Appendix D1: Statistical Analysis of Urban Runoff Reduction

The Residential Runoff Reduction Study

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

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Table of Contents

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: $m_{4,\mathrm{Pr}e} \equiv m_1 + d_{4,\mathrm{Pr}e} \approx 0.89 + 0.14 = 1.03$ hundredths of an inch and

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

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.