial symmetry screening (Sites 1001, 1002, and 1004 in the table above) also passed a normality test, it does not indicate the data follow a normal distribution, especially for small data sets. The test simply indicates that normality cannot be rejected for the data.

As mentioned above, the non-parametric equivalent to the ANOVA test is the Kruskal-Wallis test, which tests for a difference between the medians of independent data groups. The K-W test will also test whether the datasets are derived from the same distribution. Several statistical packages will perform this test. Results of the K-W test shown in Table 3 was generated from a statistical add-on to Microsoft Excel® called Analyse-It™.

Comparison of the mean ranks in Table 3 provides an indication of whether the data groups are derived from the same distribution. A p values < 0.05 indicates that two or more the data groups have different distributions. Examination of the mean ranks in Table 3 shows that Sites 1001, 1002, and 1005 have somewhat similar mean ranks and Sites 1003 and 1004 have somewhat different mean ranks. This suggests that Sites 1003, 1004 have a different distribution than the other sites. Therefore, it is determined that the K-W test should be performed on just Sites 1001,

1002, and 1005. These results are shown in Table 4. Notice that the p-value is now greater than 0.05, so the distributions of the total nitrogen data are not significantly different. Based on this analysis, Site 1002 should be used as the only control site for comparison of total nitrogen data. These analyses will need to be repeated for the other water quality constituents.

Table 3. Example of Kruskal-Wallis test results for total nitrogen at the test sites prior to intervention.

Test	**Kruskal-Wallis ANOVA**		
Comparison	Total Nitrogen: 1001, 1002, 1003, 1004, 1005		
Performed by	GeoSyntec Consultants		
n	115		
Total Nitrogen	**n**	**Rank sum**	**Mean rank**
1001	23	1128.0	49.04
1002	23	1162.0	50.52
1003	23	774.0	33.65
1004	23	2150.0	93.48
1005	23	1456.0	63.30
Kruskal-Wallis statistic	41.71		
p	<0.0001	(chisqr approximation)	

Table 4: Example of Kruskal-Wallis test results for total nitrogen at the Site 1001, 1002, and 1005 prior to intervention.

Test	**Kruskal-Wallis ANOVA**		
Comparison	Total Nitrogen: 1001, 1002, 1005		
Performed by	GeoSyntec Consultants		
n	69		
Total Nitrogen	**n**	**Rank sum**	**Mean rank**
1001	23	710.0	30.87
1002	23	761.0	33.09
1005	23	944.0	41.04
Kruskal-Wallis statistic	3.27		
p	0.1948	(chisqr approximation)	

Based on these example analyses of the pre-intervention TN data, it is clear that Site 1004 should not be considered as a control site for total nitrogen, and Site 1003 should be used with caution.

Comparison of Water Quality Data Before and After Intervention

Side-by-side box plots and probability plot comparisons of pre-intervention and post-intervention were constructed to identify any apparent differences in the central tendency and concentration distributions between the two data sets. Figure 4 shows side-by-side box plots of total nitrogen at all of the test sites. Site 1004 was omitted due to its high variability. Notice that Site 1001 shows a distinct decrease in total nitrogen, while the other sites do not. However, other sites do show a decreasing trend in median concentration and inter-quartile ranges.

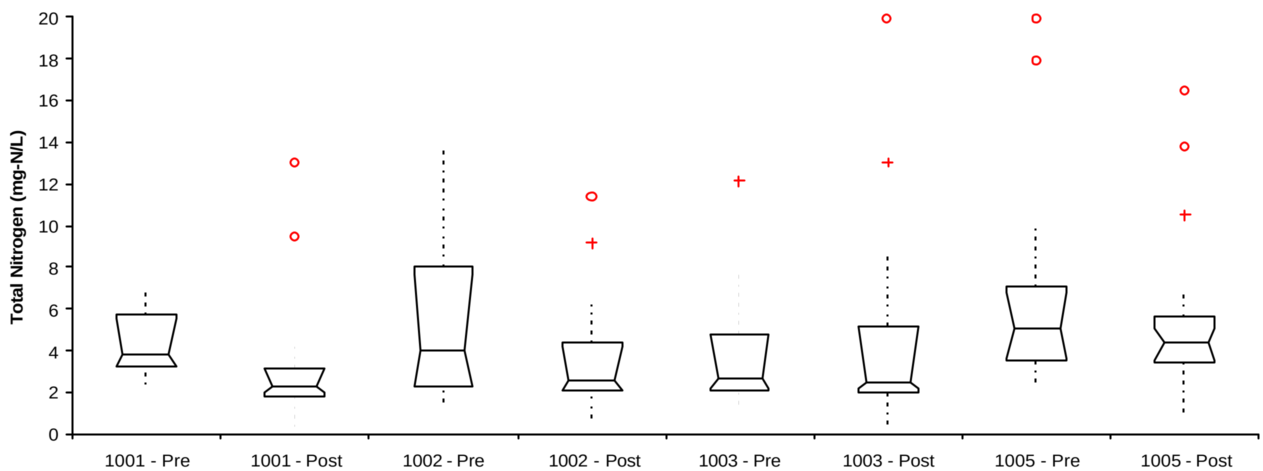


Figure 4. Side-by-side box plots of pre- versus post-intervention for total nitrogen at all sites.

Figure 5 is a probability plot of total nitrogen for Site 1001 before and after intervention. (Additional probability plot comparisons are included in Appendix C.) Notice that there is a distinct reduction in total nitrogen at the site. However, since these data are from different time-periods, this difference could be related to temporal variability.

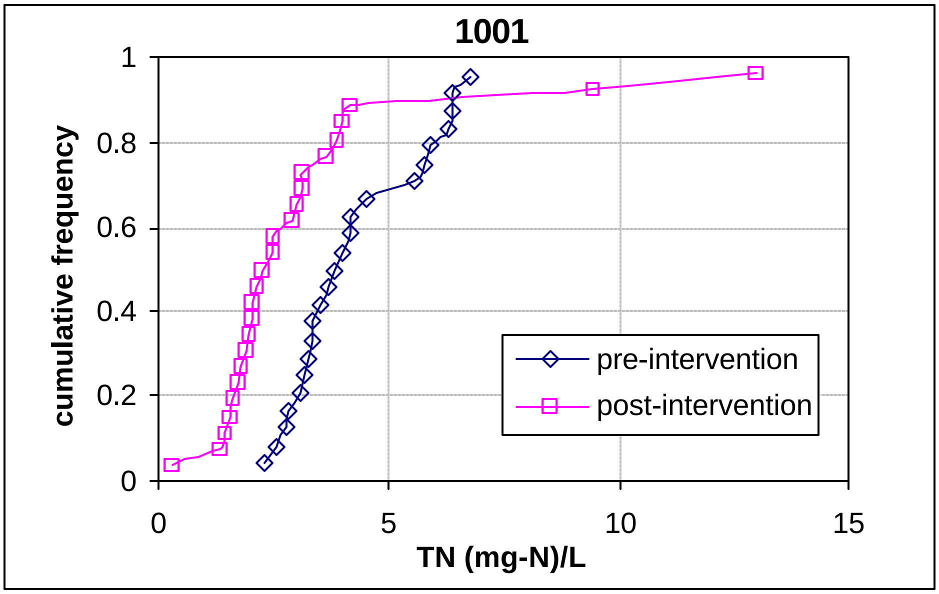


Figure 5. Example probability plot of pre- versus post-intervention at Site 1001 for total nitrogen.

To evaluate if temporal variability caused by the different monitoring periods has anything to do with the difference in total nitrogen concentrations, the probability plot of the pre- and post-intervention period for Site 1001 is plotted with those for Site 1002 and Site 1005 (as these were determined to be the only valid control sites). These comparison plots are shown in Figure 6 and Figure 7. Notice that for pre-intervention, the distribution of Site 1001 more closely follows the distribution of Site 1005 than that of Site 1002, and for post-intervention the opposite is true. This indicates that the year-to-year variability alone cannot explain the reduction in total nitrogen at Site 1001. However, this would need to be statistically verified.

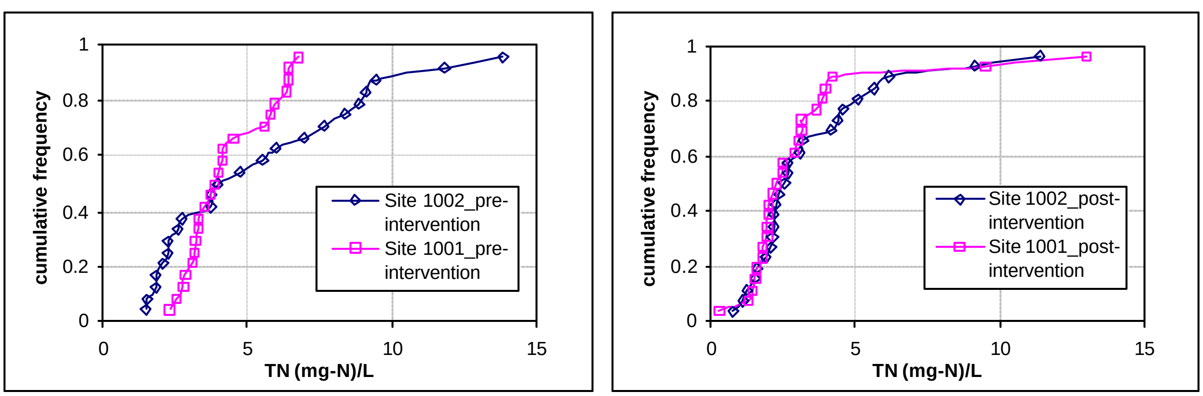


Figure 6. Example probability plot for total nitrogen of Site 1001 versus Site 1002 for the pre- and post-intervention periods.

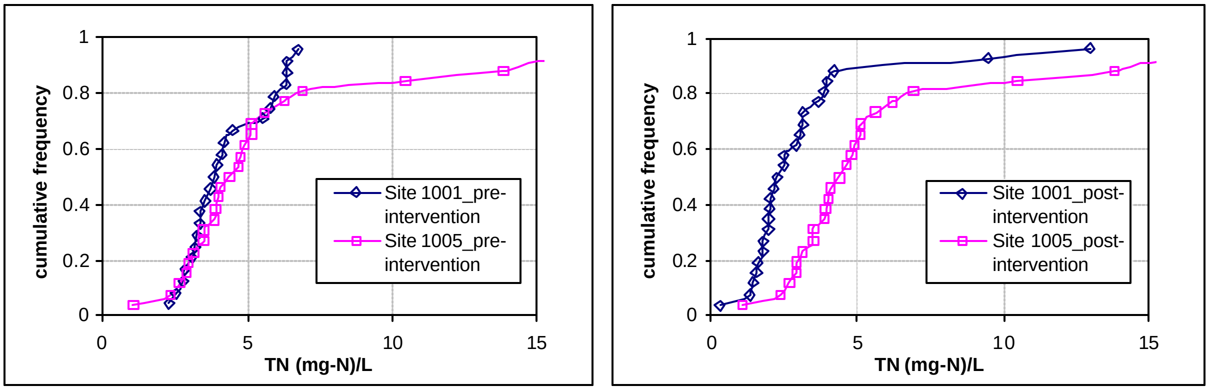


Figure 7. Example probability plot for total nitrogen of Site 1001 versus Site 1005 for the pre- and post-intervention periods.

As mentioned earlier, the Mann-Whitney test (rank-sum) can be used to determine if there is a statistical difference in the median values of two independent data sets (by rejecting the hypothesis that they are the same). Table 5, Table 6, and Table 7 show the output of the Mann-Whitney tests from the Analyse-It™ statistical package on Sites 1001, 1002, and 1005, respectively. Notice that there is a statistically significant difference ($p<0.05$) in the medians between the pre- versus post-intervention total nitrogen data at both Sites 1001 and 1002, but not at Site 1005. Furthermore, the difference in the medians at Site 1001 is at a higher level of confidence (more statistically significant) than the difference at Site 1002 (i.e., greater than 99% significant compared to about 96% significant). The magnitudes of these differences (Hodges-Lehmann estimator) are about 1.5 and 1.3 mg-N/L for Sites 1001 and 1002, respectively. These tests indicate that the difference in the total nitrogen medians at Site 1001 from pre-intervention to post-intervention cannot be explained by the year-to-year variation alone (e.g., the intervention appears to have had an effect). It also indicates that the public education applied to Site 1005 did not appear to make a significant difference.

Table 5: Example Mann-Whitney test for difference in medians for total nitrogen at Site 1001 from pre- versus post-intervention.

Test	**Mann-Whitney test**			
Alternative hypothesis	1001: Pre ≥ Post			
Performed by	GeoSyntec Consultants			
n	48			
1001	**n**	**Rank sum**	**Mean rank**	**U**
Pre	23	736.0	32.00	115.0
Post	25	440.0	17.60	460.0
Difference between medians	1.497			
95.2% CI	0.883	to +∞	(normal approximation)	
Mann-Whitney U statistic	115			
1-tailed p	0.0002	(normal approximation)		

Table 6. Example Mann-Whitney test for difference in medians for total nitrogen at Site 1002 from pre- versus post-intervention.

Test	**Mann-Whitney test**			
Alternative hypothesis	1002: Pre ≥ Post			
Performed by	GeoSyntec Consultants			
n	48			
1002	**n**	**Rank sum**	**Mean rank**	**U**
Pre	23	651.0	28.30	200.0
Post	25	525.0	21.00	375.0
Difference between medians	1.289			
95.2% CI	0.065	to +∞	(normal approximation)	
Mann-Whitney U statistic	200			
1-tailed p	0.0355	(normal approximation)		

Table 7. Example Mann-Whitney test for difference in medians for total nitrogen at Site 10052 from pre- versus post-intervention.

Test	**Mann-Whitney test**			
Alternative hypothesis	1005: Pre ≥ Post			
Performed by	GeoSyntec Consultants			
n	48			
1005	**n**	**Rank sum**	**Mean rank**	**U**
Pre	23	610.0	26.52	241.0
Post	25	566.0	22.64	334.0
Difference between medians	0.530			
95.2% CI	-0.446	to +∞	(normal approximation)	
Mann-Whitney U statistic	241			
1-tailed p	0.1686	(normal approximation, corrected for ties)		

Comparison of Constituent Fluxes Before and After Intervention

The statistical procedures applied to the concentrations examples above should also be applied to the constituent fluxes (mass loadings). For completeness, an abridged example analysis will be provided here. Figure 8 includes side-by-side box plots and probability plots of total nitrogen flux data (mg/acre/day) for Site 1001 at pre- and post-intervention. Note there appears to be a significant decrease in the median, as well as an overall reduction in the distribution of values.

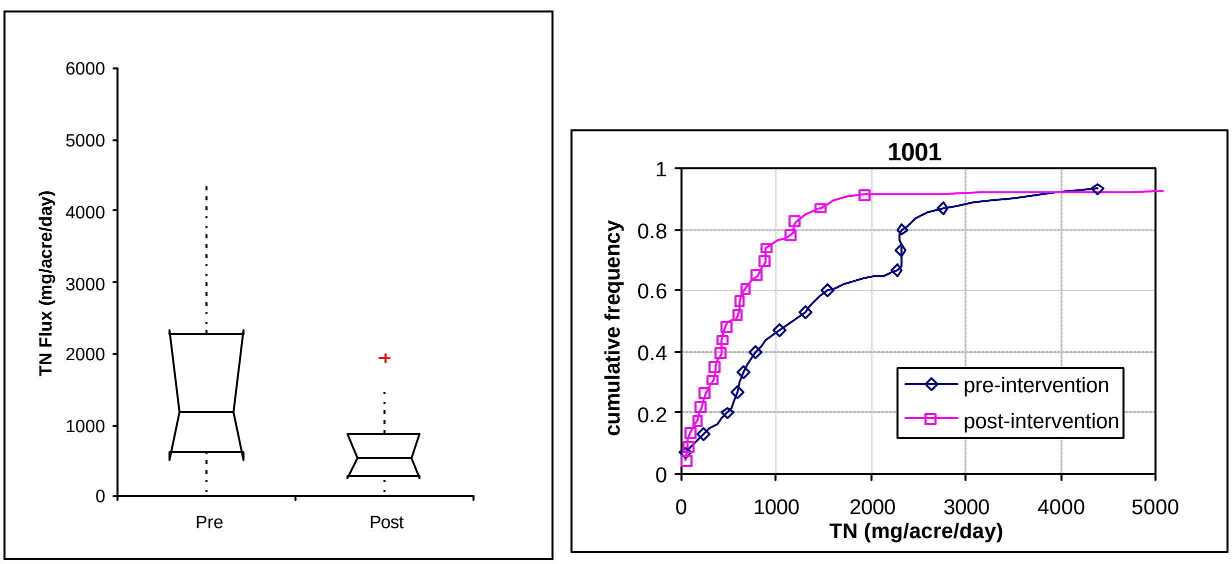


Figure 8. Side-by-side box plot and probability plots of pre- versus post-intervention for total nitrogen flues at Site 1001.

Table 8 shows the results of the Mann-Whitney test (rank-sum) for the total nitrogen flux at Site 1001. Notice the difference in the medians from pre- to post-intervention are statistically significantly different at the 95% confidence level ($p<0.05$). The magnitude of the difference (the Hodges-Lehmann estimator) is approximately 530 mg/acre/day, indicating a relatively large reduction in total nitrogen loads from the neighborhood. However, as discussed below, the extent to which the ET controllers contributed to this reduction is unclear.

The nitrogen fluxes used in this analysis were computed as the product of the measured concentration and the average daily flow. Therefore, the reduction in TN flux could be due to a reduction in flow, a reduction in concentration, or a combination of both. Analyses presented earlier showed a statistically significant reduction in median TN concentration at site 1001 between the pre- and post-intervention periods. Similarly, analyses discussed in the R3 report indicate that there was a statistically significant reduction in flow at site 1001 between the pre- to post-intervention periods; however, it was cautioned that the pre- and post-intervention periods are not comparable due to seasonal differences in the data collection period. Thus, observed reductions in flow in 1001 could be influenced by seasonal factors, and therefore the extent to which the ET controllers contributed to a reduction in flow is unknown. Consequently, reductions in TN flux could be attributed to a combination of TN reduction, flow reduction, and/or seasonal factors.

Table 8. Example Mann-Whitney test for difference in medians for total nitrogen flux at Site 1001 from pre- versus post-intervention.

Test	**Mann-Whitney test**			
Alternative hypothesis	1001_flux (mg/acre/day): Pre ≥ Post			
Performed by	GeoSyntec Consultants			
n	36			
1001_flux (mg/acre/day)	**n**	**Rank sum**	**Mean rank**	**U**
Pre	14	320.0	22.86	93.0
Post	22	346.0	15.73	215.0
Difference between medians	529.389			
95.1% CI	115.985	to +∞	(normal approximation)	
Mann-Whitney U statistic	93			
1-tailed p	0.0239	(normal approximation)		

Based upon the above results, we believe that it would be valuable to complete a more robust statistical evaluation of the data, as we believe that some significant management implications could be determined.

4. Possible Implications for TMDL Compliance.

The R3 Study results were examined in the context of existing TMDLs in the San Diego Watershed. Most of the existing TMDLs are reviewed below and possible inferences and implications of the R3 Study data for TMDL compliance are discussed. The sediment and organophosphorus pesticide TMDLs were not reviewed because sediment data were not collected (the vast majority of sediments are transported by storm flows) and because Schiff and Tiefenthaler (2003) have previously conducted an extensive analysis of the organophosphorus pesticide data.

4.1. Nitrogen

Nitrogen Water Quality Objectives and TMDLs **–** The Basin Plan water quality objectives for nitrogen in San Diego Creek are 13 mg/L Total Inorganic Nitrogen (TIN) in Reach 1, and 5 mg/L TIN in Reach 2 (RWQCB, 1995). Reach 1 extends from Newport Bay to Jefferey Road, and Reach 2 extends from Jefferey Road to the headwaters. There is no numeric standard for nitrogen in Upper Newport Bay in the Basin Plan.

The nitrogen TMDL for Upper Newport Bay is based on the general goal of reducing nutrient loads to Newport Bay by 50 percent, to levels observed in the early 1970's (USEPA, 1998b). The nitrogen TMDL sets phase-in limits on total nitrogen (TN) loads to Newport Bay (see Table 9). Separate loads are established for the dry and wet seasons (dry season is from April 1 to September 30). In addition, the winter load is exclusive of storm flows with an average daily flow greater than 50 cfs in San Diego Creek at Campus Drive.

There is no TMDL for nitrogen loads in San Diego Creek, Reach 1 because it was reasoned that attainment of the 50 percent reduction in nitrogen loads to Newport Bay would result in compliance with the Basin Plan in-stream water quality standard for Reach 1 (13 mg/l TIN). However, for Reach 2 it was determined that the average in-stream nitrogen concentrations would likely remain close to or above the Basin Plan in-stream water quality standard (5 mg/L TIN), even with attainment of the Newport Bay TMDLs. Therefore a TMDL of 14 lbs/day TN was established for Reach 2 (see Table 9) and is applicable for all flows exclusive of storm flows greater than an average daily flow of 25 cfs in San Diego Creek at Culver Drive.

Table 9: Summary of Nutrient TMDLs for Upper Newport Bay and San Diego Creek

TMDL	Dec 31, 2002	Dec 31, 2007	Dec 31, 2012
Newport Bay Watershed, TN – Summer load (4/1 to 9/30)	200,097 lbs	153,861 lbs	
Newport Bay Watershed, TN – Winter load (10/1 to 3/31; non-storm)			144,364 lbs
Newport Bay Watershed, Total Phosphorus – Annual Load	86,912 lbs	62,080 lbs	
San Diego Creek, Reach 2, daily load			14 lbs/day
Urban Runoff Allocation for the Newport Bay Watershed Summer load Winter load	 22,963	 11,481	 38,283

Study Data Comparison with Nitrogen Water Quality Objective **–** The Basin Plan water quality objectives are expressed in terms of total inorganic nitrogen (TIN), which is comprised of nitrate/nitrite nitrogen and ammonia. By far the majority of the TIN in San Diego Creek is comprised of nitrate/nitrite nitrogen, as measured ammonia concentrations were typically quite low with a majority below the detection limit. For this reason, only the nitrate/nitrate concentration data are compared to the Basin Plan objectives in this report.

Table 10 shows the mean and median nitrate/nitrite concentrations measured in the five study watersheds. The mean and median nitrate/nitrite concentration in all watersheds except 1004 are below the Reach 2 Basin Plan objective of 5 mg/l TIN. As discussed previously, Site 1004 may not be a representative control site because the underlying distribution of pre-intervention nitrogen data appears to be different from the other sites. Similar arguments may also be true Site 1003. With exception of Site 1004, mean nitrate/nitrite concentrations suggests that, <u>on average</u>, residential runoff from these watersheds do not contribute to the exceedance of Basin Plan standards for TIN in receiving waters in San Diego Creek, Reach 1 and 2. The Reach 2 water quality objective was occasionally exceeded in the all watersheds, except for the post intervention conditions in 1001 and 1002.

The mean and median nitrate/nitrate concentrations in watershed 1004, and 1005 exhibit exceedances of the 5 mg/l standard during pre- and/or post intervention conditions. Watershed 1004, in particular, had high levels of measured nitrate/nitrite concentrations, especially during the pre-intervention period. A number of these high readings exceed the Reach 1 water quality objective of 13 mg/l TIC. The results from watershed 1004 are not consistent with those from the other four study watersheds, and the source of the high readings is unknown. Localized conditions involving excessive fertilizer usage by a few users could possibly be a factor in these elevated readings. In particular, the R3 mentions an unknown connection to a neighboring watershed, which could explain the source of elevated nutrient levels.

Table 10: Mean and Median Nitrate/Nitrite Concentration (mg/l) by Watershed (all data)

	1001		1002		1003		1004		1005	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
n	23	25	23	25	24	25	23	25	24	25
Mean	2.56	1.47	2.57	1.07	2.13	1.71	36.50	6.61	2.61	4.13
Median	2.32	1.38	1.56	0.93	1.68	0.94	16.88	2.29	2.45	1.48
n>5 mg/l	1	0	4	0	1	2	18	8	2	1
n>13 mg/l	0	0	0	0	0	0	12	4	0	1

The Mann-Whitney (rank-sum) test was performed to compare the statistical difference between median concentrations during pre- and post-intervention periods (see example in Section 3 above). The median nitrate/nitrite in the post-intervention period was lower in all watersheds, and the difference was statistically significant at the 0.05 confidence level. As the control stations exhibited this trend, these data (i.e. entire data sets with unequal seasonal coverage) cannot be used to ascertain if the structural and educational BMPs were effective in reducing the runoff concentrations of nitrate/nitrite.

Clearly there is another factor contributing to reduced concentrations in the post intervention period. One possibility that was investigated is differences in seasons, year-to-year variability, and sampling times of the pre- and post-intervention data. Table 11 shows mean and median concentrations for comparable seasons and sampling times. Note there are still noticeable reductions in all of the median concentrations, except Site 1005. Applying the Mann-Whitney (rank-sum) test to these data it was found that statistically significant differences between median nitrate/nitrite concentrations in the pre- and post-intervention periods occurred only in watersheds 1001 and 1004, as compared to all watershed when all data are considered. These results indicate that seasonal effects are present in these data and should be considered in the study evaluation. It may be inferred from these result that there were significant reductions in the nitrate/nitrite concentration in the intervention watershed during the wet season that may, in part, be attributable to the structural BMPs. It is unknown whether similar reductions would occur in dry weather runoff during the dry season because such data were not collected during the pre-intervention period.

Table 11: Mean and Median Nitrate/Nitrite Concentration (mg/l) by Watershed for Comparable Seasons and Sampling Times[1]

	1001		1002		1003		1004		1005	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
n	18	14	18	14	19	14	18	14	19	14
Mean	2.38	1.43	1.95	0.95	2.17	1.66	26.24	6.57	2.24	6.27
Median	2.22	1.48	1.16	0.96	1.50	1.02	8.94	2.06	2.03	1.96
n>5 mg/l	0	0	2	0	1	1	13	4	1	1
n>13 mg/l	0	0	0	0	0	0	7	3	0	1

1 – evening samples were deleted from the pre-intervention data. The post-intervention data include only those data collected in months identical to the pre-intervention period.

Study Data Comparison with Nitrogen TMDLs - The nitrogen TMDL is expressed in terms of total nitrogen (TN) loads. TN concentrations were calculated from the monitoring data as the sum of the nitrate/nitrite nitrogen and TKN nitrogen. Table 12 shows the mean and median TN concentrations measured in the five study watersheds. The mean and median TN concentration in dry weather runoff are generally in the range of 2 to 5 mg/l, with the exception of watershed 1004 where substantially higher concentrations were measured. The rank sum tests indicated that median TN concentrations are significantly lower (in a statistically sense) in the post-intervention period in watershed 1001 (structural BMPs, see Table 5), and in watershed 1002 (control, see Table 6), and based on the probability plots in Appendix C, Site 1004 is expected to as well. However, sites 1003 and 1005 did not show statistically significant reductions. These results did not change when only subsets of the data were used to consider possible affects stemming from the sampling time and sampling months.

Table 12: Mean and Median TN Concentration (mg/l) by Watershed

	1001		1002		1003		1004		1005	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
All Data										
n	23	25	23	25	23	25	23	25	23	25
Mean	4.24	3.09	5.31	3.44	3.66	4.42	48.00	10.18	6.89	7.74
Median	3.84	2.27	3.95	2.55	2.66	2.50	19.01	5.57	5.06	4.36
Subsets[1]										
n	18	14	18	14	18	14	18	14	18	14
Mean	4.18	2.78	4.51	2.63	3.71	3.71	33.99	8.91	6.98	9.91
Median	3.62	2.02	3.22	2.21	2.51	2.47	12.14	3.74	4.17	3.96

1 – Data subsets with comparable sampling time and seasons. Evening samples were deleted from the pre-intervention data. The post-intervention data include only those data collected in months identical to the pre-intervention period.

TN flux estimates were calculated for watersheds 1001 and 1005 (Table 13). The draft R3 report indicates that the flow measurements in watershed 1002-1004 are not reliable and therefore flux estimates were not calculated for these watersheds. Flux estimates were calculated as the product of the constituent concentration and the average daily flow occurring on the day of the sample collection. The flux estimates were found to be quite variable as they depend on both flow and concentration measurements. Table 13 shows that median TN flux estimates decrease from the pre- to post-intervention periods for both watersheds. Mann-Whitney (rank sum) tests show the reductions to be statistically significant (Table 8). Because comparable data are not available for the control sites, it is not possible to infer whether these reductions are influenced by the ET controllers in the intervention watershed (1001). Also, as previously discussed, the reduction in TN flux may be attributable to a reduction in flow, a reduction in concentration, seasonal factors, or a combination of these.

Table 13: Mean and Median TN Flux (mg-N/acre/day) by Watershed

	1001		1005	
	Pre	**Post**	**Pre**	**Post**
All data				
n	14	22	10	21
Mean	1476	1667	2104	6537
Median	1164	530	1568	1177
Subset[1]				
n	12	14	10*	8
Mean	1384	587	2104	1716
Median	902	497	1568	960

1 – Data subsets with comparable sampling time and seasons. Evening samples were deleted from the pre-intervention data. The post-intervention data include only those data collected in months identical to the pre-intervention period.
* – Same as the all data case

Although the flux estimates in Table 13 are limited in number, duration, and location, they can be used to speculate about the magnitude of the urban area contribution of TN loads to Newport Bay and the potential reduction in loads from structural and nonstructural BMPs. Based on the limited flux data, the annual TN load to Newport Bay in dry weather runoff from urban areas in the San Diego Creek Watershed is estimated to range between 37,000 to 50,000 lbs per year under existing land-use conditions (see Table 14). This is for the most part below the 2012 urban runoff allocation of 49,764 lbs. The annual TN load is estimated to increase to 50,000-67,000 lbs per year under built-out conditions.

According to the 2001 report on the nutrient TMDL (OCPFED, 2001), the average daily TN load in San Diego Creek at Campus Drive was 540 lbs/day between July 2000 and June 2001. This converts to an annual load of about 197000 lbs, which is below the 2007 TMDL (note: San Diego Creek is the majority but not sole contributor of TN loads to Newport Bay). Estimates in Table 14 suggest that dry weather runoff from urban areas account for about 20 to 25% of the annual TN in the San Diego Creek Watershed. If it is assumed that flux reductions observed in the post intervention period are attributable to the structural and nonstructural BMPs, and if similar interventions could hypothetically be implemented on a watershed-wide basis, then the potential reduction in annual dry weather TN loads is estimated to range between 12,500-20,000. This would represent a reduction of about 6-10% of the current TN loads and about 30-40% of the estimated current dry weather urban loads. Note these estimates are based on few data collected in a limited area, and should therefore be considered preliminary in nature.

Table 14: Estimated Annual TN Loads in Dry Weather Runoff from Urban Areas in the San Diego Creek Watershed

	TN flux (mg-N/acre/d)	Annual TN Load to Newport Bay (lbs) Existing land-use[1]	Annual TN Load to Newport Bay (lbs) Built-out land-use[2]
Pre-intervention conditions	1160 – 1560	37,300 – 50,500	50,000 – 67,000
Post-intervention conditions	530 – 1180	17,000 – 38,000	23,000 – 51,000
Potential reduction		~12,500 – 20,000	~16,000 – 27,000

1 –Used 40000 acres or about 53% of the San Diego Creek Watershed area (IRWD, 2003). For comparison, urban land use in 1999 use was estimated at 35,500 acres of the watershed area at Campus Drive (Tetra-Tech, 2000).
2 – Used 53500 acres or about 71% of the San Diego Creek Watershed area (IRWD, 2003).

The following conclusion can be made based on the analyses above:

- Average and median nitrate/nitrite concentrations in dry weather runoff are below the Reach 2 water quality objective (5 mg/l), for most but not all study watersheds.
- Occasional exceedance of the Reach 2 water quality objective occurred in all study watersheds
- The majority of measured nitrate/nitrite concentrations in watershed 1004 during the pre-intervention period were greater than the Reach 2 water quality objective of 5 mg/l. These data are not consistent with those from the other watersheds. The cause is unknown, but could possibly be related to the unknown connection to neighboring nursery discussed in the R3 report.
- Sampling periods (months) and sampling time (morning versus evening) was found to affect the statistical significance of differences between pre- and post- intervention median nitrate/nitrate concentration in some of the watersheds. The sampling period and sampling time did not affect the statistical significance of differences between pre- and post-intervention median TN concentrations.
- Median TN fluxes in watershed 1001 and 1005 were statistically smaller in the post-intervention period. The extent to which the structural and nonstructural BMPs contributed to these reductions cannot be determined due to the lack of reliable flow data in the control sites.
- Preliminary estimates of annual TN loads to Newport Bay in dry weather runoff from urban sources range between 37,000 to 50,000 lbs per year, or about 20 to 25% of the current TN loads.
- The potential reductions in annual dry weather TN loads due implementation of BMPs on a watershed basis is estimated to range between 12,500-20,000 pounds per year. This would represent a reduction of about 6-10% of the current TN loads and 30-40% of the urban loads.

4.2. Phosphorus

The majority of the annual TP load in the San Diego Creek Watershed occurs in the wet season, and has been correlated with sediment loads generated by storm events (USEPA, 1998b). This correlation suggests that a majority of phosphorus occurs in particulate form attached to sediments. The main sources of the total phosphorus (TP) are in Peters Canyon Wash and San Diego Creek above Culver Drive (USEPA, 1998b).

Phosphorus TMDL – There is no numeric objective for phosphorus for San Diego Creek in the Basin Plan. Because measured TP and sediment loads are correlated, it was determined in the TMDL that a 50 percent reduction in TP loads would be achieved through compliance with the sediment TMDL (USEPA, 1998a). Accordingly, the TMDL for TP was based on a 50 percent reduction of average annual load estimated at 124,160 lbs (USEPA, 1998b). The TMDLs are applicable for all flow conditions. The target compliance date was set for December 31, 2007.

The annual TP load allocation for urban areas is 4102 lbs by 2002, reducing to 2960 lbs by 2007. According to the USEPA (1998b) the TP is allocated in the same proportion as sediments. The annual urban area (stabilized vs. construction) sediment allocation for the Newport Bay Watershed is 50 tons distributed over 95.3 square miles (see Table 5 in USEPA, 1998a). This is a very small allocation over a large area. By contrast, note that the annual construction allocation is 6500 tons distributed over the assumed 3.0 square miles under construction in any one year. Using the same proportions of sediment load allocations, the TP load rate based on the 2007 urban allocation is 2960 lbs/95.3 square miles = 0.0485 lbs/acre/yr. If the construction and urban allocations are combined, the TP load rate based on the combined 2007 urban and construction allocations is (2960+12810) lbs/(95.3+3.0) square miles = 0.251 lbs/acre/yr.

Study Data Comparison with TMDLs – Similar to the nitrogen TMDL, the phosphorus TMDL is expressed in terms of total annual (TP) loads. Table 15 shows the mean and median TP concentrations measured in the five study watersheds. The mean and median TP concentrations in dry weather runoff are below 1.2 mg/l in all watersheds, with the exception of watershed 1004 where substantially higher concentrations were measured. Comparison of the pre- and post-intervention median TP concentrations in all data (Table 15) reveals an increase in the median TP concentration during the post-intervention period for all watersheds except the intervention watershed 1001 and 1004. In contrast, when subsets of the data with similar seasons and sampling times are considered (Table 15), there is a decrease in the median TP concentration in all watersheds except 1005. This indicates that there are seasonal influences in the data, which presumably are related to rainfall. Unfortunately there are no data available to permit comparison of pre- and post-intervention concentrations for dry weather flows during the dry season.

Table 15: Mean and Median TP Concentration (mg/l) by Watershed

	1001		1002		1003		1004		1005	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
All Data										
n	23	25	23	25	24	25	23	24	24	25
Mean	0.73	0.60	0.92	0.84	0.98	1.21	3.33	1.50	1.01	1.19
Median	0.60	0.51	0.77	0.82	0.62	0.67	2.54	1.05	0.73	0.85
Subsets[1]										
n	18	14	18	14	19	14	18	13	19	14
Mean	0.78	0.47	0.91	0.67	1.13	0.57	2.62	1.33	0.93	1.24
Median	0.61	0.41	0.73	0.56	0.75	0.58	1.82	1.07	0.75	0.83

1 – Data subsets with comparable sampling time and seasons. Evening samples were deleted from the pre-intervention data. The post-intervention data include only those data collected in months identical to the pre-intervention period.

TP flux estimates were calculated for watersheds 1001 and 1005 using the approach discussed in the nitrogen section above. Table 16 shows that median TP flux estimates decrease from the pre- to post-intervention periods in the intervention watershed (1001) but not in the education only watershed. Mean fluxes increase in both watersheds, but as discussed earlier, the mean values are strongly influenced by outliers and do not provide a good measure of central tendency for these data. Application of the Mann-Whitney (rank sum) test shows the reduction in median TP flux in 1001 is statistically significant. This suggests that the structural BMPs had a positive influence in reducing the TP fluxes, but because comparable data are not available for the control sites, it is not possible to ascertain the extent to which the ET controllers contributed to these reductions. Also, as discussed previously, reductions in flux could be influenced by several factors: reduction in concentration, reduction in flow, and/or seasonal variability.

Table 16: Mean and Median TP Flux (mg-P/acre/day) by Watershed (all data)

	1001		1005	
	Pre	Post	Pre	Post
All data				
n	14	22	10	21
Mean	265	370	473	1327
Median	164	109	219	219

Similar to the previous analyses of TN loads, the TP flux estimates in Table 16 can be used to speculate about the magnitude of the urban area contribution of TP loads to Newport Bay and the potential reduction in loads from structural BMPs. Based on the limited flux data, the annual TP load to Newport Bay in dry weather runoff from urban areas in the Newport Bay Watershed is estimated to range between about 5,000 to 11,000 lbs per year (see Table 17) based on a total urban area of 95.3 square miles obtained from Table 5 of the sediment TMDL (USEPA, 1998a). These estimated annual TP loads are greater than the urban allocation (for both dry and wet weather) and are less than the combined urban and construction allocations (Table 17). Note,

however, that these estimates are based on dry weather data only, and it is expected that a major portion of the TP loads will occur in runoff from winter storms. Therefore, actual annual TP loads would be expected to be greater. If it hypothesized that flux reductions observed in the intervention watershed 1001 could be realized over the entire watershed, then the potential reduction in annual dry weather TP loads from urban areas is estimated at 2700 lbs. As stated previously, these estimates are based on few data collected in a limited area, and should therefore be considered preliminary in nature.

Table 17: Estimated Annual TP Loads in Dry Weather Runoff from Urban Areas in the San Diego Creek Watershed

	TP flux (mg-P/acre/d)	**Annual TP Load Rate to Newport Bay (lbs/acre/year)[1]**	**Annual TP Load to Newport Bay (lbs/year)**
2007 Urban Area Allocatoion for Newport Bay		0.0485	2960
2007 Combined Urban and Construction Area Allocatoion for Newport Bay		0.251	15770
Pre-intervention conditions (median fluxes)	164 – 219	0.132 – 0.176	8049 – 10748
Post-intervention conditions (median fluxes)	109 – 219	0.088 – 0.176	5350 – 10748
Potential reduction			2700

1 - urban area is 95.3 square miles and the construction area is 3.0 square miles based on Table 5 in USEPA, 1998a

4.3. Metals

Metals TMDLs **–** The USEPA (June 2002) determined that TMDLs are required for dissolved copper, lead, and zinc in San Diego Creek, Upper Newport Bay, and Lower Newport Bay, and that TMDLs are required for cadmium in San Diego Creek and the Upper Newport Bay. The TMDLs for San Diego Creek are expressed as concentration limits, based on the CTR criteria at various hardness values that are associated with different flow regimes (Table 18). The flow regimes are based on 19 years of flow measurements in San Diego Creek at Campus Drive. The concentration-based TMDLs apply to all freshwater discharges to San Diego Creek, including discharges from agricultural, urban, and residential lands, and storm flow discharges. The

applicable flow regime at any location in the entire watershed is determined on the basis of discharge at Campus Drive.

Table 18: Summary of Dissolved Metal TMDLs for San Diego Creek

Dissolved Metal (mg/l)	Base flow (0–20 cfs) hardness @ 400 mg/L		Small flows (21-181 cfs) hardness @ 322 mg/L		Medium flows (182-814 cfs) hardness @ 236 mg/L		Large flows (>814 cfs) hardness @ 197 mg/L
	Acute	**Chronic**	**Acute**	**Chronic**	**Acute**	**Chronic**	**Acute**
Cadmium	19.1	6.2	15.1	5.3	10.8	4.2	8.9
Copper	50	29.3	40	24.3	30.2	18.7	25.5
Lead	281	10.9	224	8.8	162	6.3	134
Zinc	379	382	316	318	243	244	208

Metals Sources **–** The USEPA (June 2002) conducted a source analysis as part of the TMDL preparation. Surface runoff is the largest contributor of metals loads in the San Diego Creek Watershed, which includes natural and man made source (USEPA , June 2002). Much of the metals loads are from natural sources. The estimated anthropogenic contributions are metal specific and range from about 33% for zinc to 63% for cadmium (USEPA, June 2002). A primary anthropogenic source of heavy metals is runoff from urban roads, which contributes to sources of cadmium (tire wear), copper (brakes, tires), lead (brakes, tires, fuels and oils), and zinc (tires, brakes, galvanized metals). Use of copper sulfate by nurseries may also be a minor source of copper loads. Other copper and zinc uses in building materials (roofing and roof drains) may be another source.

The USEPA found that metal inputs were heavily influenced by rainfall and stream flow rates. Monitoring results were reported to be highly variable due to different rainfall amounts and flows during each water year. The EPA estimated that base flows account for 25% of the total metal loadings, with the remainder from low, medium and large flows caused by storms.

The EPA's preliminary analyses suggest that: 1) a primary source of metals in dry weather runoff in the study watershed is from roads (i.e. wash off of metals in driveways, parking lots, streets, gutters, etc.); 2) the runoff concentrations will be influenced by rainfall which result in wash off of accumulated metals; and 3) the concentrations can be variable depending on the amount of rainfall.

Study Data Comparison with Base Flow TMDLs **–** The metals TMDLs for base flow conditions are based on meeting the CTR criteria at a total hardness of 400 mg/l. The CTR criteria express maximum allowable concentrations in receiving waters for acute (short term) and chronic (4-day) exposure periods. The acute and chronic criteria are expressed as values that cannot be exceeded more that once in three years. Although the criteria are applicable in the

receiving waters and not in the urban runoff per se (i.e. the measured dry weather discharge), exceedance of the CTR in the urban discharge would suggest a potential for the discharge to contribute to an exceedance in the receiving waters.

Table 19 shows the mean and median heavy metal concentrations in the five study watersheds. (*Note to IRWD reviewer: we assumed that the analytical results are for dissolved metals based on guidance from IRWD, but this is not clearly indicated in the data base or draft report; it is likely the case as base flows are typically low in suspended sediments.*) With the exception of mean copper concentrations in some of the watersheds, all mean and median concentrations were below the chronic and acute CTR criteria. Copper, lead, and zinc concentrations occasionally exceeded the chronic CTR criteria, and copper and zinc concentrations occasionally exceeded the acute criteria. These exceedances suggest that the dry weather runoff can potentially contribute to an exceedance in the receiving waters. However, if intervention is determined to be effective in reducing runoff flows, then the BMPs would help to reduce impacts of these potential exceedances by allowing for greater dilution with the in-stream flows.

Table 19: Mean and Median Metal Concentrations (µg/l) by Watershed (all data)

	1001		**1002**		**1003**		**1004**		**1005**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Cadmium										
n	23	25	23	25	24	25	23	25	24	25
Mean	0.26	0.14	0.47	0.44	0.27	0.17	0.64	0.22	0.21	0.29
Median	0.27	0.10	0.24	0.10	0.10	0.10	0.36	0.10	0.10	0.10
n>6.2 µg/l	0	0	0	0	0	0	0	0	0	0
n>19.1 µg/l	0	0	0	0	0	0	0	0	0	0
Copper										
n	23	25	23	25	24	25	23	25	24	25
Mean	13.5	16.9	27.3	30.3	11.5	26.6	21.8	17.7	32.1	30.8
Median	11.5	11.4	10.9	14.0	11.1	14.3	12.7	11.4	12.3	20.4
n>29.3 µg/l	2	2	3	7	0	2	5	4	3	5
n>50 µg/l	0	1	3	3	0	2	2	3	3	2
Lead										
n	23	25	23	25	24	25	23	25	24	25
Mean	0.8	1.6	5.9	4.7	0.8	1.6	3.5	1.5	1.0	3.2
Median	0.6	0.6	0.9	1.2	0.6	0.8	0.7	0.7	0.7	1.3
n>10.9 µg/l	2	1	2	3	0	0	2	0	0	1
n>281 µg/l	0	0	0	0	0	0	0	0	0	0
Zinc										
n	23	25	23	25	24	25	23	25	24	25
Mean	58.7	37.2	115.2	86.3	56.3	56.8	83.6	40.9	74.0	75.0
Median	56.0	50.2	53.4	57.2	50.7	53.9	50.8	43.8	52.4	54.5
n>382 µg/l	0	0	1	2	0	0	1	0	0	0
n>379 µg/l	0	0	1	2	0	0	1	0	0	0

We were unable to locate dry weather metals monitoring information in the Central Irvine Channel, which is the immediate receiving water of the study watersheds (*IRWD please confirm*). OCPFRD dry weather monitoring data are available in San Diego Creek at Campus Drive, which is quite a ways downstream from the study watersheds. Data collected between 12/01 and 6/02 (Table 20) show that average dry weather concentrations at Campus Drive are well below mean and median concentrations measured in dry weather runoff from the study watersheds. Similar comparisons cannot be made for lead and cadmium because the method detection limits in the OCPFRD data are greater than those in the R3 data. None of the OCPFRD dry weather data exceed the chronic or acute criteria.

These comparisons suggest that metal loads in dry weather runoff from the study (urban) watersheds could be a contributing factor to dry weather copper and zinc loads measured at Campus Drive. These dry weather discharges do not result in non-compliance of the base flow metal TMDL at Campus (based on the reviewed data only). It is unknown if the elevated concentrations measured in the dry weather urban runoff result in exceedance of the CTR criteria in the immediate receiving waters. Note that if flow reductions observed in the intervention watershed are attributable to the ET controllers, then these controllers would help to reduce impacts from any potential exceedances of the TMDL because the discharges would be subject to greater dilution by the in-stream flows.

Table 20: Summary of OCPFRD Dry Weather Monitoring Data in San Diego Creek at Campus Drive (12/01 to 6/02)

	Cadmium	Copper	Lead	Zinc
Sample number	24	24	24	24
Range	All < 1 μg/l	<2 – 16 μg/l	<2-2.4 μg/l	<10-16
Mean		7.4 μg/l	most <2 μg/l	most <10
Median-		6.8 μg/l		

4.4. Pathogens

Pathogens are agents or organisms that can cause diseases or illnesses, such as bacteria and viruses. Fecal coliform bacteria are typically used as an indicator organism because direct monitoring of human pathogens is generally not practical. Fecal coliform are a group of bacteria that are present in large numbers in the feces and intestinal tracts of humans and animals, and can enter water bodies from human and animal waste. The presence of fecal coliform bacteria implies the water body is potentially contaminated with human and/or animal waste, suggesting the potential presence of associated pathogenic organisms.

Fecal Coliform TMDL **–** The RWQCB has adopted phased TMDL criteria for pathogens, with the initial focus on additional monitoring and assessment to address areas of uncertainty. The

goal of the Newport Bay TMDL is compliance with water contact recreational standards by 2014:

> Fecal coliform concentration of not less than five samples per 30 days shall have a geometric mean less than 200 most probable number (MPN)/100ml, and not more than 10 percent of the samples shall exceed 400 MPN/100ml for any 30-day period.

A second goal is to achieve the shellfish harvesting standards by 2020:

> The monthly median fecal coliform concentration shall be less than 14 MPN/100 mL, and not more than 10 percent of the samples shall exceed 43 MPN/100 mL.

The TMDLs are applicable for all flow regimes.

***Study Data Comparison with Fecal Coliform TMDLs* –** Table 21 shows the mean and median fecal coliform concentrations measured in the five study watersheds. 70% to 100% percent of all fecal coliform measurements were greater than 400 MPN/ml in all study watersheds. This level of exceedance is substantially greater than the allowable 10%. The mean and median fecal coliform concentrations also exceed the 400 MPN/100ml criterion in all study watersheds. There was insufficient data to calculate the 30-day geometric mean (a minimum of 5 samples per 30 days needed), however, the TMDL criterion (30-day geometric < 200 MPN/100 ml) would likely be exceeded, assuming that any additional data would be of the same magnitude as those collected. Exceedance of the TMDL criteria in all study watersheds suggests that urban dry weather runoff is likely a contributing factor to any dry weather exceedance of the TMDL in the receiving waters.

Table 21: Mean and Median Fecal Coliform Concentration (MPN/100ml) by Watershed

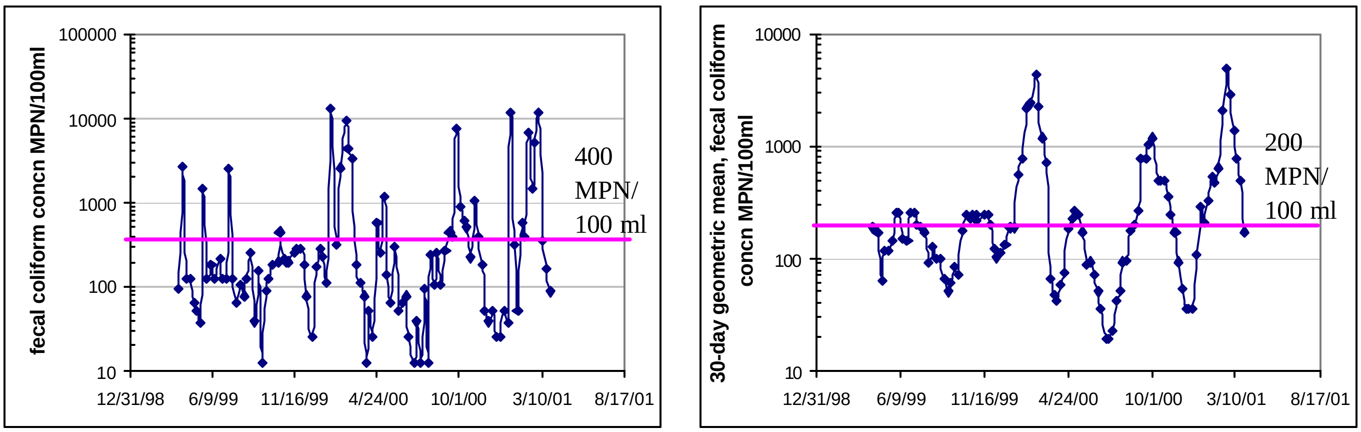
	1001		**1002**		**1003**		**1004**		**1005**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
All Data										
n	22	24	21	24	23	24	21	24	23	24
Mean	4921	3003	5582	128193	34526	28980	28205	34185	17976	10326
Median	2300	1400	1700	3000	13000	4000	13000	13000	8000	8000
% > 400 MPN/100ml	82%	67%	86%	79%	100%	88%	95%	83%	92%	93%
Subsets[1]										
n	17	14	17	14	18	14	17	14	18	14
Mean	2545	3054	3090	5074	13783	37479	23312	20166	8524	6109
Median	2200	950	1400	1400	8000	2650	8000	6500	4000	2900
% > 400 MPN/100ml	100%	71%	82%	79%	100%	86%	94%	79%	100%	93%

1 – Data subsets with comparable sampling time and seasons. Evening samples were deleted from the pre-intervention data. The post-intervention data include only those data collected in months identical to the pre-intervention period.

We were unable to locate dry weather coliform monitoring information in the Central Irvine Channel, which is the immediate receiving water of the study watersheds (*IRWD please confirm*). Therefore it is unknown if elevated fecal coliform concentrations measured in the

study watershed contribute to an exceedance of the TMDL in the immediate receiving waters. The OCPFRD has collected dry and wet weather *E. coli* monitoring information in San Diego Creek at Campus Drive (OCPFRD, September 2001), which is considerably downstream from the study watersheds. A plot of the equivalent fecal coliform concentration (assuming an 80% *E. coli* content) shows exceedance of the TMDL occurs primarily during the wet season, although dry season exceedances are also evident (see Figure 9). This suggests that dry weather urban runoff is potentially a contributing factor to exceedance of the TMDL in dry weather flows at Campus Drive. The ET controllers would reduce the impacts from these potential exceedances if they were determined to be effective reducing the dry weather runoff volumes.

Figure 9: Time Series of Fecal Coliform Levels San Diego Creek at Campus Drive (converted from measured E. coli concentrations)



Median fecal coliform concentrations presented in Table 21 may be used to evaluate the influence of the structural and non-structural BMPs. When all monitoring dataset is considered, the median fecal coliform concentrations are equivalent or increase from pre- to post-intervention conditions in all watersheds except the 1001 (intervention watershed) and 1003 (a control watershed). Based on the Mann-Whitney (rank-sum) test, the reduction in median concentrations in 1001 and 1003 is significantly significant at the 95% confidence level. Thus the watershed with the irrigation controllers corresponded to a significant reduction in median fecal coliform concentrations, in comparison to 2 of the 3 control sites, while the education only watershed exhibited no discernable reduction in median concentrations.

When subsets of the data with similar seasons and sampling times are considered (Table 21), there is a decrease in the median fecal coliform concentration in all watersheds except 1002. However, because of the smaller sample sizes, the decrease is median concentration is statistically significant only in watershed 1003. This suggests that there could be seasonal influences in the monitoring data, but the data are not sufficient to determine if there are statistically significant differences in the median concentrations.

5. References

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Schiff, K.C. and L.L.Tiefenthaler, June 2003. Contributions of organophosphorus pesticides from residential land uses during dry and wet weather. Technical Report 406, Southern California Coastal Water Research Project.

USEPA (Region 9), 1998a. *Total Maximum Daily Loads for Sediment and Monitoring and Implementation Recommendations; San Diego Creek and Newport Bay, California*

USEPA (Region 9), 1998b. *Total Maximum Daily Loads for Nutrients; San Diego Creek and Newport Bay, California*

USEPA, June 2002. Total Maximum Daily Loads for Toxic Pollutants – San Diego Creek and Newport Bay, California, June 14, 2002.

Tetra Tech, Inc., July 2000c. Newport Bay Watershed Urban Nutrient TMDL Compliance Evaluation.

Appendix A - Time-Series Plots

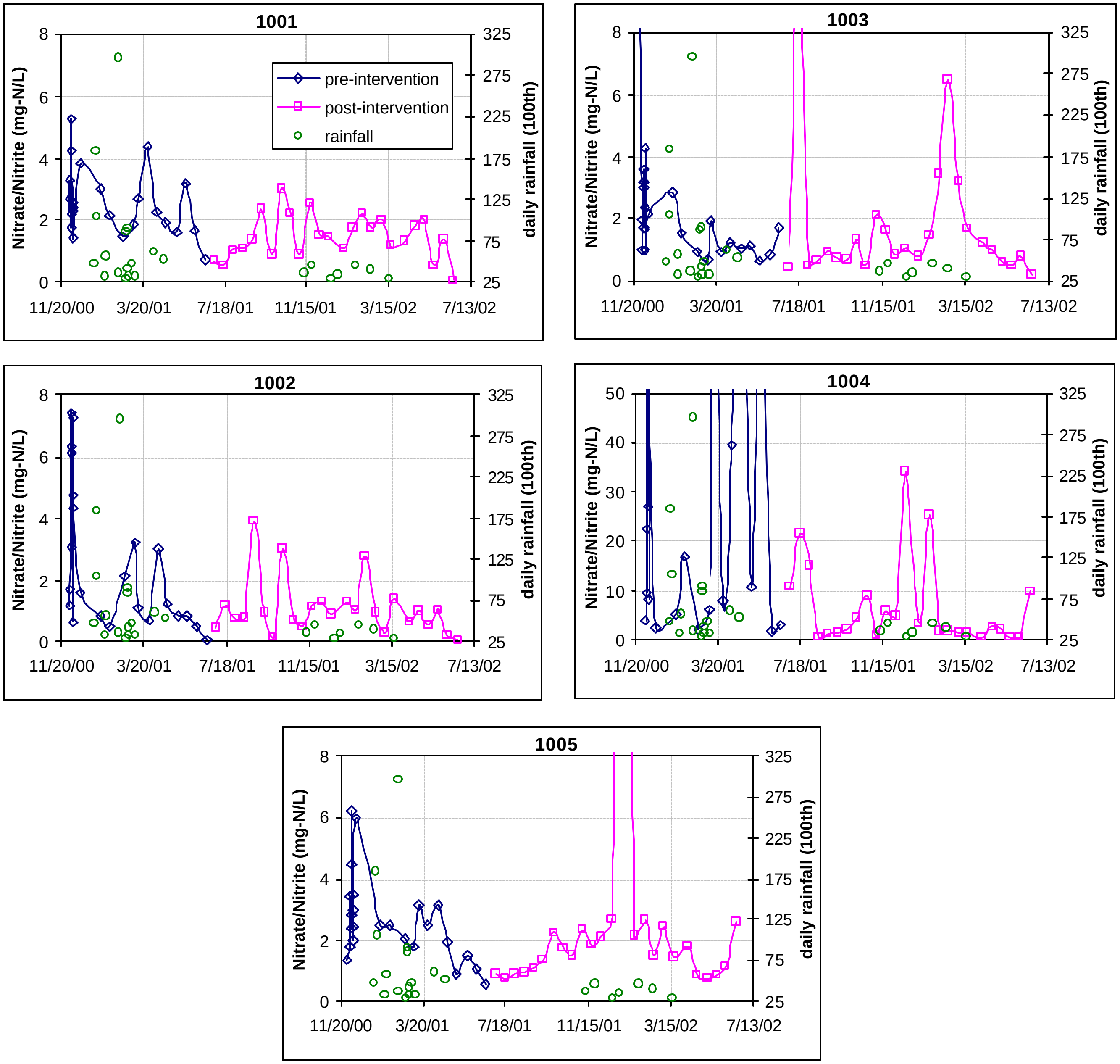


Figure A-1: Time Series of Nitrate/Nitrite in Dry Weather Samples (all data)

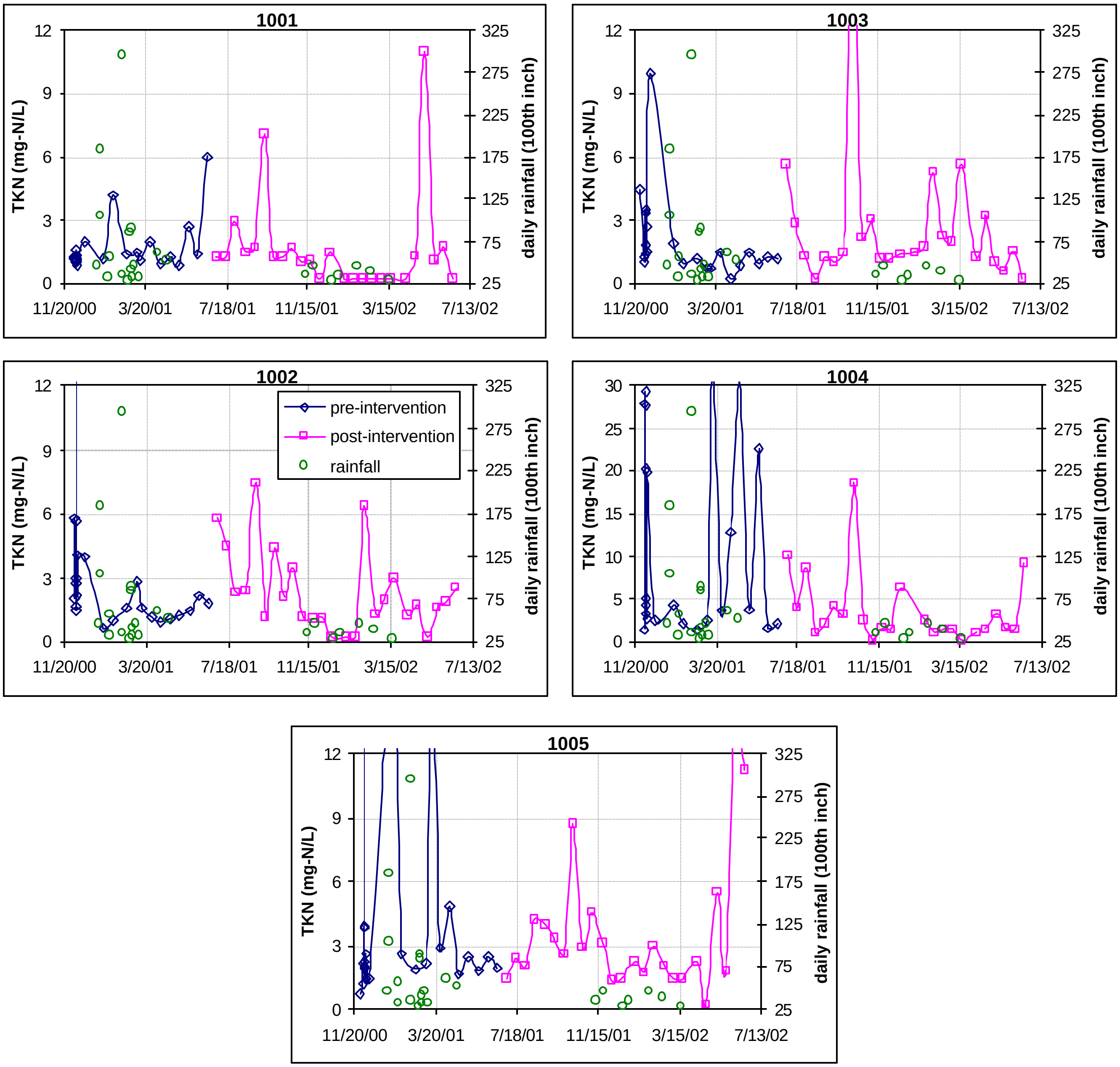


Figure A-2: Time Series of TKN in Dry Weather Samples (all data)

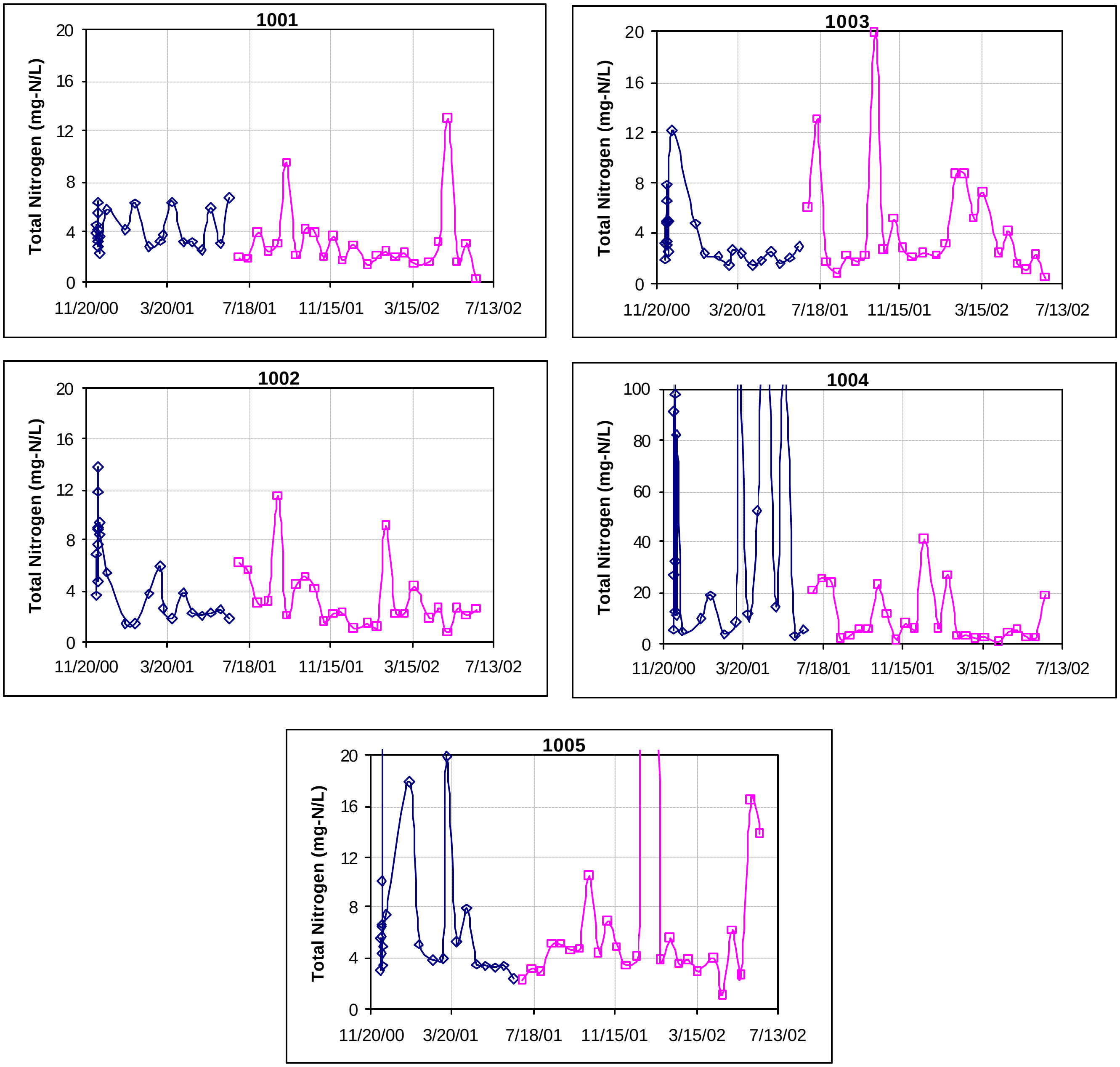


Figure A-3: Time Series of TN (Calculated) in Dry Weather Samples (all data)

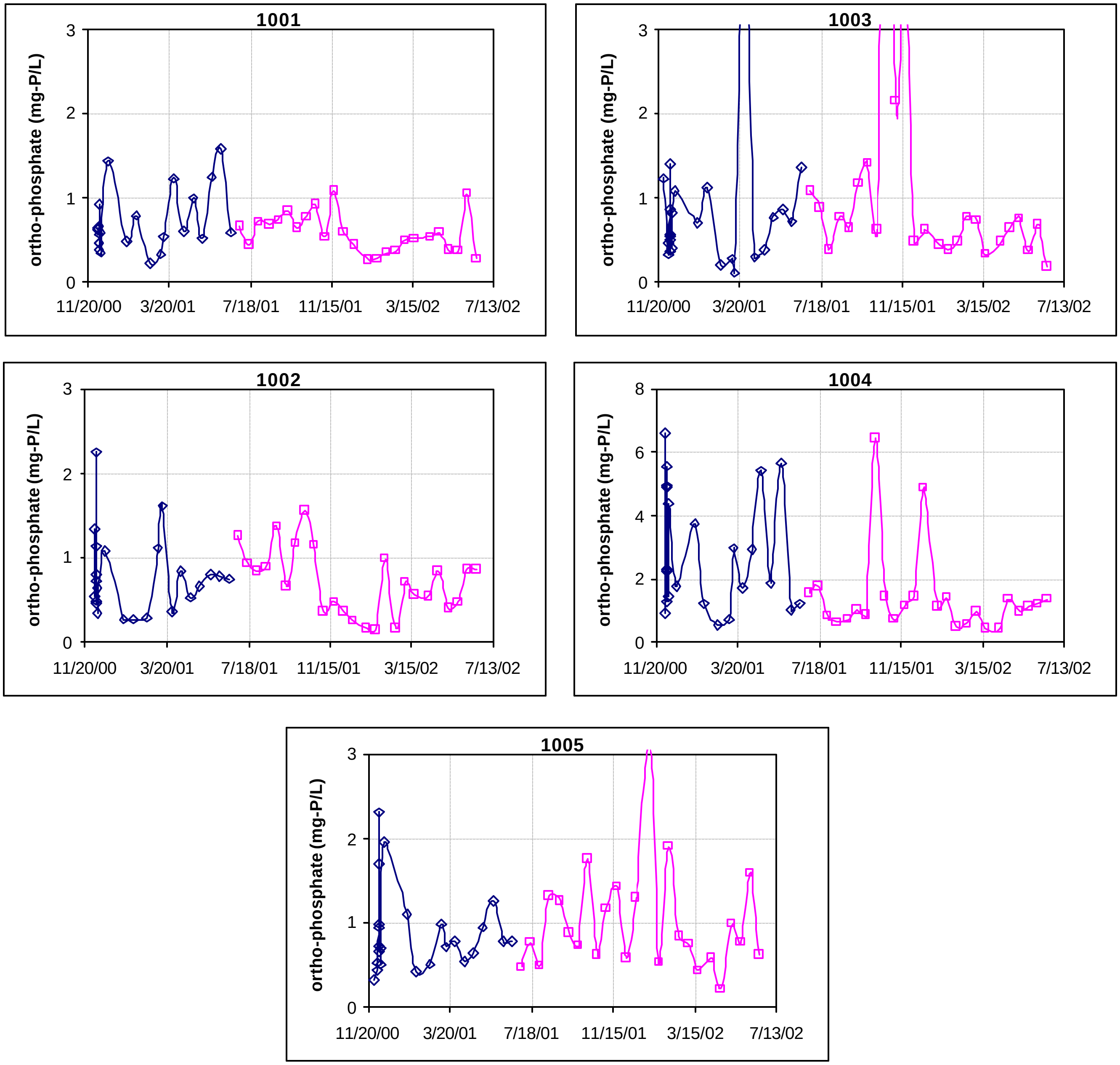


Figure A-4: Time Series of Ortho-Phosphate in Dry Weather Samples (all data)

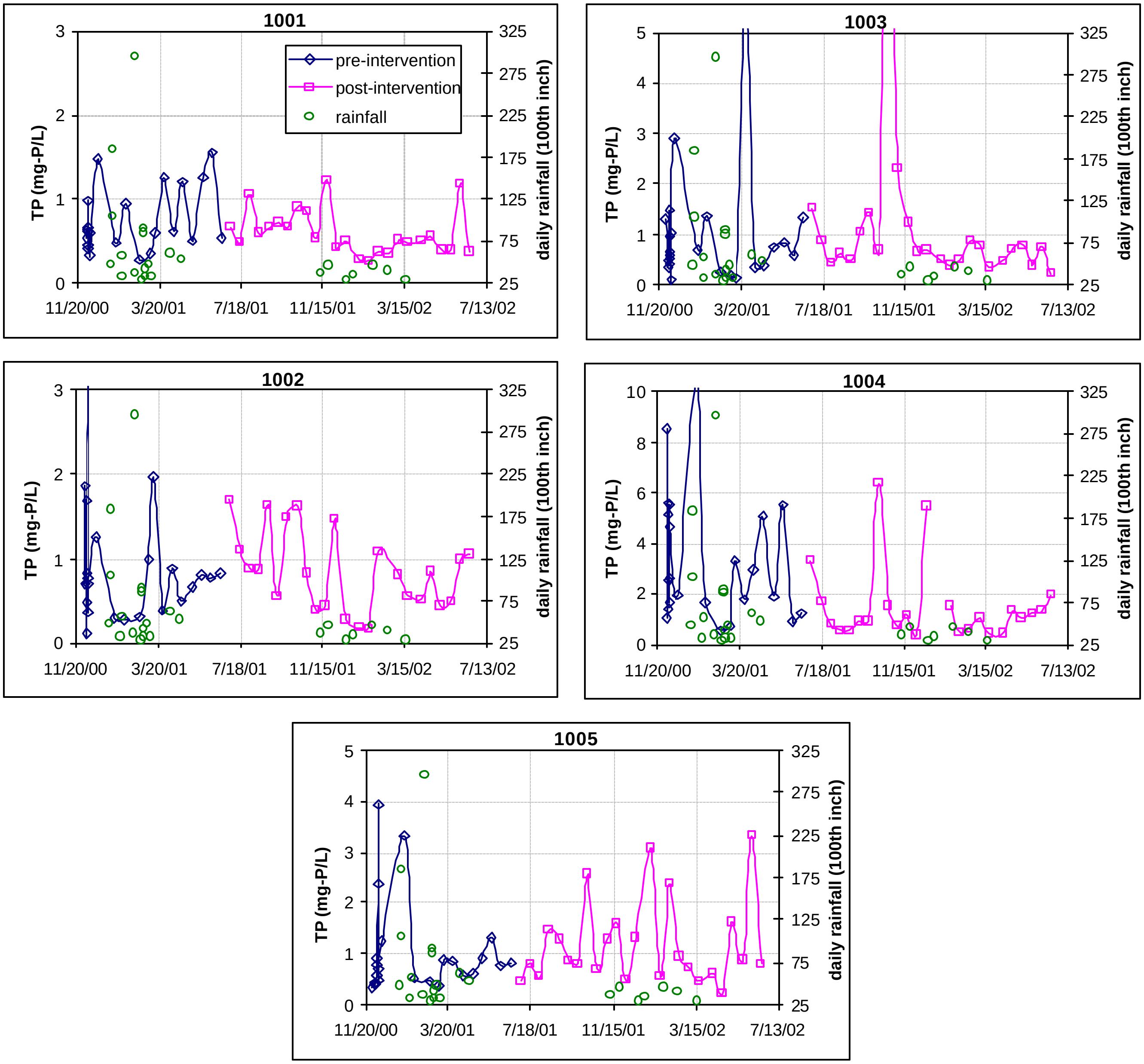


Figure A-5: Time Series of Total-Phosphorus in Dry Weather Samples (all data)

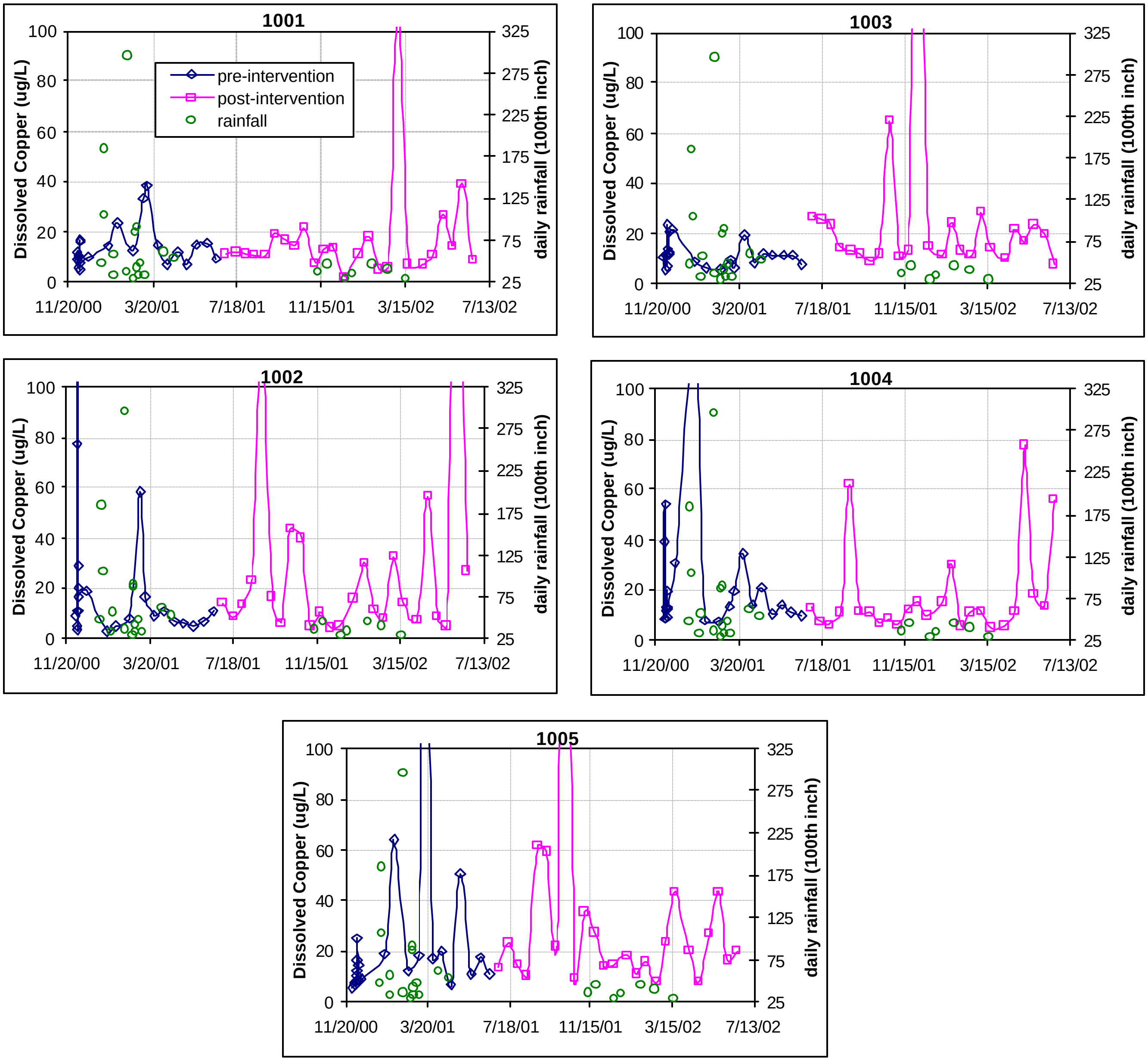


Figure A-6: Time Series of Dissolved Copper in Dry Weather Samples (all data)

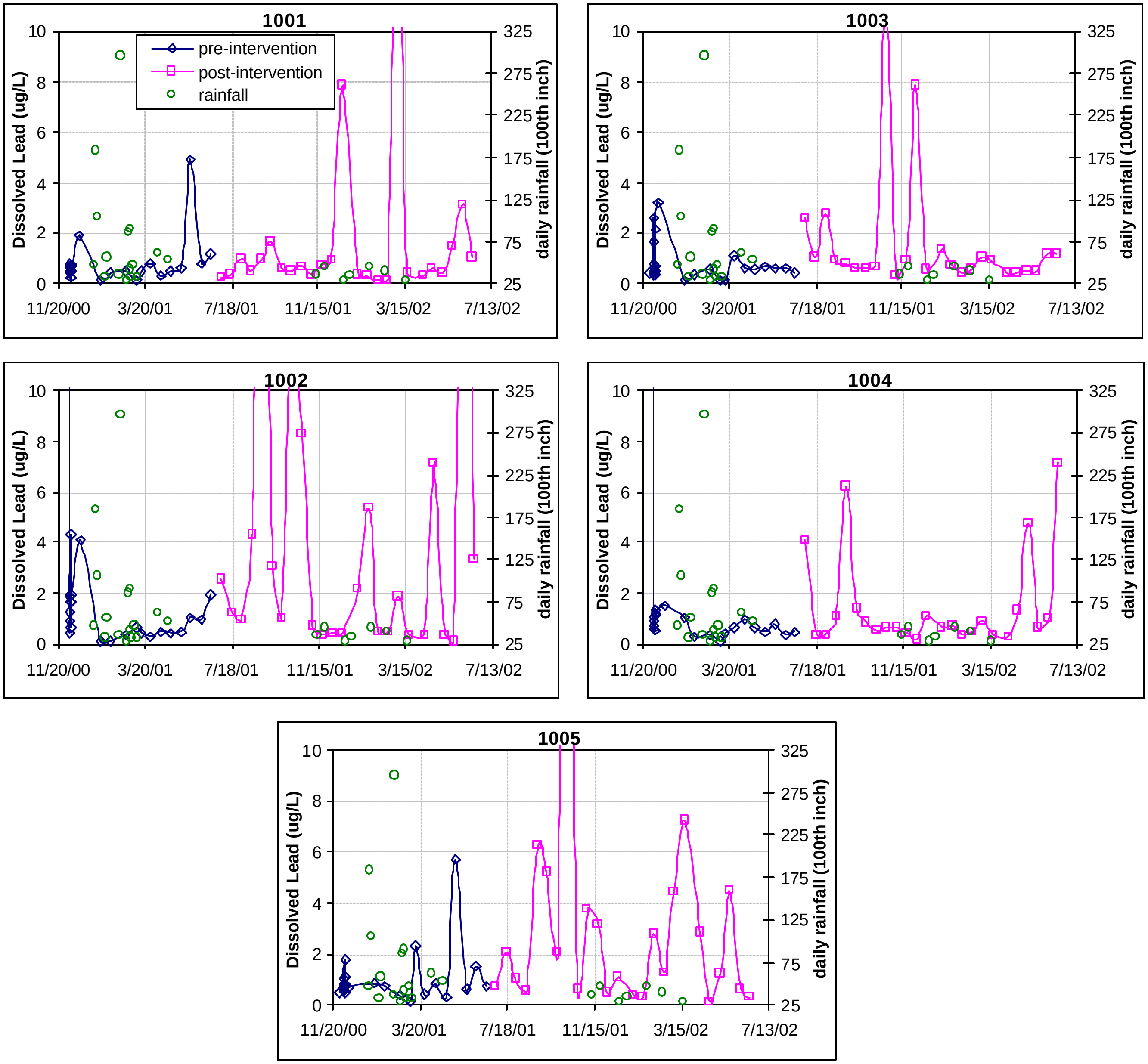


Figure A-7: Time Series of Dissolved Lead in Dry Weather Samples (all data)

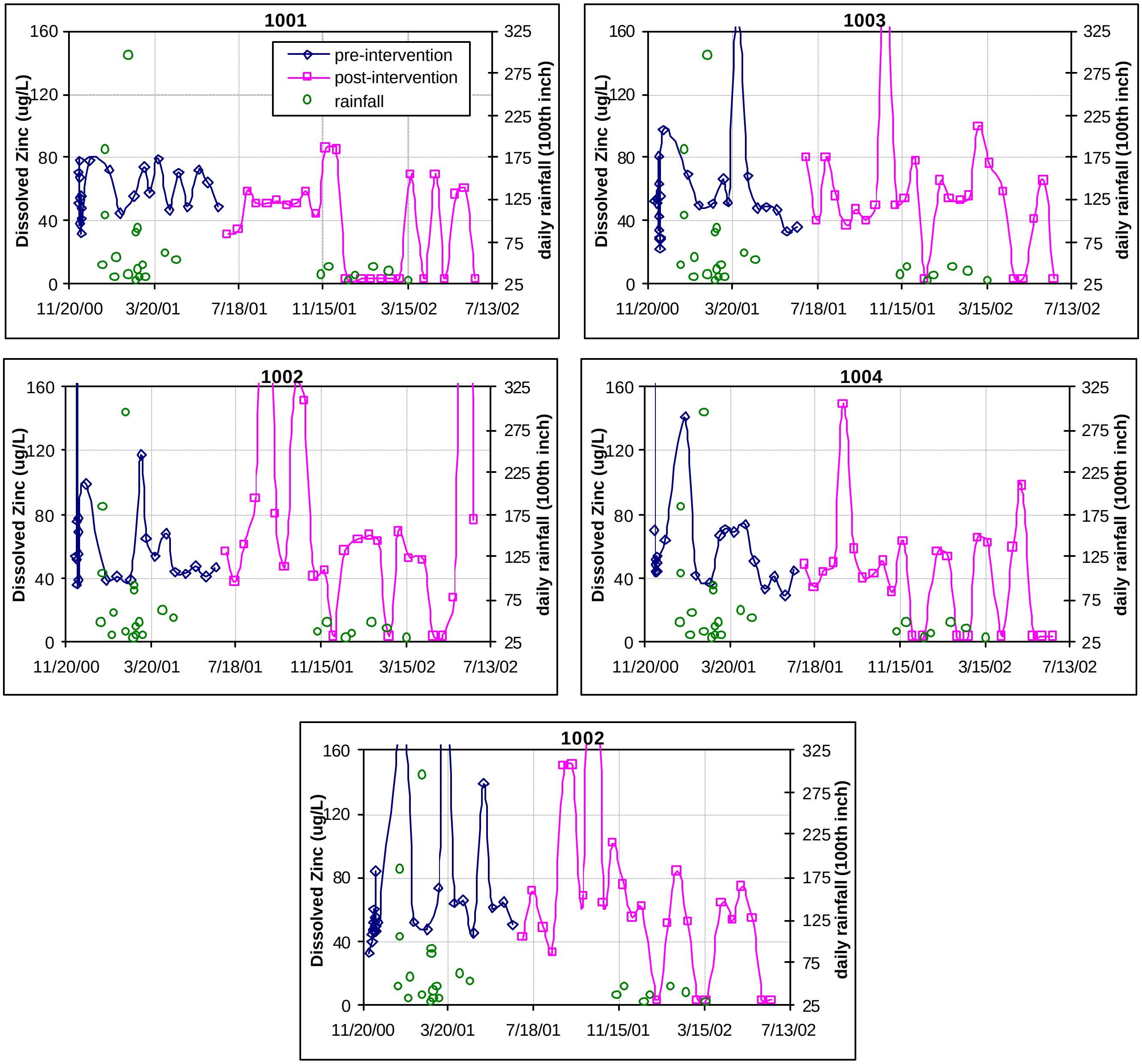
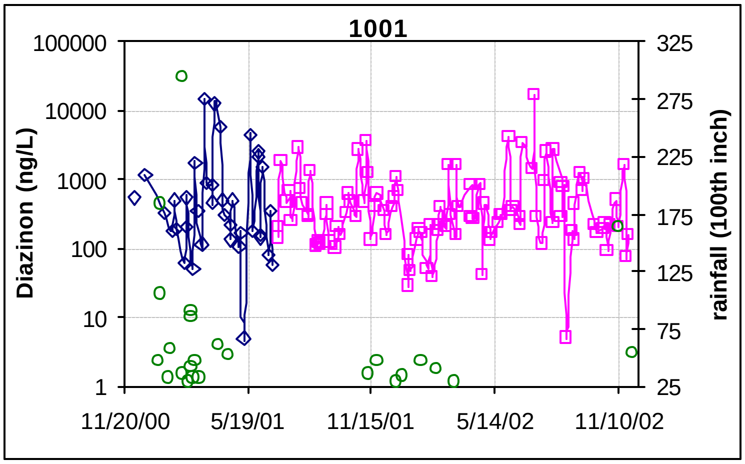
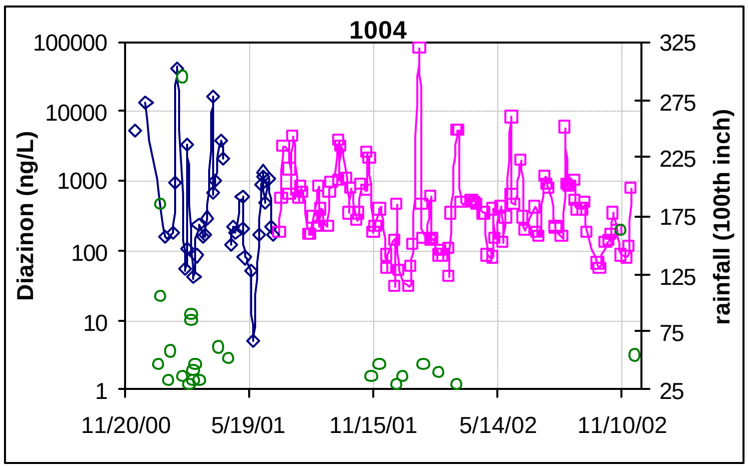


Figure A-8: Time Series of Dissolved Zinc in Dry Weather Samples (all data)





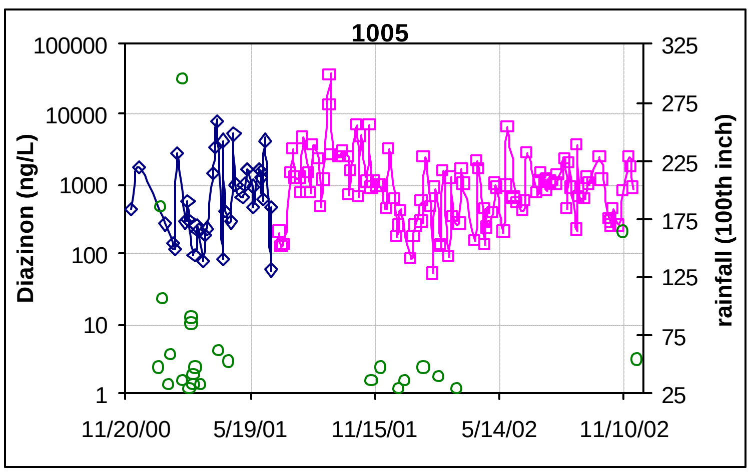


Figure A-9: Time Series of Diazinon in Dry Weather Samples (all data)

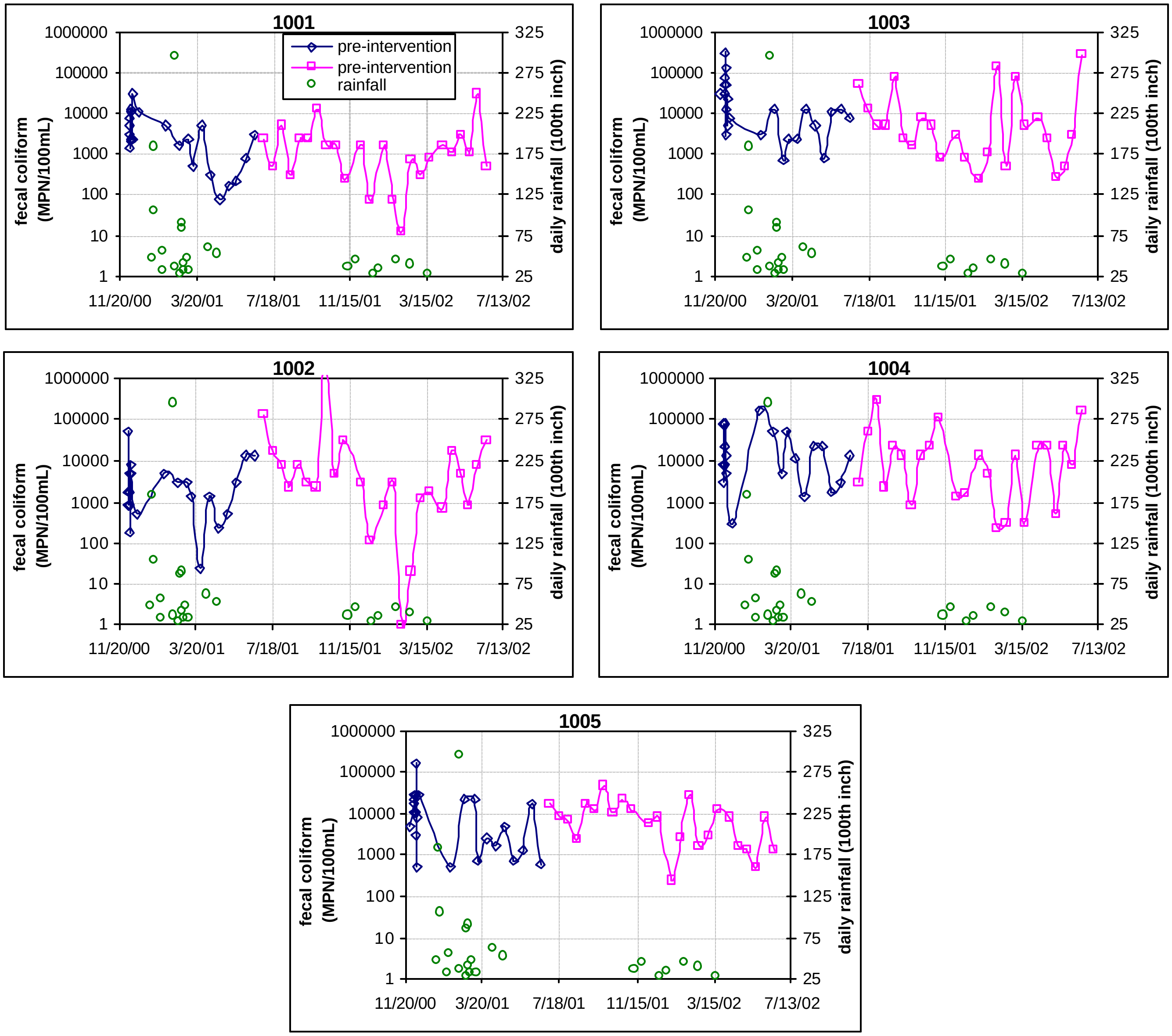


Figure A-10: Time Series of Fecal Coliform in Dry Weather Samples (all data)

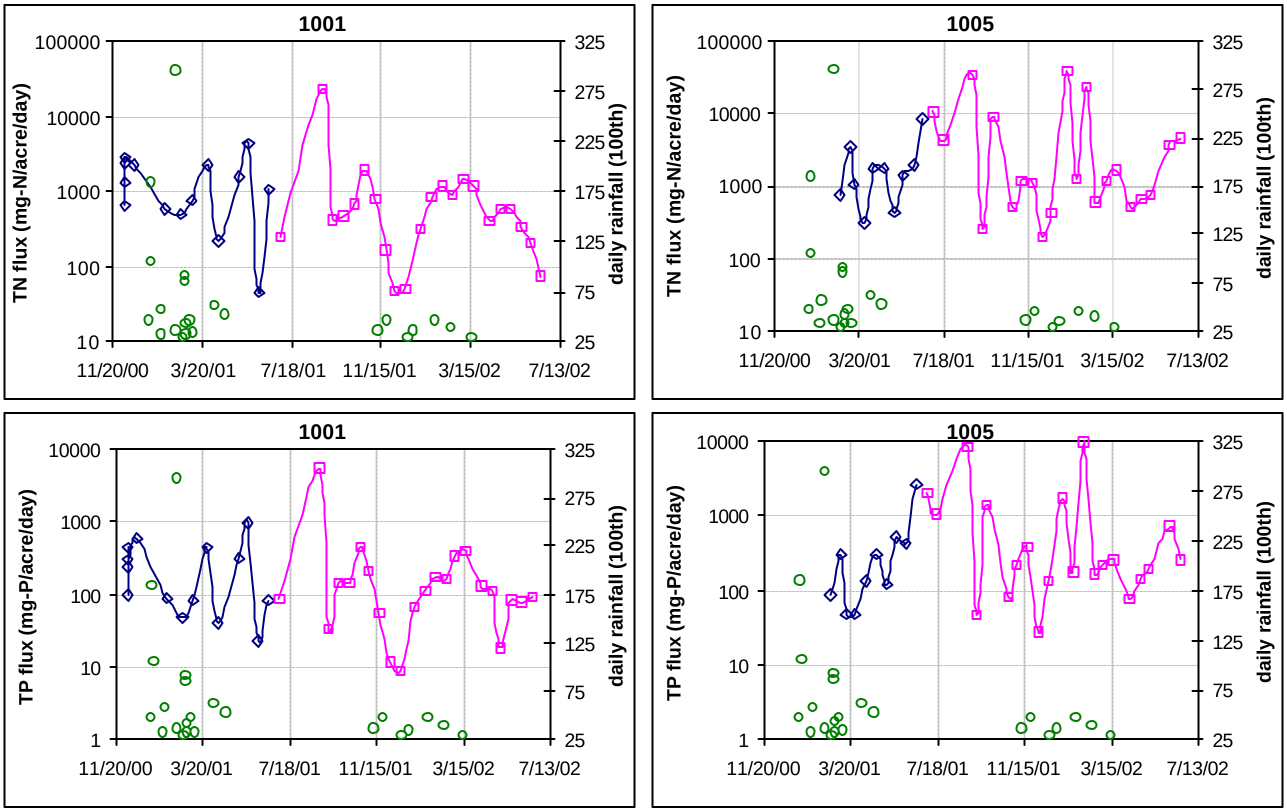


Figure A-11: Time Series of Nutrient Fluxes in Dry Weather Samples (all data)

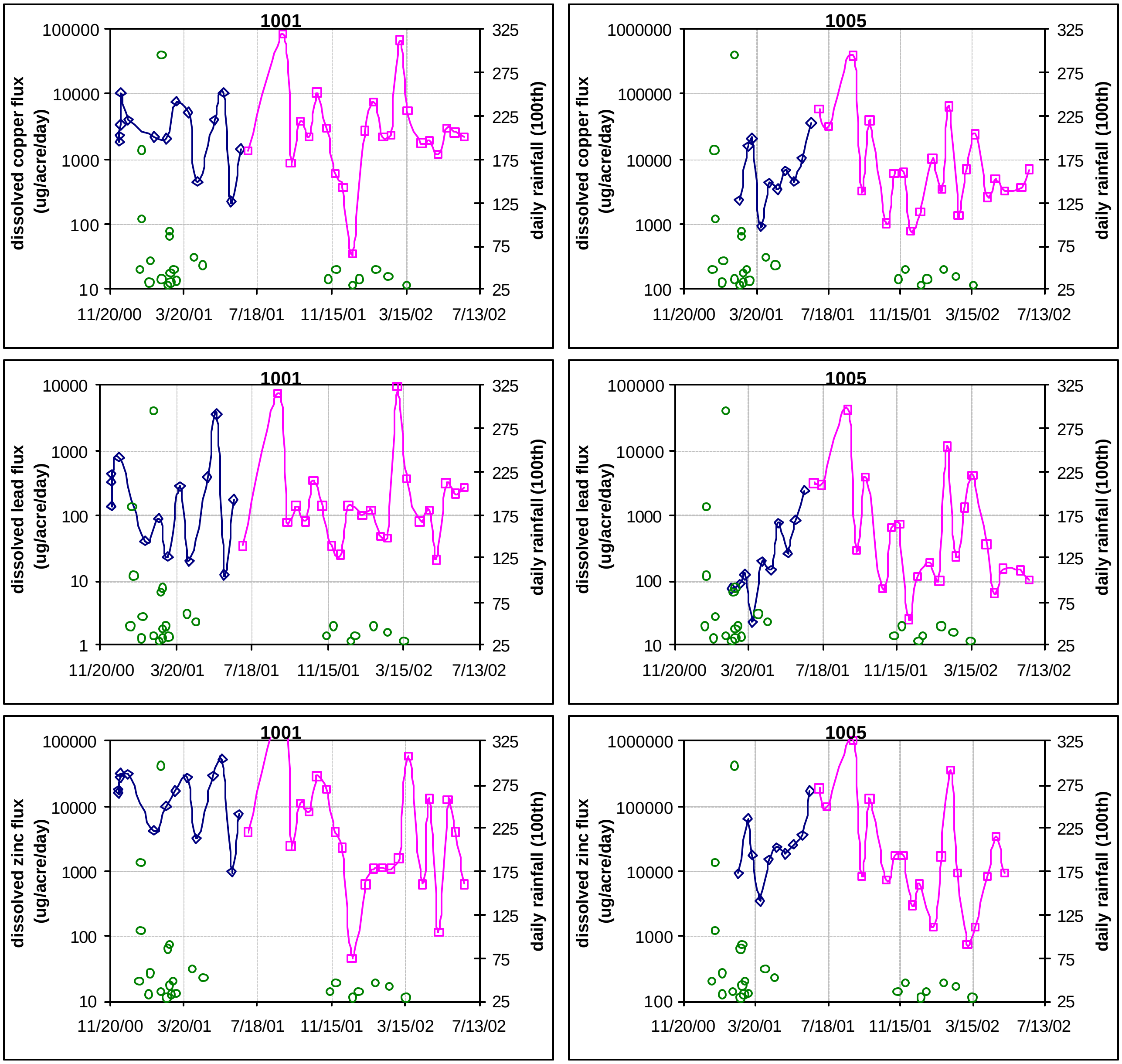


Figure A-12: Time Series of Dissolved Metal Fluxes in Dry Weather Samples (all data)

Appendix B – Summary Statistics

Table B-1: Descriptive Statistics

		1001		1002		1003		1004		1005	
Parameter	Statistic	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Nitrate/Nitrite as N	n	23	25	23	25	24	25	23	25	24	25
(mg-N/L)	% > MDL/RL	100%	96%	96%	96%	100%	100%	100%	100%	100%	100%
	Mean	2.56	1.47	2.57	1.07	2.13	1.71	36.50	6.61	2.61	4.13
	Median	2.32	1.38	1.56	0.93	1.68	0.94	16.88	2.29	2.45	1.48
	Trimmed mean	2.37	1.44	1.80	0.89	1.61	1.01	25.04	3.33	2.41	1.60
	min	0.74	0.05	0.05	0.05	0.65	0.20	1.70	0.60	0.54	0.73
	max	5.26	2.97	7.42	3.92	9.96	10.16	109.90	34.40	6.21	64.90
	25th percentile	1.81	1.05	0.82	0.53	0.98	0.64	5.62	1.43	1.79	0.96
	75th percentile	3.10	1.99	3.77	1.18	2.49	1.60	70.76	8.95	3.11	2.22
	St Dev	1.08	0.70	2.34	0.91	1.94	2.21	37.82	8.78	1.40	12.68
	IQR	1.29	0.94	2.95	0.65	1.51	0.96	65.14	7.52	1.32	1.26
	Skewness, gs	0.84	0.14	1.00	1.89	3.11	2.96	0.76	2.01	1.19	4.98
	gcr	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	symmetric?	Y	Y	N	N	N	N	Y	N	N	N
TKN	n	23	25	23	25	24	25	23	24	24	25
(mg-N/L)	% > MDL/RL	100%	64%	100%	84%	96%	92%	96%	92%	100%	96%
	Mean	1.68	1.63	2.74	2.37	1.97	2.71	11.50	3.72	4.08	3.61
	Median	1.27	1.21	1.78	1.90	1.38	1.46	4.26	1.91	2.23	2.39
	Trimmed mean	1.29	0.77	1.95	1.87	1.40	1.69	7.51	2.23	2.29	2.57
	min	0.88	0.25	0.68	0.25	0.25	0.25	1.44	0.25	0.76	0.25
	max	6.02	11.00	13.20	7.48	9.97	18.60	31.81	18.60	17.43	15.30
	25th percentile	1.13	0.25	1.33	1.13	1.01	1.20	2.55	1.41	1.88	1.71
	75th percentile	1.57	1.46	2.86	2.98	1.85	2.87	21.46	4.03	3.15	4.01
	St Dev	1.19	2.40	2.68	1.96	1.97	3.64	11.61	4.21	4.90	3.41
	IQR	0.44	1.21	1.53	1.85	0.84	1.67	18.90	2.62	1.26	2.30
	Skewness	2.84	3.16	3.00	1.23	3.24	3.77	0.75	2.31	2.29	2.34
	Gcr	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	symmetric?	N	N	N	N	N	N	Y	N	N	N
Ammonia as N	n	23	25	23	25	24	25	23	24	24	25

Parameter	Statistic	1001 Pre	1001 Post	1002 Pre	1002 Post	1003 Pre	1003 Post	1004 Pre	1004 Post	1005 Pre	1005 Post
(mg-N/L)	% > MDL/RL	30%	20%	74%	64%	75%	52%	87%	71%	92%	96%
	Mean	0.13	0.08	0.25	0.42	0.26	0.29	7.05	0.25	0.85	0.42
	Median	0.05	0.05	0.18	0.20	0.17	0.10	0.71	0.14	0.43	0.22
	Trimmed mean	0.05	0.05	0.19	0.13	0.19	0.11	3.43	0.12	0.50	0.24
	min	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	max	1.12	0.36	0.90	5.45	1.06	2.29	26.34	2.03	6.92	2.41
	25th percentile	0.05	0.05	0.08	0.05	0.09	0.05	0.24	0.05	0.24	0.15
	75th percentile	0.12	0.05	0.30	0.28	0.29	0.36	13.69	0.28	0.94	0.42
	St Dev	0.23	0.07	0.22	1.06	0.26	0.48	9.14	0.40	1.39	0.50
	IQR	0.07	0.00	0.22	0.23	0.20	0.31	13.45	0.23	0.70	0.27
	Skewness	4.04	3.08	1.66	4.78	1.98	3.40	0.93	4.09	3.95	3.01
	gcr	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	symmetric?	N	N	N	N	N	N	Y	N	N	N
TN (calculated)	n	23	25	23	25	23	25	23	25	23	25
(mg-N/L)	% > MDL/RL	100%	80%	98%	90%	98%	96%	98%	96%	100%	98%
	Mean	4.24	3.09	5.31	3.44	3.66	4.42	48.00	10.18	6.89	7.74
	Median	3.84	2.27	3.95	2.55	2.66	2.50	19.01	5.57	5.06	4.36
	Trimmed mean	3.94	2.40	4.53	2.76	2.93	3.01	33.11	6.47	5.08	4.42
	min	2.30	0.30	1.50	0.78	1.46	0.45	3.28	0.74	2.48	1.07
	max	6.76	12.99	13.83	11.40	12.12	19.91	141.06	40.80	20.41	67.12
	25th percentile	3.20	1.79	2.27	2.10	2.11	2.04	9.05	2.71	3.52	3.47
	75th percentile	5.68	3.13	8.02	4.36	4.81	5.17	94.79	19.18	7.07	5.62
	St Dev	1.41	2.67	3.56	2.51	2.48	4.39	49.17	10.73	5.29	12.85
	IQR	2.48	1.34	5.75	2.26	2.70	3.13	85.74	16.47	3.55	2.15
	Skewness	0.55	2.82	0.84	1.87	2.13	2.27	0.74	1.37	1.88	4.46
	gcr	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	symmetric?	Y	N	Y	N	N	N	Y	N	N	N
ortho-phosphate	n	23	25	23	25	24	25	23	25	24	25
(mg-P/L)	% > MDL/RL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Mean	0.71	0.58	0.79	0.72	0.81	1.26	2.84	1.40	0.89	1.00
	Median	0.58	0.53	0.73	0.72	0.64	0.64	2.23	1.10	0.76	0.77
	Trimmed mean	0.60	0.56	0.69	0.70	0.63	0.66	2.42	1.10	0.77	0.87
	min	0.23	0.26	0.28	0.15	0.11	0.19	0.52	0.43	0.33	0.22
	max	1.58	1.08	2.25	1.56	4.01	10.60	6.57	6.45	2.31	3.11
	25th percentile	0.47	0.38	0.48	0.41	0.38	0.47	1.25	0.75	0.55	0.59
	75th	0.86	0.72	0.96	0.93	0.92	0.89	4.63	1.42	0.98	1.29

Parameter	Statistic	1001 Pre	1001 Post	1002 Pre	1002 Post	1003 Pre	1003 Post	1004 Pre	1004 Post	1005 Pre	1005 Post
	percentile										
	St Dev	0.37	0.23	0.47	0.39	0.77	2.11	1.89	1.35	0.49	0.62
	IQR	0.39	0.34	0.48	0.52	0.54	0.42	3.38	0.67	0.44	0.70
	Skewness	1.13	0.60	1.55	0.32	3.27	4.03	0.60	3.03	1.66	1.79
	gcr	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	symmetric?	N	Y	N	Y	N	N	Y	N	N	N
TP (mg-P/L)	n	23	25	23	25	24	25	23	24	24	25
	% > MDL/RL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Mean	0.73	0.60	0.92	0.84	0.98	1.21	3.33	1.50	1.01	1.19
	Median	0.60	0.51	0.77	0.82	0.62	0.67	2.54	1.05	0.73	0.85
	Trimmed mean	0.61	0.53	0.72	0.77	0.65	0.68	2.73	1.06	0.72	0.95
	min	0.27	0.26	0.11	0.16	0.11	0.23	0.53	0.34	0.33	0.22
	max	1.55	1.22	3.65	1.69	6.18	11.70	10.37	6.38	3.92	3.32
	25th percentile	0.47	0.39	0.43	0.49	0.35	0.49	1.52	0.60	0.50	0.60
	75th percentile	0.97	0.67	0.94	1.08	1.08	0.87	5.11	1.55	0.91	1.46
	St Dev	0.38	0.27	0.77	0.47	1.26	2.23	2.58	1.51	0.92	0.83
	IQR	0.50	0.28	0.51	0.59	0.73	0.38	3.59	0.96	0.40	0.86
	Skewness	1.00	1.07	2.27	0.49	3.39	4.68	1.26	2.41	2.35	1.38
	gcr	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	symmetric?	N	N	N	Y	N	N	N	N	N	N
Cadmium (ug/L)	n	23	25	23	25	24	25	23	25	24	25
	% > MDL/RL	61%	12%	61%	36%	38%	16%	74%	36%	38%	44%
	Mean	0.26	0.14	0.47	0.44	0.27	0.17	0.64	0.22	0.21	0.29
	Median	0.27	0.10	0.24	0.10	0.10	0.10	0.36	0.10	0.10	0.10
	Trimmed mean	0.20	0.10	0.20	0.12	0.12	0.10	0.33	0.12	0.12	0.15
	min	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	max	0.56	0.79	3.40	3.50	1.77	0.92	4.54	1.22	0.92	1.89
	25th percentile	0.10	0.10	0.10	0.10	0.10	0.10	0.16	0.10	0.10	0.10
	75th percentile	0.39	0.10	0.40	0.26	0.26	0.10	0.42	0.23	0.25	0.45
	St Dev	0.15	0.15	0.78	0.79	0.37	0.20	1.15	0.25	0.20	0.37
	IQR	0.29	0.00	0.30	0.16	0.16	0.00	0.27	0.13	0.15	0.35
	Skewness	0.29	4.04	3.21	3.06	3.37	3.08	3.09	3.05	2.56	3.47
	gcr	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	symmetric?	Y	N	N	N	N	N	N	N	N	N
Copper (ug/L)	n	23	25	23	25	24	25	23	25	24	25
	% > MDL/RL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Mean	13.5	16.9	27.3	30.3	11.5	26.6	21.8	17.7	32.1	30.8
	Median	11.5	11.4	10.9	14.0	11.1	14.3	12.7	11.4	12.3	20.4

Parameter	Statistic	1001 Pre	1001 Post	1002 Pre	1002 Post	1003 Pre	1003 Post	1004 Pre	1004 Post	1005 Pre	1005 Post
	Trimmed mean	11.6	12.1	10.7	15.4	10.7	16.2	13.9	11.3	13.2	19.8
	min	5.2	1.9	3.2	4.6	5.6	7.2	7.3	5.1	5.4	7.9
	max	38.4	108.0	278.4	226.6	23.4	227.0	119.3	77.4	389.6	210.0
	25th percentile	8.4	8.8	6.2	8.0	8.0	11.6	10.0	7.5	8.7	14.2
	75th percentile	15.0	16.9	17.9	29.8	12.3	23.4	20.5	15.2	18.6	27.5
	St Dev	8.3	20.5	57.5	48.2	5.1	43.3	24.2	18.9	77.4	40.2
	IQR	6.7	8.1	11.8	21.8	4.2	11.8	10.5	7.7	9.9	13.3
	Skewness	1.9	4.0	4.1	3.3	1.1	4.5	3.3	2.3	4.7	4.0
	gcr	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	symmetric?	N	N	N	N	N	N	N	N	N	N
Lead	n	23	25	23	25	24	25	23	25	24	25
(ug/L)	% > MDL/RL	91%	92%	91%	96%	88%	100%	96%	100%	96%	96%
	Mean	0.79	1.59	5.93	4.72	0.82	1.59	3.47	1.47	1.01	3.24
	Median	0.60	0.60	0.89	1.20	0.59	0.81	0.72	0.69	0.74	1.30
	Trimmed mean	0.57	0.62	0.94	1.65	0.56	0.81	0.77	0.76	0.72	1.79
	min	0.10	0.10	0.10	0.10	0.10	0.28	0.10	0.21	0.10	0.10
	max	4.91	14.90	81.70	30.87	3.19	10.90	37.74	7.16	5.70	28.10
	25th percentile	0.46	0.38	0.41	0.40	0.42	0.53	0.48	0.44	0.52	0.62
	75th percentile	0.74	0.97	1.91	4.30	0.71	1.14	1.13	1.09	0.92	3.77
	St Dev	0.97	3.18	17.63	8.10	0.79	2.46	9.19	1.91	1.11	5.56
	IQR	0.28	0.59	1.50	3.90	0.29	0.61	0.65	0.65	0.40	3.15
	Skewness	3.81	3.63	4.06	2.58	1.95	3.16	3.32	2.14	3.62	4.02
	gcr	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92
	symmetric?	N	N	N	N	N	N	N	N	N	N
Zinc	n	23	25	23	25	24	25	23	25	24	25
(ug/L)	% > MDL/RL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Mean	58.7	37.2	115.2	86.3	56.3	56.8	83.6	40.9	74.0	75.0
	Median	56.0	50.2	53.4	57.2	50.7	53.9	50.8	43.8	52.4	54.5
	Trimmed mean	58.6	26.4	54.2	57.6	51.2	53.1	53.2	27.7	54.5	58.3
	min	32.5	2.5	35.4	2.5	22.1	2.5	29.5	2.5	32.3	2.5
	max	79.2	86.2	1069.7	429.6	171.0	231.0	429.0	149.0	330.0	512.0
	25th percentile	48.1	2.5	41.7	40.4	40.9	40.2	43.3	2.5	46.9	42.8
	75th percentile	71.4	58.2	72.1	76.9	63.9	65.5	69.0	58.6	64.6	74.5
	St Dev	14.1	29.1	219.7	109.1	29.9	44.4	97.0	35.1	63.0	99.1
	IQR	23.2	55.7	30.4	36.5	23.0	25.3	25.7	56.1	17.7	31.7
	Skewness	-0.1	-0.1	4.1	2.6	2.6	2.4	3.0	1.1	3.4	3.8
	gcr	0.96	0.92	0.96	0.92	0.94	0.92	0.96	0.92	0.94	0.92

Parameter	Statistic	1001		1002		1003		1004		1005	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	symmetric?	Y	Y	N	N	N	N	N	N	N	N
Diazinon	**n**	37	104					36	104	39	104
(ng/L)	**% > MDL/RL**	97%	99%					97%	100%	100%	100%
	Mean	1457	748					2694	1556	1295	1711
	Median	345	291					231	346	614	884
	Trimmed mean	420	352					442	369	783	902
	min	5	5					5	29	60	53
	max	14465	16590					41402	80969	7910	34838
	25th percentile	156.8	166.6					157.6	150.2	262.8	415.8
	75th percentile	890.4	641.6					1119.2	791.3	1601.5	1609.8
	St Dev	3140.5	1753.2					7505.6	7977.2	1655.4	3741.7
	IQR	733.6	475.0					961.6	641.1	1338.7	1194.0
	Skewness	3.4	7.5					4.4	9.8	2.3	7.2
	gcr	0.77	0.47					0.78	0.47	0.75	0.47
	symmetric?	N	N					N	N	N	N
Chlorpyrifos	**n**	37	104								
(ng/L)	**% > MDL/RL**	57%	40%								
	Mean	38.3	456.4								
	Median	25.0	10.0								
	Trimmed mean	18.9	10.0								
	min	5.0	5.0								
	max	213.7	45094.0								
	25th percentile	10.0	5.0								
	75th percentile	42.2	28.7								
	St Dev	51.1	4419.7								
	IQR	32.2	23.7								
	Skewness	2.5	10.2								
	gcr	0.77	0.47								
	symmetric?	N	N								

Appendix C – Probability Plot Comparisons

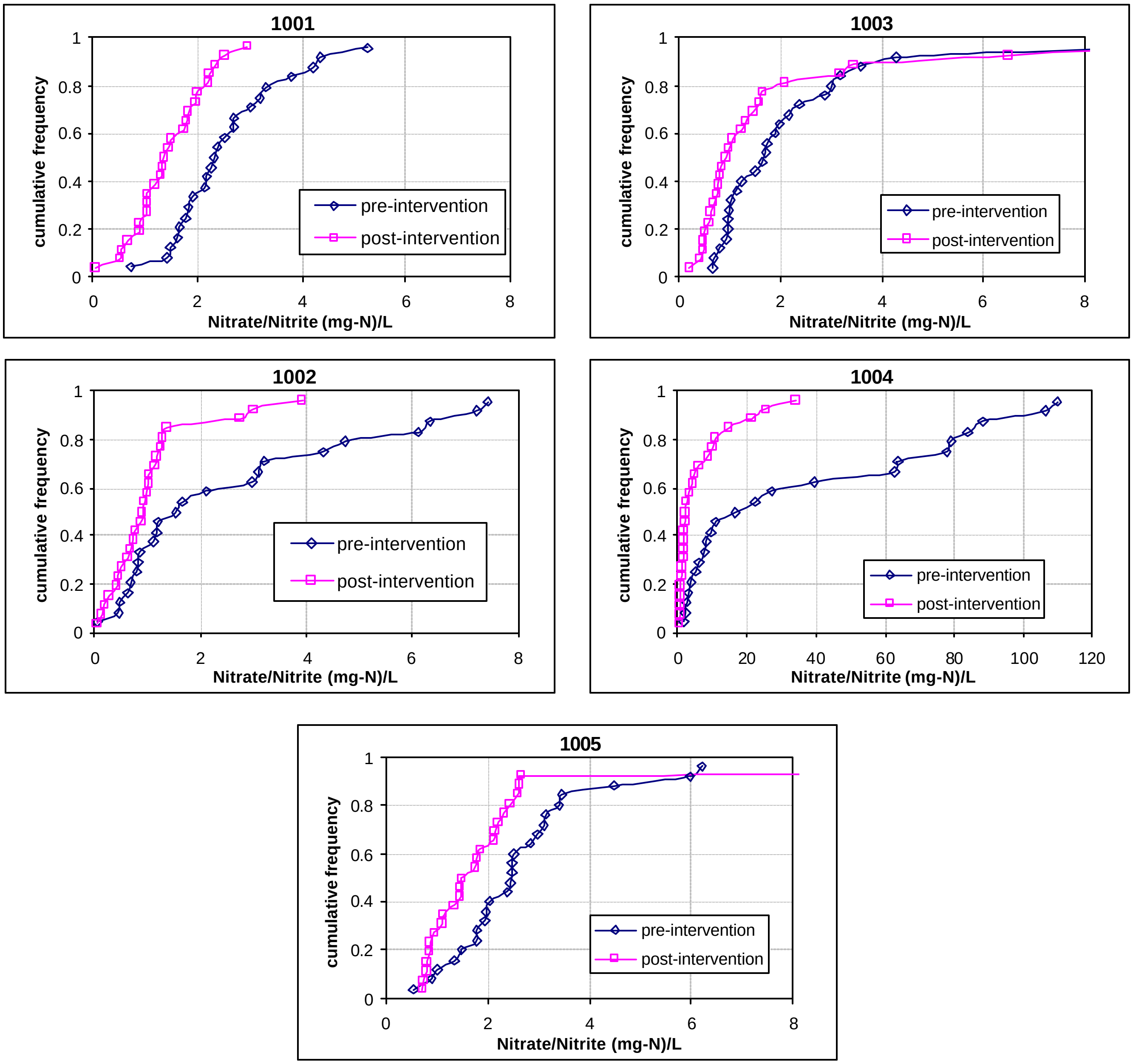


Figure C-1: Cumulative Frequency of Nitrate/Nitrite in Dry Weather Samples (all data)

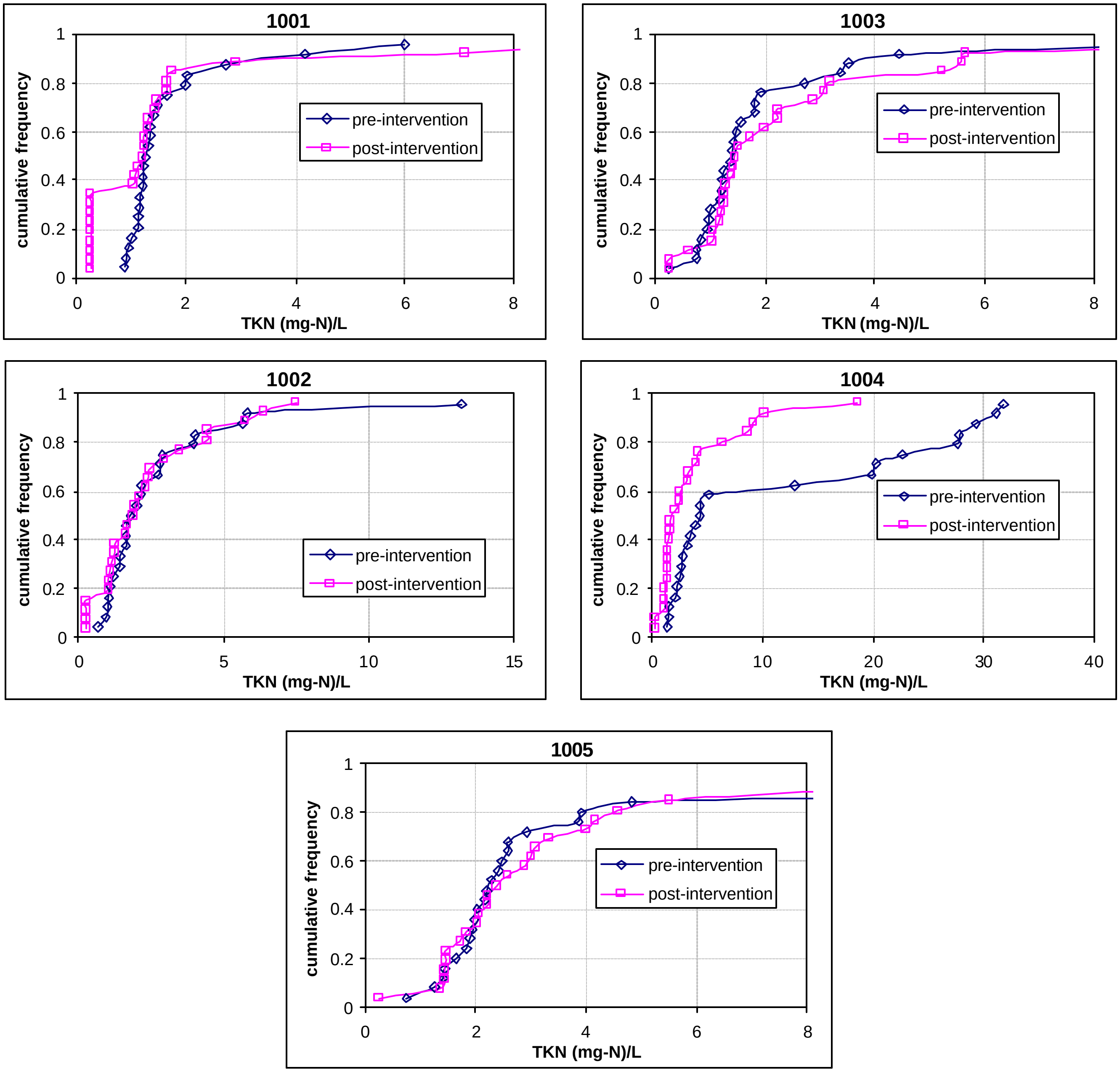


Figure C-2: Cumulative Distribution of TKN in Dry Weather Samples (all data)

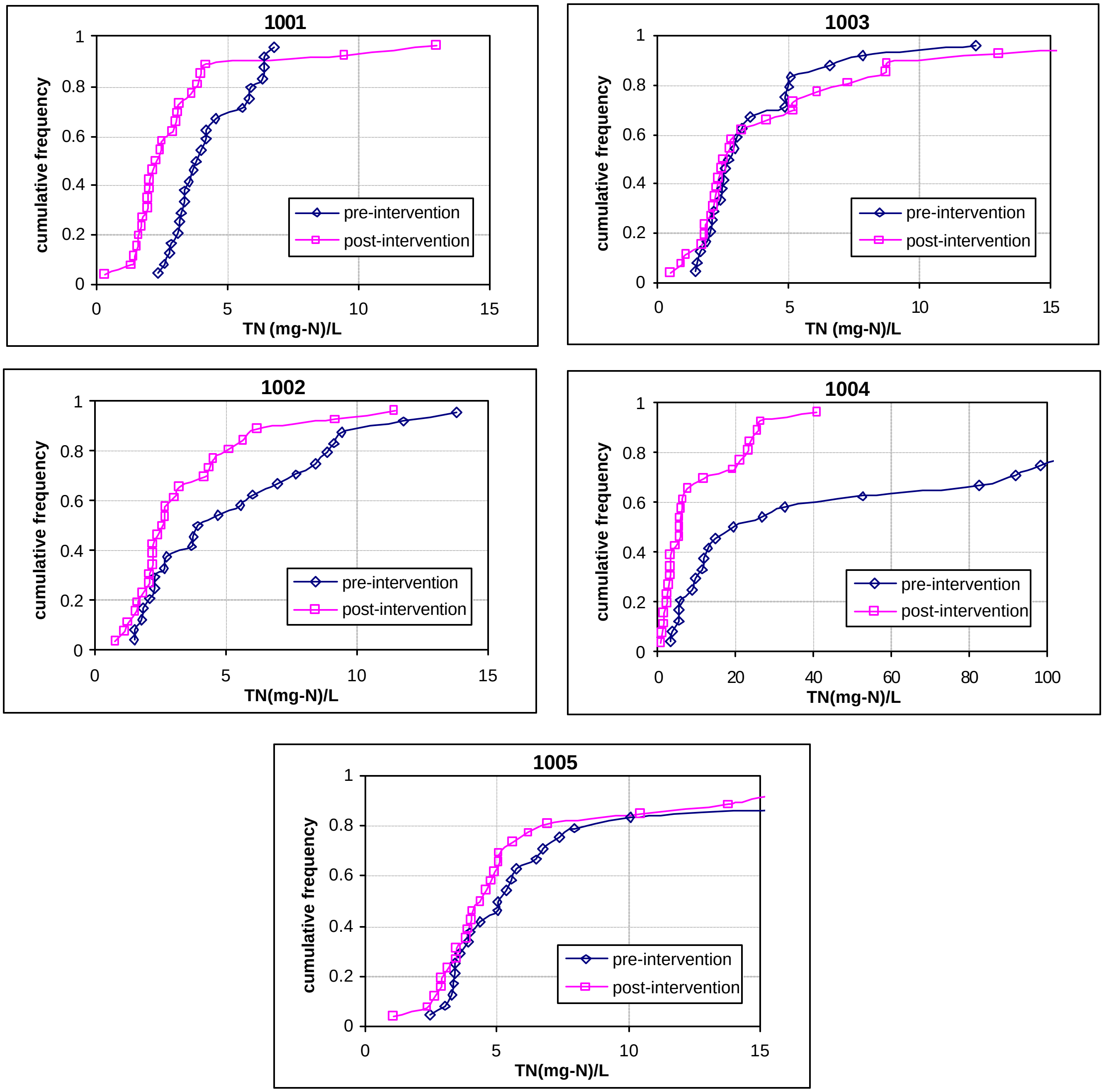


Figure C-3: Cumulative Distribution of TN (Calculated) in Dry Weather Samples (all data)

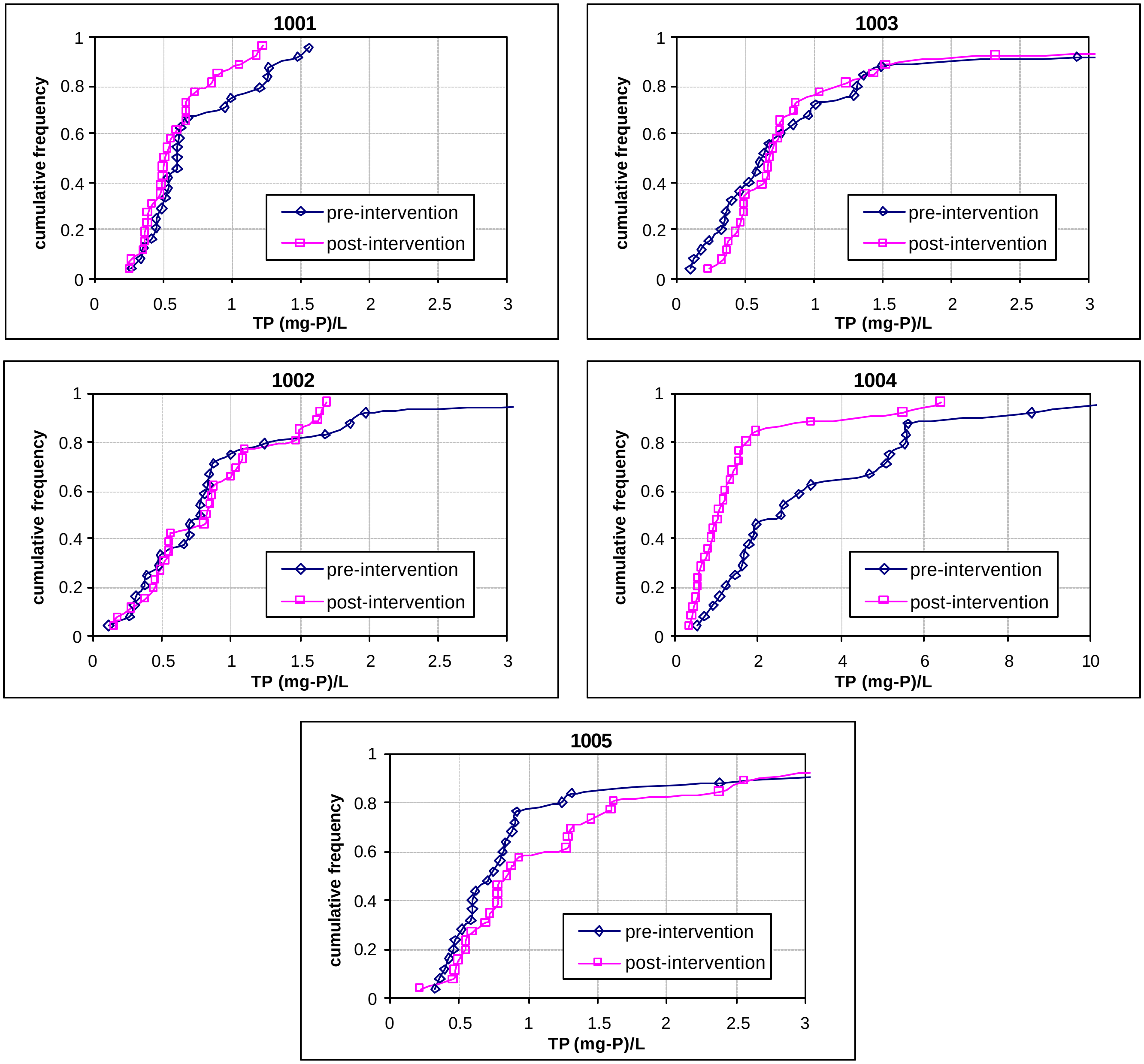


Figure C-4: Cumulative Distribution of TP in Dry Weather Samples (all data)

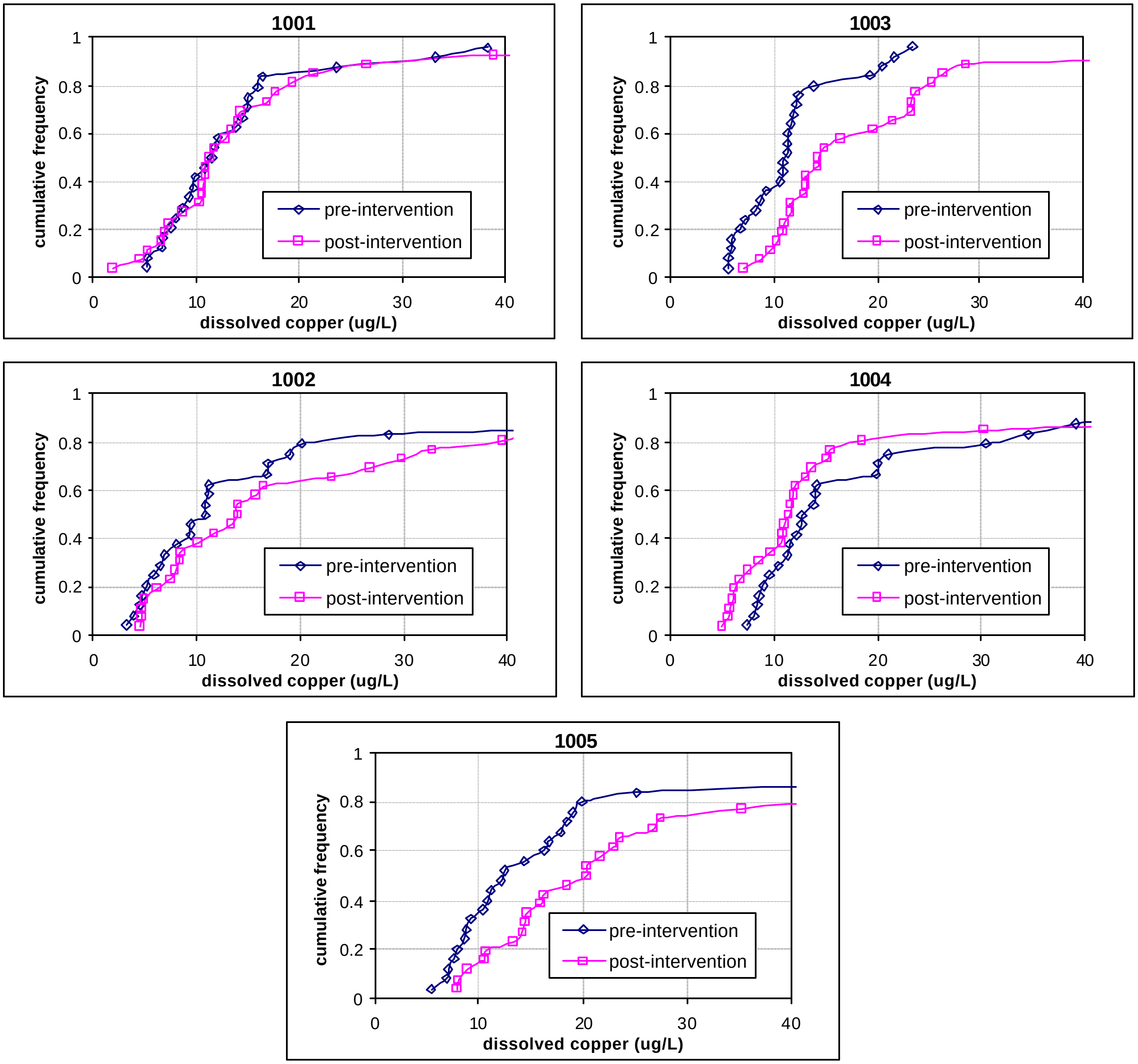


Figure C-5: Cumulative Distribution of Dissolved Copper in Dry Weather Samples (all data)

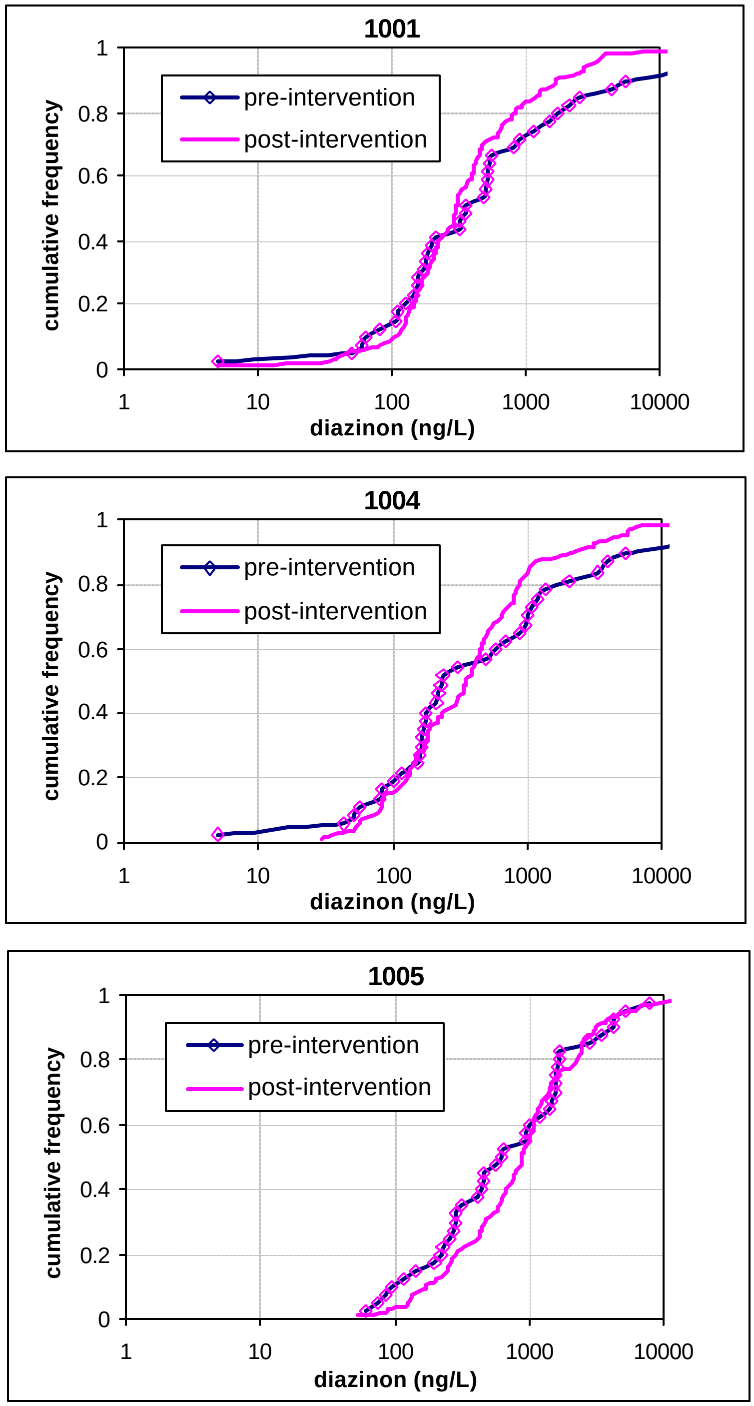


Figure C-6: Cumulative Distribution of Diazinon in Dry Weather Samples (all data)

Appendix F: Public Acceptance

The Residential Runoff Reduction Study

Appendix F: Public Acceptance

This appendix is divided into two parts. The first section describes the customer service program during the R3 Study time period and includes results of pre- and post-intervention surveys. The second part provides a representative sampling of public education materials distributed during the study. There were three groups of R3 study participants. The first group was the education group and the second group was the participants who had their home irrigation controllers replaced with an ET controller and lastly the control groups that received no treatment. The education group was self and randomly selected. Some of the education group participants voluntarily choose to participate in the study by replying to a letter. However, the majority of the education group was randomly selected through a door-to door campaign. The retrofit participants were selected through random "cold knocking" and through letter solicitations that explained the study.

Customer Interactions

ET Controller Installation Overview

ET Controllers were installed in two phases. The first phase was the installation of controllers at residences. The controllers were installed on the weekends between April and June 2001. The second phase of the installation process was the retrofit of City of Irvine and HOA sites. The retrofitted HOA sites watered the common areas of condominium and the City of Irvine sites watered the medians and streetscapes. Both of these two groups were all in the same watershed as the residential homes that were retrofitted. Initially, the time per installation was approximately one to one and one-half hours, depending on the number of valves. However, as

the IRWD staff became familiar with the process, which most had never done before, the time dropped to approximately one-half hour.

Residential post-installation concerns and problems

Home residents were advised that if they had any problems with the controller or if the controller required any adjustments, they should call the water district for assistance. IRWD's customer service department telephone number was left on the ET controller on a sticker. All calls related to the ET controller were logged in separately and routed to the appropriate staff member for assistance. Table 1 presents a summary of calls received from residential residents during the R3 study period. Generally, there were four common types of calls: 1) customer misunderstanding ("no problem" category), 2) installation-related issues, 3) system flaws, and 4) ET controller malfunctions.

Table 1: Telephone Log Summary

April 2001	1	August 2001	13	December 2001	1	April 2002	2
May 2001	12	September 2001	4	January 2002	4	May 2002	3
June 2001	7	October 2001	5	February 2002	9	June 2002	6
July 2001	13	November 2001	3	March 2002	4	July 2002	2

The first type were calls where the customer had a misunderstanding on the way the ET controllers were supposed to operate. In this type of call there was a "problem, where no problem actually existed". A common example was when a resident called to say that the sprinklers were not turning on every night. The staff member would then explain to the resident that with proper irrigation management it is normal if the irrigation sprinklers do not turn on every night.

The second types of calls received were either related to programming or installation-related mistakes. These usually occurred when the installation staff entered an incorrect value in the programming process. In other cases, a landscape contractor for the City of Irvine or HOA sites had incorrectly programmed the controller. Both groups were instructed at the beginning of the study to call IRWD to meet with a staff member who would adjust the ET controller for them.

The third category of calls included problems that were a result of a lack of irrigation system maintenance or a flaw in the design of the system. These problems were the responsibility of the homeowner to fix and were not related to the actual malfunctioning of the ET controller. For example, a customer called customer service and said that his lawn was turning brown because it was not being watered correctly. A site visit by staff would discover that the controller was set correctly, but the problem was that overgrown plant material was interfering with the normal spray pattern of the nozzle. It was this obstruction by plant material that caused the brown spot and not the settings on the ET controller.

The fourth category of calls was related to the ET controller malfunctioning. The calls from study participants were that the controller had stopped responding and the display was frozen, incorrect date or time display, or a signal dropout caused by a faulty program version. If resetting the unit or resending the ET signal could not correct the problem, the ET controllers were often changed out with a new controller with the latest version of the program. City of Irvine and HOA controllers with older versions of the controller were upgraded by uploading a new version of the program from a device provided by the manufacturer.

Tracking of Water Consumption of the City of Irvine and HOA Sites

In addition to responding to CSR calls, weekly meter reads were incorporated into the study as part of irrigation water management in order to monitor each site for excessive water usage. One ET controller installed for selected City of Irvine street landscapes was able to cover a larger area than the same controller installed in a residence. In addition, each of the City of Irvine retrofit sites had dedicated landscape irrigation water. Because of this, it was easier to track weekly water consumption of 18 meters instead of monitoring 112 residential meters. Weekly meter reads was a convenient way for staff to monitor water usage and to evaluate the performance of the ET controllers. Study staff periodically met with City of Irvine landscape staff to discuss the condition of the landscape and to discuss any other concerns. The landscape supervisor said that the appearance of the landscapes with the ET controllers were equal to similar city sites that did not have the ET controller.

One of the advantages of the ET controller is that it was able to receive a new ET signal if there was an unexpected change in weather conditions after a weekly signal had already been sent out. The controllers were grouped by water district zone, ET zone, and Zip code. Changes in weather conditions warranted staff to either increase the ETo or decrease the ET_o. During the rainy weeks, a signal would be sent to the all of the controllers that would pause the watering schedule for the appropriate number of days, this was referred to as a “rain pause signal”. Additionally, the controllers had a feature that allowed each valve to be micro-managed without having to adjust the entire watering schedule.

City of Irvine and Home Owner Associations

There are numerous benefits that can result from the installation of the ET controllers in a City environment as a water management tool. Costs that are associated with maintaining a city streetscape are labor hours and equipment. During the rainy season, city staff shuts off irrigation controllers for a given number of days that is determined by the amount of rainfall. This process is completed by manually having a city employee drive to each controller and turn the controllers off. This can be a very time intensive activity. In comparison the ET controllers are able to receive a rain pause signal and all the controllers in an area can be turned off within minutes. Hence, the ET controller can provide potential savings in labor and equipment required for programming each individual controller. It eliminates the guesswork as to whether or not to turn off the controllers. This savings in time and labor can be very substantial when the system needs to be shut down and then turned back on due to rain. With this system the city can allocate their resources more efficiently by focusing on landscape system maintenance instead of spending time on those tasks that can be performed with the ET controller technology. In addition, city staff will be able to cover a larger area. The water management features of the technology can maintain healthy landscapes and can help the city avoid penalty charges.

City and HOA controllers could be installed during regular business hours and no overtime was required for staff. These two groups were flexible about the installation times. In future programs or implementation of this technology it may be possible to train the local landscaper or contractor to install and monitor the controller. Monitoring the controller includes inspections of the irrigated area and meter reads. The local landscapers are probably the most familiar with irrigation controllers and could be cost effective to have them install the ET controller.

Customer Surveys

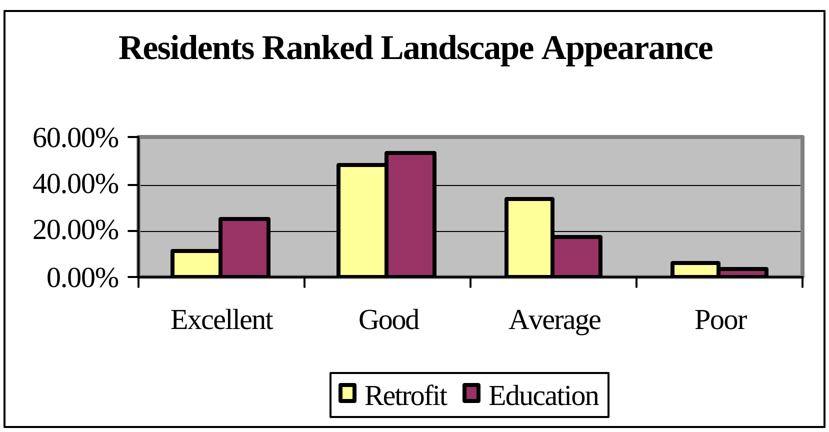
Pre-Survey Goal

The purpose of the pre-survey was to determine if the retrofit group and the education had similar irrigation practices and attitudes.

Survey Distribution

The pre-survey was distributed to the retrofit group while installation of the controller was taking place. Retrofit study participants were asked to fill-out the survey while staff was installing the controller. The education group received their survey as part of the initial educational packet that was randomly distributed to residents. Education group participants were provided a stamped addressed envelope to return their survey to the Irvine Ranch Water District. Ninety-seven (109/112) percent of those that received a survey from the retrofit group mailed the survey back. Twenty-four percent (53/225) of residents in the education group mailed back a survey.

Figure 1: Landscape Appearance



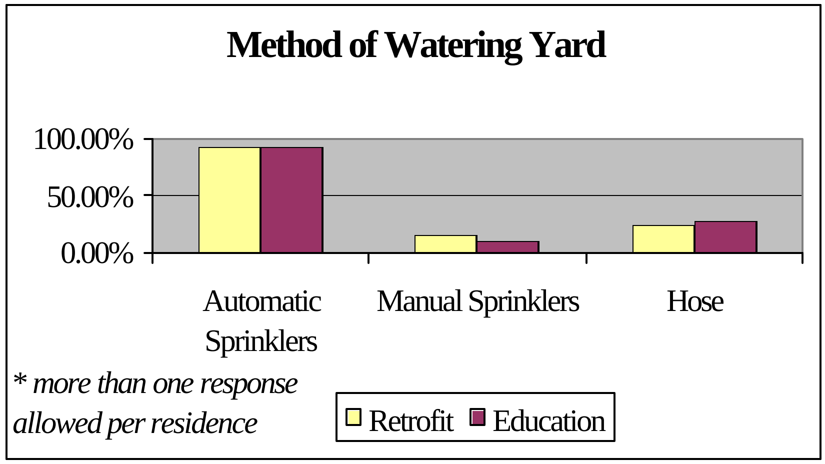
Selected Responses

A look at Figure 1 to the right shows the responses of both of the groups. Both groups gave similar responses. A majority of the residents in both groups believe that the appearance of the yard is average to good. Notice that the "excellent" response was selected by more of the education group that the retrofit group. One possible explanation for

this response is that the staff was on-site while people were filling out their survey in the retrofit group.

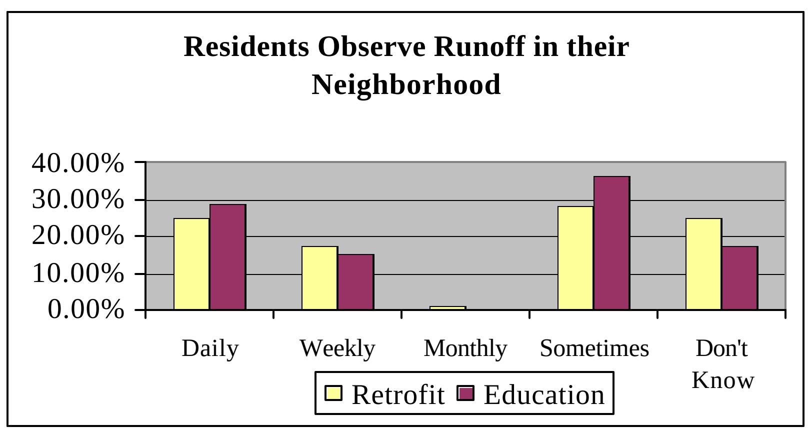
Residents were asked how they watered their lawn. Figure 2 shows responses across groups were very similar. The percentage of people in the retrofit and education group that use automatic sprinklers, manual sprinklers, or a hose are similar. The survey shows that the retrofit and education groups have similar watering behaviors. A majority of the participants used automatic sprinklers. This is important because the R3 study focuses on retrofitting the automatic irrigation controllers as a water management tool.

Figure 2: Watering Methods



Residents were asked how often they observed runoff in their neighborhood. The data presented in Figure 3 shows that residents in both groups have similar attitudes and views of urban runoff.

Figure 3: Runoff Observed



Residents were asked if they used fertilizers in their landscape. As shown Figure 4 at right, fertilizer use in both groups is almost the same. Their behavior when it comes to applying fertilizers is also the same.

Figure 4: Use of Fertilizers

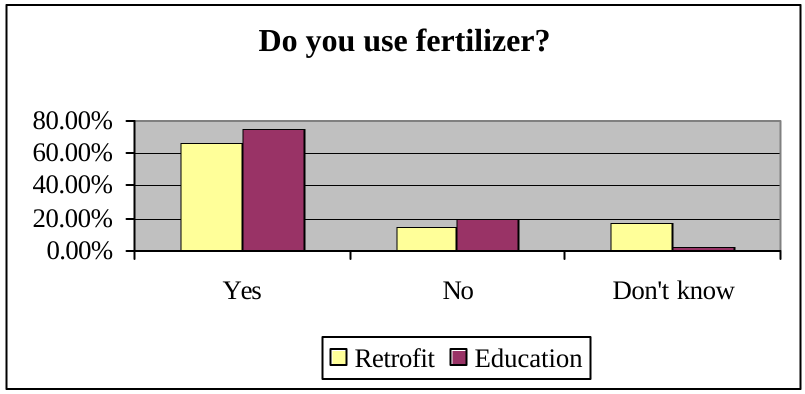


Figure 5: Use of Chemicals

Residents were also asked if they used chemicals to control pests or weeds in their yard. Figure 5 shows their responses.

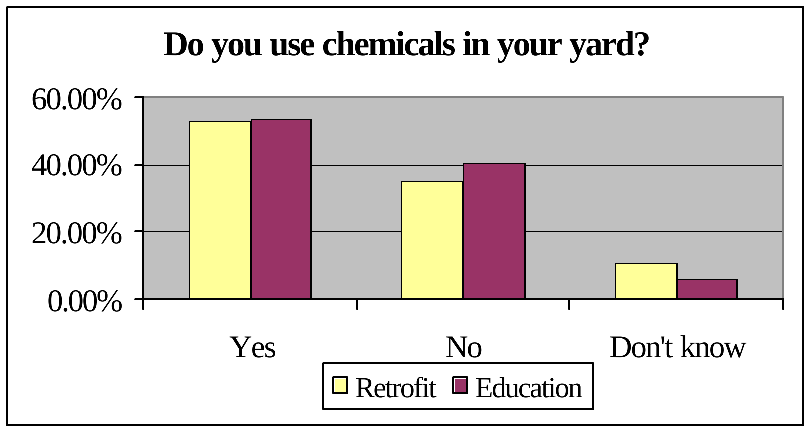


Table 2: Pre-Survey Responses

R3 Study Pre-Survey Results		
	Retro	Education
Who is responsible for yard maintenance at your home?		
Adult	68.81%	76.92%
Children	3.67%	3.85%
Yard Service	49.54%	40.38%
How is your yard watered?		
Automatic Sprinklers	92.66%	92.31%
Manual Sprinklers	14.68%	9.62%
Hose	23.85%	26.92%
How often is your yard watered?		
Summer- Days Per Week	RV	RV
Summer-Minutes Per Day	RV	RV
Summer-Don't Know	10.09%	5.77%
Winter - Days Per Week	RV	RV
Winter - Minutes Per Day	RV	RV
Winter-Don't Know	10.09%	9.62%
Controller Times Changed	RV	RV
How often do you see water runoff in your neighborhood?		
Runoff in Neighborhood-Daily	24.77%	28.85%
Runoff in Neighborhood-Weekly	17.43%	15.38%
Runoff in Neighborhood-Monthly	0.92%	0.00%
Runoff in Neighborhood-Sometimes	28.44%	36.54%
Runoff in Neighborhood-Don't Know	24.77%	17.31%
How often are patios, sidewalks, and driveways cleaned at your home?		
Driveways are cleaned-Daily	0.00%	1.92%
Driveways are cleaned-Weekly	39.45%	40.38%
Driveways are cleaned-Monthly	24.77%	21.15%
Driveways are cleaned-Sometimes	33.03%	34.62%
Driveways are cleaned-Other	RV	RV
How do you clean driveways	RV	RV
Who is responsible for pest and weed control in your yard?		
I am - Responsible for Weed/Pest Control	59.63%	67.31%
Yard Service- Responsible for Weed/Pest Control	30.28%	17.31%
Pest Control Service - Responsible for Weed/Pest Control	15.60%	25.00%
Dont Use Weed or Pest Control Service	6.42%	11.54%
Other - Responsible for Weed/Pest Control	0.00%	0.00%
Do you use chemicals to control pests or weeds in your yard?		
Chemicals are used to control pests/weeds	53.21%	53.85%
Chemicals are not used to control pests/weeds	34.86%	40.38%
Don't know if chemicals are used	11.01%	5.77%
Chemicals used are	RV	RV
Chemicals used, How often?	RV	RV

Do you use fertilizer in your yard?		
Fertilizer is used	66.06%	75.00%
Fertilizer is NOT used	14.68%	19.23%
Don't know if fertilizer is used	16.51%	1.92%
If Fertilizer used, which ones?	RV	RV
If Fertilizer used,how often?	RV	RV
Who is responsible for dispocal of unused landscape chemicals?		
I am - Responsible for disposal of unused chems	48.62%	63.46%
Pest Control - Responsible for disposal of unused chems	8.26%	5.77%
Yard Service - Responsible for disposal of unused chems	0.00%	0.00%
Don't know who - Responsible for disposal of unused chems	11.93%	7.69%
How are chems disposed of?	RV	RV
Rank the overall appearance of your yard?		
Appearance of yard-Excellent	11.93%	25.00%
Appearance of yard-Good	48.62%	53.85%
Appearance of yard-Average	33.94%	17.31%
Appearance of yard-Poor	6.42%	3.85%
Appearance of yard-Very Poor	0.00%	0.00%
How serious do you consider urban ruoff?		
Neighborhood Urban Runoff = Very Serious	6.42%	15.38%
Neighborhood Urban Runoff = Serious	16.51%	17.31%
Neighborhood Urban Runoff = Needs Improvement	46.79%	38.46%
Neighborhood Urban Runoff = No Problem	22.02%	23.08%
Irvine Urban Runoff = Very Serious	5.50%	15.38%
Irvine Urban Runoff = Serious	15.60%	11.54%
Irvine Urban Runoff = Needs Improvement	39.45%	42.31%
Irvine Urban Runoff = No Problem	18.35%	11.54%
Orange Co Urban Runoff = Very Serious	7.34%	15.38%
Orange Co Urban Runoff = Serious	21.10%	25.00%
Orange Co Urban Runoff = Needs Improvement	44.95%	34.62%
Orange Co Urban Runoff = No Problem	4.59%	1.92%
California Urban Runoff = Very Serious	13.76%	19.23%
California Urban Runoff = Serious	19.27%	21.15%
California Urban Runoff = Needs Improvement	40.37%	36.54%
California Urban Runoff = No Problem	3.67%	1.92%
Is there animal waste that gets left in you yard?		
Animal Waste is left in yard	35.78%	26.92%
Animal Wate is NOT left in yard	63.30%	69.23%
If Animal Waste is left in yard, then what type of animal	RV	RV
How many people live in your home?		
Household Adults	RV	RV
Household Children	RV	RV
*(RV) Responses Varied		

Post-Survey Goal

The purpose of the post-survey was to determine the attitudes of the study participants towards the ET controller and to determine if the education material had an impact on modifying behavior of the recipients. Specifically, determining whether or not there was an acceptance of the ET controller as a way of managing their landscape and was there a change in irrigation practices and behaviors because of the education material.

Survey Distribution

The post-survey was distributed to both of the groups through the mail. Twenty-three (52/225) percent of the education group participants responded to the survey and forty-five percent (50/112) of the retrofit group participants responded.

ET Controller

The majority of the retrofit households acknowledged their satisfaction with the ET controller's performance and agreed that they would recommend the ET controller to their friends. It appears that the residents liked the controller and did not mind having someone else manage their irrigation-watering schedule. Data shows that households accepted the controller as a method of saving water, reducing runoff, and watering their landscape. The survey shows that twice the number of retrofit households observed a decrease in their water bill than the education households did. A majority of the education households did not observe a change in their water bills. Data appears to show that the appearances of the retrofit landscapes were ranked equally with those landscapes that were part of the education group. It can therefore be concluded that the survey showed that the lower use of water did not create landscaped that were inferior to the

education group. The customer's perception of a lower bill is important for the success of any long-term conservation program.

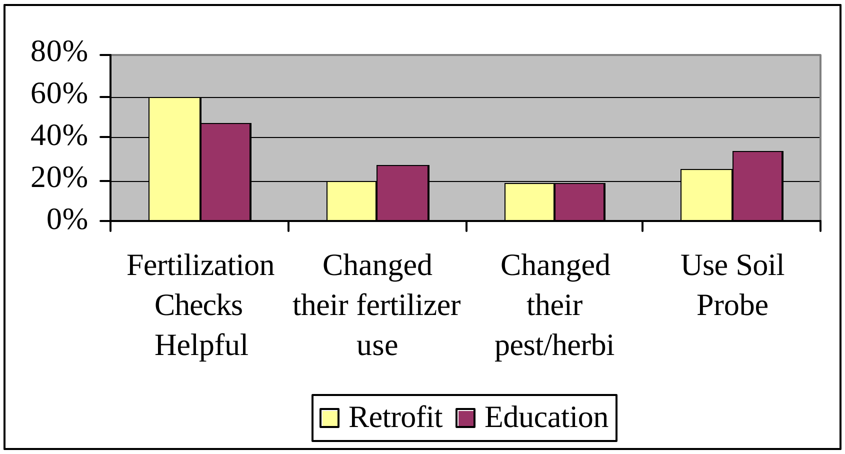
The retrofit and education group were asked if they were willing to pay for an ET controller signal. A majority of the households in both of the groups would not be willing to pay for an ET signal. The ET controller costs approximately $150.00 and the signal fee is $48 per year. The ET controller would be able to save less than 2 ccfs per month, which is a savings of about $14 per year. It appears that the savings in water use per year is not large enough for the water customer to pay for an ET signal.

ET Controller Selected Responses

- 72% of the retrofit households were satisfied with the ET Controller.
- 70% of the retrofit households would recommend the ET Controller to others.
- 44% of the retrofit households saw a decrease in their water bill,
- 38% saw their bill as unchanged.
- 23% of the education households saw a decrease in their water bill,
- 63% saw their water bills as unchanged.
- 69% of the education households ranked the appearance of their yard as good to excellent.
- 70% of the retrofit households ranked the appearance of their yard as good to excellent.
- 69% of the education households would not be willing to pay for an ET signal.
- 58% of the retrofit households would not be willing to pay for an ET signal.

Education Program

Figure 6: Impacts on Education Program



The results of the education program are summarized on Figure 6. More than half of the education households acknowledged that they sometimes or most of the time would change the settings on their controller according to ET via the monthly letter's suggested schedule. Monthly letters provided monthly landscape maintenance tips. Here, the majority of the households in both of the groups liked the tips on the irrigation checks, and fertilization sections. Although most people read these sections, a vast majority (80%) of households in both of the groups did not change their use of pesticides, herbicides, or fertilizers. In addition to the education materials, a soil probe was given to both groups at the beginning of the study. A soil probe is a tool that takes a soil sample and allows the user to see the depth and amount of moisture available to the plants. This allows the user of the soil probe to determine if the plants require more or less irrigation. More than half of the households in both groups only used the soil probe once or not at all. The majority of the people never used the soil probe at all. From a program point of view, people enjoy the education materials but they appear to have little effect on modifying behavior.

Education Material Selected Responses

- 54% of the education households changed their irrigation controller schedule (based on the recommendations included in the monthly tips) most of the time or sometimes.
- 58% of the education households and 42% of the retrofit households believed that the irrigation checks (part of the monthly tips) were helpful.
- 44% of the education households and 58% of the retrofit households believed that the fertilization checks (part of the monthly tips) were helpful.
- 81% of the education and 82% of the retrofit households have not changed their use of pesticides and herbicides.
- 73% of the education households and 80% of the retrofit households have not changed their use of fertilizer.
- 62% of the education households and 76% of retrofit households did not use the soil probe or they only used it once.

Table 3: Post-Survey Results

R3 Study Post-Survey Results						
1. Rank the overall appearance of your yard.						
	Excellent	Good	Average	Poor	Very Poor	
Education	9.62%	59.62%	30.77%	1.92%	0.00%	
Retrofit	16.00%	54.00%	24.00%	4.00%	2.00%	
2. Have you seen any change in your water bill in the past 12 months?						
	Increase	Decrease	Unchanged			
Education	9.62%	23.08%	63.46%			
Retrofit	14.00%	44.00%	38.00%			
3. Which monthly monthly tips were helpful to you?						
	Irrigation Checks	Watching for Runoff	Pest& Weed Control	Fertilization	None were Helpful	Dd Not Read
Education	57.69%	28.85%	23.08%	44.23%	1.92%	9.62%
Retrofit	42.00%	30.00%	46.00%	58.00%	2.00%	18.00%
4. How often did you use the soil probe?						
	Once	2 to 6 times	More than 6 times	Only for the Rain	Did Not Use	
Education	11.54%	30.77%	1.92%	3.85%	50.00%	
Retrofit	12.00%	16.00%	6.00%	0.00%	64.00%	
5. How often do you see water runoff in your neighborhood? (choose one)						
	Daily	Weekly	Monthly	Sometimes	Don't Know	
Education	25.00%	32.69%	5.77%	26.92%	11.54%	
Retrofit	10.00%	36.00%	2.00%	40.00%	16.00%	
6. How often are patios, sidewalks and driveways cleaned at your home? (choose						
	Daily	Weekly	Monthly	Sometimes	Never	
Education	0.00%	46.15%	21.15%	30.77%	3.85%	
Retrofit	2.00%	48.00%	16.00%	32.00%	4.00%	
7. How do you clean patios, sidewalks and driveways at your home?						
	Hose	Broom	Blower	Other		
Education	44.23%	63.46%	30.77%	RV		
Retrofit	48.00%	58.00%	36.00%	RV		
8. Have you changed your use of pesticides and herbicides in the yard in the past 12 months?						
	Yes	No	How?			
Education	15.38%	80.77%	RV			
Retrofit	16.00%	82.00%	RV			
9. Have you changed the use of fertilizer in your yard in the past 12 months?						
	Yes	No	How?			
Education	23.08%	73.08%	RV			
Retrofit	18.00%	80.00%	RV			
10. Is there animal waste that gets left in your yard?						
	Yes	No	What type of animal			
Education	21.15%	75.00%	RV			
Retrofit	36.00%	64.00%	RV			
11. How serious a problem do you consider urban runoff? (choose one)						
	Very Serious	Serious	Needs Improvement	No Problem		
Education	3.85%	38.46%	46.15%	9.62%		
Retrofit	12.00%	28.00%	52.00%	10.00%		
12. Were you satisfied with the test irrigation controller installed to manage the landscape water?						
	YES	NO	Why			
Retrofit	72.00%	24.00%	RV			
13. Would you recommend this irrigation controller to others?						
	YES	NO	Why			
Retrofit	70.00%	24.00%	RV			
14. Would you pay a monthly fee to have signal sent to the controller for landscape water management as tested in this study						
	YES	NO	How Much?			
Education	26.92%	69.23%	RV			
Retrofit	38.00%	58.00%	RV			
15. How often did you change your irrigation controller to the times provided in the monthly tips?						
	Every Month	Most of the Time	Sometimes	Once or Twice	Never	
Education	5.77%	28.85%	25.00%	23.08%	15.38%	