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).

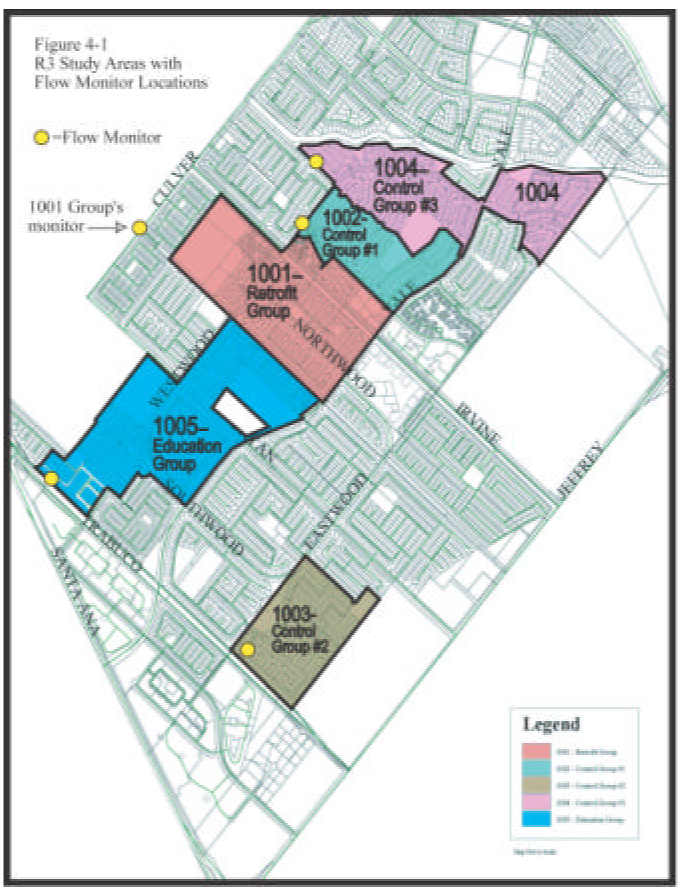
The first variable in the equation, velocity, was measured by velocity wafers placed below the surface of the runoff stream to measure the velocity of the water. These electronic devices were attached to metal plates positioned at the bottom of the concrete pipes that carried runoff. Each velocity wafer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

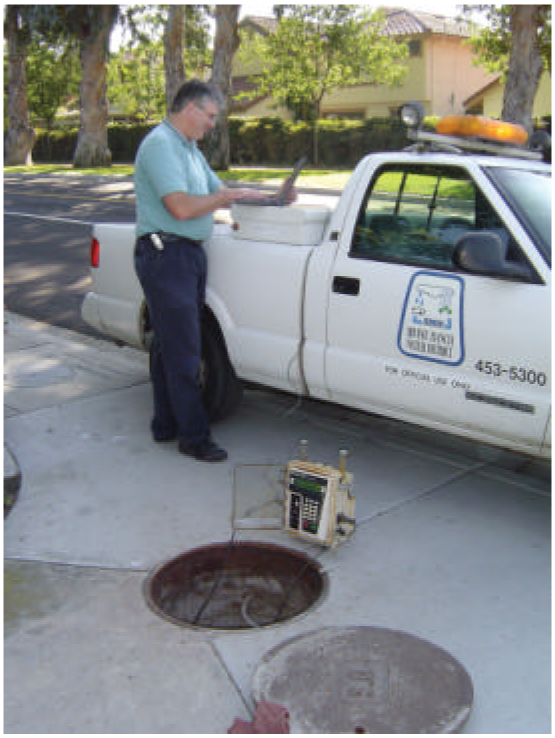
Maintaining the flow monitors in good working order required an R3 Study field staff member to visit each of the five data collection locations twice per week. At each site, staff would open the manhole and lift out the monitor. Then, the storm drainpipe would be inspected for any obstruction or interference 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**		**Estimated Permeable Area**		**Total Area**	
	sq.ft.	**acres**	**sq. ft.**	**acres**	**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.

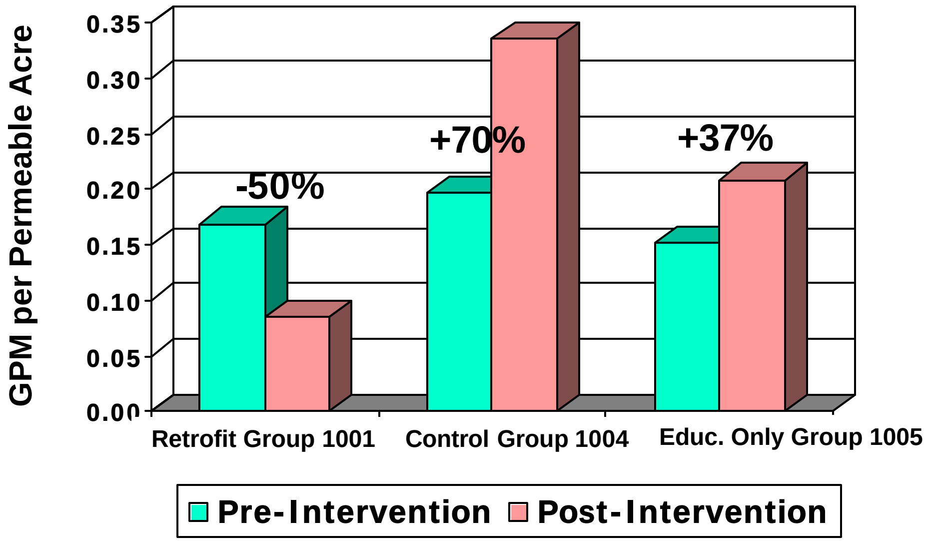
The changes in runoff estimated during the R3 study are summarized on Figure 4-3 and described in more detail below. Additional descriptions of the regression models are presented in Appendices D1 and D2.

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:

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

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

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.