
THE RELATIONSHIP BETWEEN STORMWATER QUALITY AND DEMOGRAPHICS



City Of Austin
Watershed Protection and
Development Review Department
Environmental Resources Management Division



Water Quality Report Series

April 1, 2007

COA-ERM/WQM 2007-1

THE RELATIONSHIP BETWEEN STORMWATER QUALITY AND DEMOGRAPHICS

Prepared by

City of Austin
Watershed Protection and Development Review Department
Environmental Resource Management Division
Water Quality Monitoring Section

Project Team

Roger Glick, P.E., Ph.D., Section Manager
Truman Zhu, Data Analyses, Water Quantity
Baolin Bai, Data Analyses, Water Quality
James Hubka, Data Analyses, Data Processing and Database Development
Richard Robinson, Data Processing and Data Management
Sam Mahmoud, Field Data Collection and Data Management
Steve Manning, Field Data Collection and Data Management
Aboli Moezzi, Field Data Collection and Data Management
Jeff Selucky, Field Data Collection and Data Management

Ryan Robinson, City Demographer

ERM Division Manager

Tom Ennis, P.E.

WPDR Department Management

Nancy L. McClintock, Assistant Director
Victoria J. Li, P.E., Director

THE RELATIONSHIP BETWEEN STORMWATER QUALITY AND DEMOGRAPHICS

Executive Summary

The City of Austin Stormwater Quality Monitoring Program has been collecting runoff quantity and quality data since the early 1980s. Prior studies have indicated that water quality may be affected by physical factors such as land use and impervious cover but these reports also noted a high degree of variability among sites with similar physical factors. This report examines the variability in runoff quality data from single-family residential watersheds and explores the relationships to population demographics.

Mean watershed runoff concentrations of seventeen pollutants from eleven single-family residential watersheds were statistically compared. The statistical tests indicated significant differences among watersheds, but the seventeen different tests were difficult to compare. An indicator variable combining the values of the seventeen pollutants was developed to help resolve this difficulty. Clear differences among the watersheds were seen using the indicator variable. Physical factors such as age of infrastructure were estimated to see if they could be used to explain the variability but these did not provided a complete explanation of the variability.

The second part of this report examined the population demographics in the monitored watersheds and how those may be related to runoff quality. Four demographics were selected for evaluations: population density, housing characteristics, income, and education. The relationship between each of these factors and the indicator variable showed a moderate correlation. Increases in education, income and owner occupancy related positively to water quality. Increases in population density adversely impacted water quality. A multivariate analysis indicated education was the most important demographic to help estimate runoff quality from single-family watersheds.

Demographic factors may not, in and of themselves, cause changes in runoff quality. However, the relationships developed in this report may be used to identify areas that may have lower water quality. This may help planners locate water quality controls and help educators target education programs.

Introduction

Many factors may influence urban stormwater quality. Water quality concentrations of various pollutants are often related to impervious cover. Several City of Austin studies (2006 and others) have demonstrated positive correlations between impervious cover and water quality pollutants. Land use also may be a factor in determining pollutant concentrations. While the previously cited City of Austin study did not find a strong relationship between land use and watershed mean concentrations, another study (COA, 2005) did show significant differences between mean event mean concentrations (EMCs) for different land uses. These differences become important when trying to tailor an educational program or select a site for a BMP retrofit program.

This study examines the variability in water quality concentrations in stormwater runoff from single-family residential (SFR) areas and explores the possibility of using population demographics to predict relative water quality from different SFR watersheds. This study uses data collected between 1985 and 2003 by the City of Austin Stormwater Quality Monitoring (SWQM) Program.

Description of SWQM

The purpose of stormwater quality monitoring (SWQM) is to provide information on stormwater runoff quantity and quality, and the pollutant removal efficiencies for various best management practices (BMPs). These efforts help protect and improve water quality in Austin's creeks, lakes and aquifers (COA, 1990; 1997; 2005; 2006).

An SWQM monitoring station consists of several basic components. Figure 1 shows a conceptual monitoring station layout. The flow meter is used to measure and record depth of flow using a depth sensor and a data logger. The flow meter is also used to control a water quality sampler. SWQM staff checks the flow meter on a regular basis to download flow and rainfall data via telephone modems. The automatic sampler can be programmed to collect samples based on volume of runoff or specified time intervals. During storm events, staff observes the progress of the runoff event and sampling process, making adjustments to the sampling program as needed. The monitoring station is powered by solar panels and deep-cycle batteries to prevent the loss of power during storm events. Some monitoring stations are equipped with dial-out alarms to notify the assigned staff if a predetermined set of conditions exists (flow, rainfall, etc.) (COA, 1997; 2006).

SWQM continuously monitors flow and rainfall at each monitoring site and collects several discrete water quality samples during runoff events. The water quality samples are analyzed by local, approved laboratories for sixteen conventional urban stormwater pollutants: five-day biological oxygen demand (BOD), cadmium (Cd), chemical oxygen demand (COD), copper (Cu), dissolved phosphorus (DP), fecal coliform (FCOL), fecal streptococcus (FSTR), ammonia (NH₃), nitrate and nitrite (NO₃+ NO₂), lead (Pb), total Kjeldahl nitrogen (TKN), total organic carbon (TOC), total phosphorus (TP), total suspended solids (TSS), volatile suspended solids (VSS),

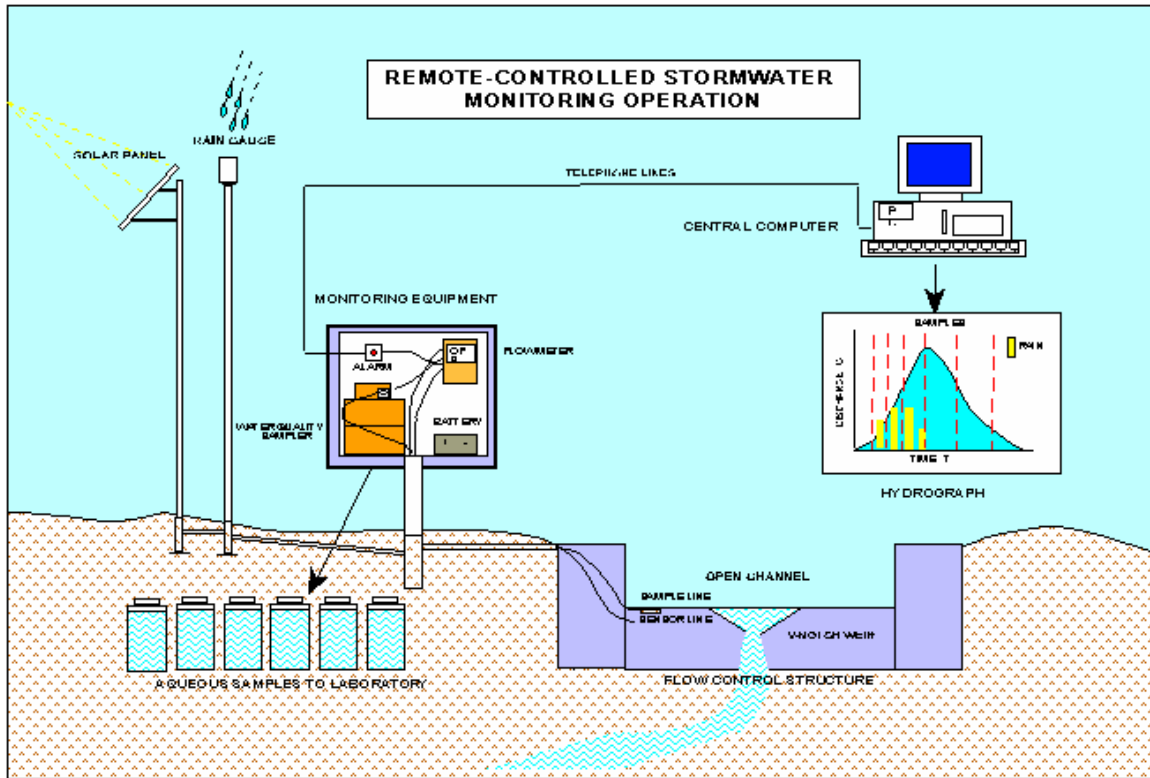


Figure 1: Typical Equipment Layout at an SWQM monitoring station

and zinc (Zn). SWQM also examines total nitrogen (TN), which is defined as TKN plus $\text{NO}_3 + \text{NO}_2$. Since discrete samples are collected rather than one composite sample, the average pollutant concentration during the storm, otherwise known as the event mean concentration (EMC), must be computed. The EMC is computed by taking the volume-weighted average of the discrete sample concentrations.

Stormwater Quality Data Analyses

A description of the monitoring sites included in this study is in Table 1 and locations may be found in the map in Figure 2. As previously mentioned, SWQM usually collects discrete samples and then computes the EMC as the flow-weighted average. Discrete samples are collected for several reasons, such as ease of sampling, ability to characterize changes during an event, and optimizing efficiency. In some cases, however, the samples are not representative of the entire runoff event. Either a portion of the storm was not sampled correctly or not enough samples were collected. In order to ensure only the best data are used, SWQM evaluates each EMC and uses the best-quality data, provided a minimum number of EMCs are available for analyses. Once the lower-quality EMCs are excluded, mean watershed concentrations are computed using a volume-weighted mean. The number of EMCs for each water quality parameter used in this study is presented in Table 2 and the EMCs are presented in Table 3.

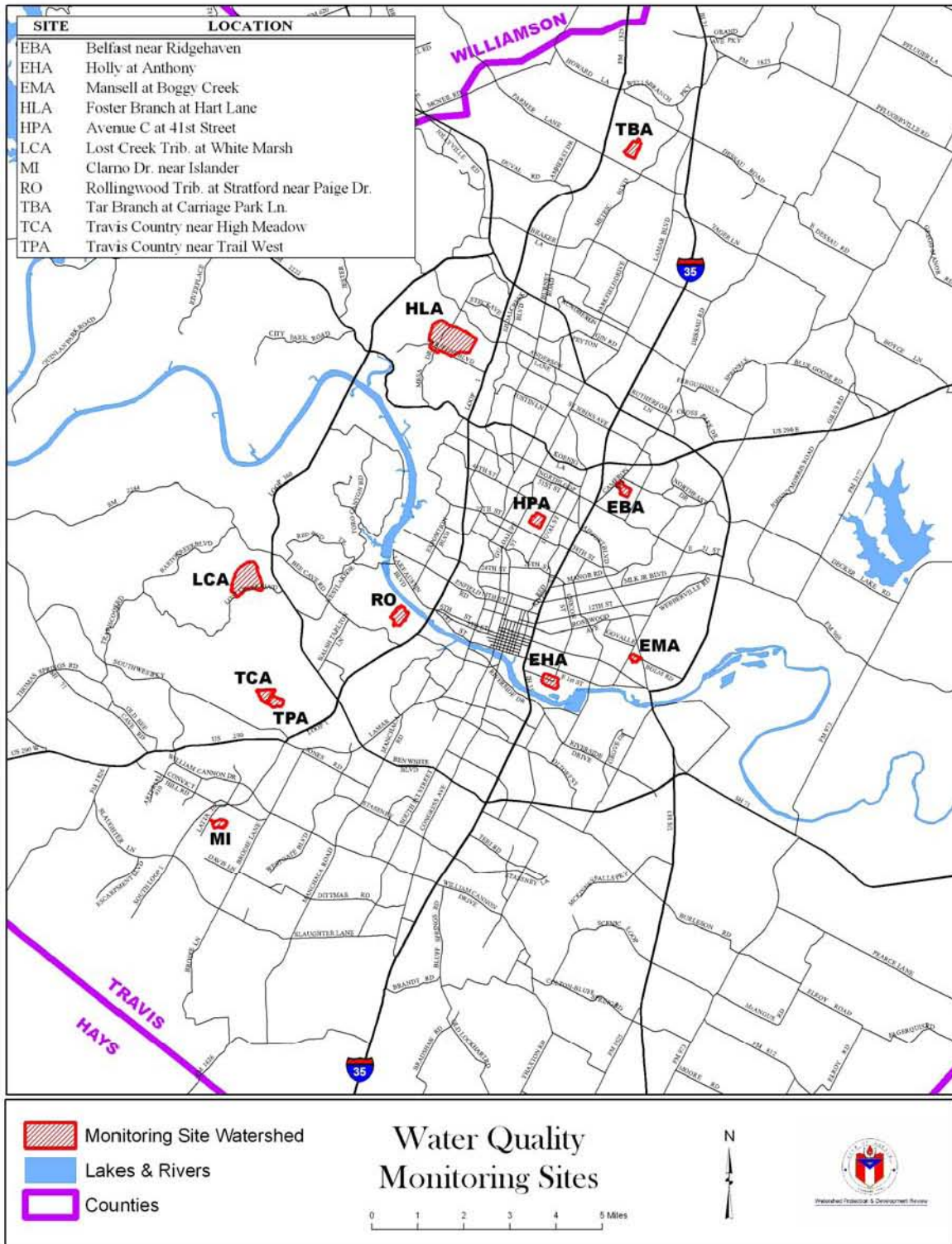


Figure 2: Location of SWQM single-family residential watersheds.

Table 1: Description of SFR Monitoring Sites

SITE	Location	Imp. Cover	Area (ac)
EBA	Belfast near Ridgehaven	40.36%	35.24
EHA	Holly at Anthony	43.42%	51.34
EMA	Mansell at Boggy Creek	42.04%	15.73
HLA	Foster Branch at Hart Lane	39.09%	329.14
HPA	Avenue C at 41st Street	53.50%	42.58
LCA	Lost Creek Trib. at White Marsh	22.50%	209.87
MI	Clarno Dr. near Islander	36.00%	27.80
RO	Rollingwood Trib. at Stratford near Paige Dr.	26.39%	62.90
TBA	Tar Branch at Carriage Park Ln.	45.21%	49.42
TCA	Travis Country near High Meadow	37.36%	40.71
TPA	Travis Country near Trail West	41.45%	41.60

First, it was necessary to determine if any of the sites had significantly different mean pollutant concentrations compared to the other sites. Two statistical tests were performed on these data to determine if any differences existed between these sites and the East Austin sites. First, an analysis of variance (ANOVA) test was performed to determine if there were any significant differences between the mean pollutant concentrations at each site. An ANOVA test determines only if at least one site is significantly different from the other sites; it does not identify which site (or sites) is different, nor does it indicate the magnitude of the difference (Lentner and Bishop, 1986; SAS, 1990, Cochran and Cox, 1957). To determine which sites are statistically different, a Duncan's mean separation test was performed to compare the means and determine which sites, if any, are significantly different (Lentner and Bishop, 1986; SAS, 1990, Cochran and Cox, 1957). With the Duncan's test, means that are in the same group are not statistically different (means may be in more than one group). These tests assume the data being analyzed are normally distributed. Since the data were lognormally distributed, the analyses were performed on the logarithm of the EMCs ($\ln(\text{EMC})$) to ensure the normality of the data (Glick, 1992; COA, 2006). These analyses will determine if there is any statistical difference in the geometric means of the EMCs at the sites. The geometric mean may differ from the volume-weighted mean presented in Table 3. The results of these tests are in the Appendix of this report.

Each test was performed once for each pollutant parameter, resulting in seventeen separate ANOVA and Duncan's tests (*See Appendix for results*). Interpreting the results of seventeen separate tests individually did not provide a clear comparison of the overall water quality at the sites. Therefore, an indicator variable was developed by combining the data for all seventeen water quality parameters to help quantify the overall water quality at each site and to aid in data interpretation. The indicator variable was created by normalizing the log-transformed EMCs for each parameter so that it would have a mean of zero and a standard deviation of one, based on the entire dataset of EMCs for that parameter. By doing this, all EMCs for a storm could be

Table 2. Number of event mean concentrations for each parameter at each site.

Site	Period of Monitoring	Parameter																
		BOD	Cd	COD	Cu	DP	FCOL	FSTR	NH ₃	NO ₃ +NO ₂	Pb	TKN	TN	TOC	TP	TSS	VSS	Zn
EBA	2000-2003	19	28	30	28	30	16	16	30	30	28	30	30	30	30	29	28	
EHA	1995-2001	31	31	33	31	32	23	27	32	32	31	32	31	33	33	33	31	
EMA	1999-2003	27	49	49	49	49	21	24	49	49	49	48	48	49	49	48	49	
HLA	1985-1995	20	1	21	20	2	19	19	21	21	20	20	20	19	21	21	2	
HPA	2000-2003	16	24	25	24	25	10	12	22	25	24	25	25	22	25	25	24	
LCA	1992-1996	22	12	22	19	20	19	18	19	21	19	22	21	18	22	20	17	
MI	1984-1986	25	---	26	26	---	25	25	26	26	26	26	26	26	26	---	26	
RO	1984-1988	14	---	15	14	---	14	15	15	15	14	15	15	14	14	15	---	
TBA	1996-2000	31	32	31	32	30	25	26	29	27	32	31	27	28	30	31	29	
TCA	1993-1996	20	19	25	20	18	15	15	24	23	20	25	23	21	25	24	23	
TPA	1993-1996	20	19	22	20	18	15	17	22	22	20	22	20	21	22	22	23	

Table 3. Mean watershed concentrations at each site.

Sites	Parameters																
	BOD (mg/l)	Cd (ug/l)	COD (mg/l)	Cu (ug/l)	DP (mg/l)	FCOL (col/100ml)	FSTR (col/100ml)	NH ₃ (mg/l)	NO ₃ +NO ₂ (mg/l)	Pb (ug/l)	TKN (mg/l)	TN (mg/l)	TOC (mg/l)	TP (mg/l)	TSS (mg/l)	VSS (mg/l)	Zn (ug/l)
EBA	9.10	0.510	47.66	4.15	0.214	73296	135605	0.181	0.449	7.84	2.00	2.45	10.28	0.484	64.6	22.1	34.96
EHA	16.61	0.761	99.50	11.43	0.255	108711	317331	0.270	0.624	44.41	2.88	3.36	15.31	1.268	259.4	62.4	153.37
EMA	28.38	0.529	124.54	11.81	0.203	55002	476780	0.191	0.407	22.07	2.53	2.94	19.67	0.677	263.2	65.1	134.09
HLA	9.66	0.306	23.09	14.27	0.050	111442	36168	0.235	0.671	50.53	0.70	1.37	6.69	0.218	150.8	15.6	52.81
HPA	16.77	0.508	63.94	5.68	0.212	97049	187869	0.169	0.457	18.96	1.68	2.13	16.22	0.445	95.8	31.8	89.34
LCA	5.39	0.305	44.10	19.96	0.087	39982	41526	0.143	0.532	5.42	1.06	1.59	5.98	0.254	143.0	49.1	45.77
MI	11.53	---	30.26	7.96	---	49676	32130	0.313	0.473	7.67	1.25	1.72	12.63	0.235	319.5	---	23.71
RO	7.14	---	22.76	6.91	---	15196	31113	0.141	1.349	16.03	0.91	2.26	12.60	0.318	420.9	---	37.11
TBA	9.89	0.594	68.56	6.74	0.139	50646	160016	0.191	0.535	11.90	1.69	2.39	10.39	0.515	212.2	34.0	76.81
TCA	5.07	0.534	39.82	6.95	0.151	74382	58528	0.116	0.357	6.05	0.90	1.31	7.69	0.254	54.9	12.8	16.40
TPA	10.60	0.665	61.21	6.35	0.233	87750	108790	0.295	0.579	7.73	1.72	2.36	7.83	0.421	128.3	32.2	36.04

Table 4. Duncan's test results for SFR sites, indicator variable.

Site	Number of EMCs	Standard Variable	
EHA	529	-0.685	a
EMA	754	-0.538	b
HPA	377	-0.156	c
TPA	345	-0.080	cd
EBA	462	0.029	de
TBA	503	0.122	e
RO	203	0.344	f
LCA	330	0.353	f
HLA	287	0.371	f
MI	329	0.388	f
TCA	360	0.701	g

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

combined into a single value representing the overall quality for that runoff event. The Duncan's test was then performed on the indicator variable to determine if the overall water quality at any of the sites was significantly different from the other sites. For clarity, the indicator variable was multiplied by -1 to produce an index with poorer water quality reflected by a lower number and better water quality a higher number.

Discussion of Monitoring Results

Results of the Duncan's means separation test on the indicator variable for the single-family residential (SFR) sites are presented in Table 4. For comparison purposes, the indicator variable results for non-SFR watersheds are presented in Table A18 (*See Appendix*). Site EHA has the lowest mean indicator variable among all sites and is significantly lower than all other SFR sites. During the period of monitoring, a buildup of sediment in the storm sewer was noted, and this was believed to possibly affect the results. No evidence was found to indicate that the sediment was caused by a collapse in the storm sewer. Surface sources are the most likely culprit. Staff also noted that when sediment was present, there were bare areas in lawns, sparse vegetation, unpaved driveways and alleys, significant trash and debris in the area, less maintenance in general, and older infrastructure in the watershed.

The indicator results for EMA are the second-lowest for SFR sites and significantly lower than all others, except EHA and W5A, the downtown entertainment area. The age of infrastructure and general character makeup of EMA is similar to EHA, but there are fewer unpaved driveways and alleys. Lawn and other maintenance (trash and debris removal) appear to be more frequent in EMA than EHA, while the vegetative cover at both sites is lower than other SFR watersheds.

EHA and EMA also have the highest mean concentration for sixteen of the seventeen individual parameters examined in this study.

These results indicate that age of infrastructure and general maintenance in an SFR watershed may impact water quality. HPA, while in a relatively affluent part of the City, is also in one of the older areas of the City. This site has an indicator variable slightly less than zero, and is the third-lowest among SFR sites in the City, but it is significantly lower than both EHA and EMA. This would tend to indicate that while age of infrastructure has some impact on stormwater quality, general maintenance and upkeep (lawn care, trash clean-up, etc.) may play a greater role when it comes to SFR areas.

Demographic Analyses

After examining the water quality data and noting differences among the various single-family watersheds, an effort was made to identify characteristics that might be used to predict water quality. As previously noted, qualitative parameters were identified that may indicate the possibility of poorer stormwater quality, but these are subjective and the data are not readily available. Therefore, an effort was made to look at the available demographics in each watershed to see if any significant relationships could be developed. Such relationship(s) could be used to identify areas of the City with potentially poor stormwater quality and to develop measures that may help improve stormwater quality.

Six separate demographic parameters were examined: population density, age of development, housing characteristics, household characteristics, educational attainment, and income characteristics. Age of development and household characteristics did not show any trends. But population density, housing and income characteristics, as well as educational attainment, did reveal possible qualitative relationships to water quality. The results of these demographics are shown in Tables 6-9.

Population Density

Table 6 is a summary of the population in each watershed. The population density in the watersheds draining to EMA and EHA is significantly higher than in the other watersheds. Regression analysis on the indicator variable and population density shows a positive correlation ($r^2 = 0.50$), meaning as population density increases, water quality index decreases (indicating degraded water quality). While the impervious cover for these watersheds is not higher than other SFR watersheds, the presence of more intense activities associated with higher populations appears to negatively impact water quality.

Housing Characteristics

Table 7 shows a breakdown of the housing characteristics of the watersheds. The demographic data for HPA may include an apartment complex that is not actually in the watershed; therefore, those data were omitted from further analyses. Regression analysis on the indicator variable and housing characteristics indicates a strong positive correlation ($r^2 = 0.67$). As owner occupancy increases, stormwater quality increases. In the case of EMA and EHA, renter-occupied housing was found more frequently than in other watersheds. While not always the case, there is a widely recognized theory that renter-occupied properties are less likely to be consistently

Table 6. Population characteristic demographics for SFR watersheds.

Watershed	Total Population	Population Density (per acre)
EBA	459	13.02
EHA	1,125	21.91
EMA	344	21.87
HLA	2,579	7.84
HPA	538	12.64
LCA	1,056	5.03
MI	483	17.37
RO	320	5.09
TBA	840	17.00
TCA	339	8.33
TPA	333	8.00

Table 7. Housing characteristic demographics for SFR watersheds.

Watershed	Total Housing Units	Occupied Housing Units	Vacant Housing Units	Vacancy Rate	Owner Occupied Housing Units	Renter Occupied Housing Units	Owner Occupancy Rate
EBA	198	194	4	2.0%	122	72	62.9%
EHA	332	321	11	3.3%	189	132	58.9%
EMA	103	102	1	1.0%	57	45	55.9%
HLA	1,059	1,043	16	1.5%	992	51	95.1%
HPA*	289	282	7	2.4%	77	205	27.3%
LCA	354	350	4	1.1%	329	21	94.0%
MI	161	160	1	0.6%	124	36	77.5%
RO	112	109	3	2.7%	102	7	93.6%
TBA	296	292	4	1.4%	227	65	77.7%
TCA	122	121	1	0.8%	118	3	97.5%
TPA	132	131	1	0.8%	119	12	90.8%

* The demographic data for HPA may include an apartment complex that is not in the watershed; those data were omitted from further analyses.

Table 8. Income characteristic demographics for SFR watersheds.

Watershed	Median Household Income	Median Family Income
EBA	\$45,170	\$47,216
EHA	\$30,938	\$27,778
EMA	\$33,281	\$37,417
HLA	\$64,728	\$97,296
HPA	\$45,054	\$85,982
LCA	\$106,856	\$107,592
MI	\$61,206	\$63,520
RO	\$96,565	\$107,241
TBA	\$59,408	\$59,496
TCA	\$92,331	\$95,561
TCP	\$92,331	\$95,561

maintained because the property owner rarely lives near the property and in many cases lives in other jurisdictions. Therefore, monitoring their property on a regular basis is limited in comparison to property owners who actually inhabit their properties. This poses a dilemma for education and outreach programs that will have to target an audience that may or may not be vested in the community in which they live.

Income

Table 8 shows the income breakdown for households in the watershed. EMA and EHA have the lowest household and family incomes of the watersheds studied. Regression analyses of these data indicate that income is positively correlated ($r^2 = 0.53$) to stormwater quality. As income increases, stormwater quality improves. However, this is not to say that there is a causal relationship between income and water quality. Studies by the U.S. Geological Survey (Mahler, 2006a and 2006b) examined different pollutants such as pesticides, metals and PAHs in creeks and groundwater. These studies found that the levels of these pollutants tended to be higher in areas generally considered wealthier; however, no direct comparison of demographics was performed. This could be a result of residents and businesses using more fertilizers, pesticides and other chemicals in these areas.

An attempt was made to develop relationships for each pollutant since some, like nutrients from fertilizers, are more associated with affluent areas. Bartlett (2006) found the use of fertilizer increased with income. While relationships for individual pollutants were similar to the indicator variables in trend, the correlations for nitrate were much weaker, indicating that if nutrients from

Table 9. Educational attainment demographics for SFR watersheds.

Watershed	Less than high school	High school graduate	Some college	Associate degree	Bachelor's degree	Post graduate degree
EBA	15.3%	15.2%	24.8%	1.9%	27.8%	15.1%
EHA	55.2%	20.2%	11.8%	1.4%	10.0%	1.4%
EMA	55.4%	28.9%	9.9%	2.0%	2.6%	1.2%
HLA	1.5%	7.0%	17.5%	4.2%	44.3%	25.5%
HPA	4.2%	7.3%	18.7%	0.0%	40.7%	29.0%
LCA	4.9%	10.7%	11.6%	3.5%	42.5%	26.8%
MI	2.6%	23.5%	26.2%	12.5%	23.4%	11.8%
RO	1.9%	8.6%	13.9%	1.7%	41.9%	32.0%
TBA	11.5%	19.1%	29.1%	5.1%	23.4%	11.7%
TCA	0.8%	5.5%	13.7%	5.8%	45.7%	28.5%
TPA	0.8%	5.5%	13.7%	5.8%	45.7%	28.5%

fertilizers are the pollutant of concern, demographics may not be an appropriate tool to identify potential problems.

These studies together would lead to the conclusion that wealth in itself does not result in better water quality. Rather, all citizens need to be better educated in ways to protect the environment and improve water quality but the education programs should be targeted to the particular audience in order to address likely problems. Low- and no-cost alternatives will be critical to achieve program success in areas of lower income.

Education

The final population demographic examined was educational attainment (*See* Table 9). The two watersheds with the poorest water quality (EMA and EHA) also have the lowest educational attainment levels. A regression analysis of percent educational attainment beyond high school and stormwater quality indicated a strong positive correlation ($r^2 = 0.63$), specifically regarding education levels greater than high school graduate. Watersheds with higher educational attainment tend to have better stormwater quality. As with income, this information does not signify a causal relationship. Bartlett (2006) found similar rates of activities, such as dumping grass clippings in storm drains, regardless of educational attainment.

Combined Demographics

Multivariate linear regression analysis was performed on these data. Using all four demographic factors resulted in the following relationship:

$$WQ = -0.89958 + 0.02302D - 1.001R + 0.00014206I + 1.272E$$

where,

- WQ = the water quality indicator variable,
- D = population density (people/acre),
- R = portion of the houses that are not owner-occupied (decimal),
- I = median household income in thousands, and
- E = is the fraction of the adult population with an educational attainment greater than high school (decimal).

This relationship has an $r^2 = 0.775$. Several of the factors are correlated to each other but collinearity analyses did not indicate a problem with the regression. Stepwise and backward selection analyses both indicated that educational attainment alone may be a suitable model but this model will miss subtle variations in watersheds with similar levels of education. Therefore, it is recommended the complete model be used. The level of importance of each factor, as determined by the analyses, are (in decreasing order) education, population density, rental occupancy, and income. Due to the correlation of the factors, this model should not be used to look at the impact of changing one factor while keeping the others constant. This will lead to erroneous results. As previously stated, these factors may not cause poor water quality but may be used as indicators to identify areas with potentially poor water quality. Tools like this analysis may be used for planning purposes when proposing new water quality or educational programs.

When the regression equation is applied to City-wide demographics it becomes easy to see areas that may have potential water quality problems associated with single-family residential land use (See Figure 3). While many of the areas indicated are normally associated with lower socio-economics, areas with potential for poor water quality are found throughout the City, including areas generally considered quite affluent. While the results of this analysis cannot conclusively determine if there is in fact a water quality problem in the orange areas and not in other areas, it will give planners another tool when deciding where to implement projects and will help narrow the scope when looking for problems.

The focus of this study was on SFR areas and did not address issues associated with multi-family residential (MFR) areas such as lofts, condominiums or apartments. These residential areas may have problems of their own related to higher densities and residents not having an ownership stake as noted with the SFR areas. These might be offset by having professional management for the common areas but it would depend on the quality of the management. In addition, MFR areas generally have higher levels of imperviousness compared to SFR which may mask any subtleties due to demographics.

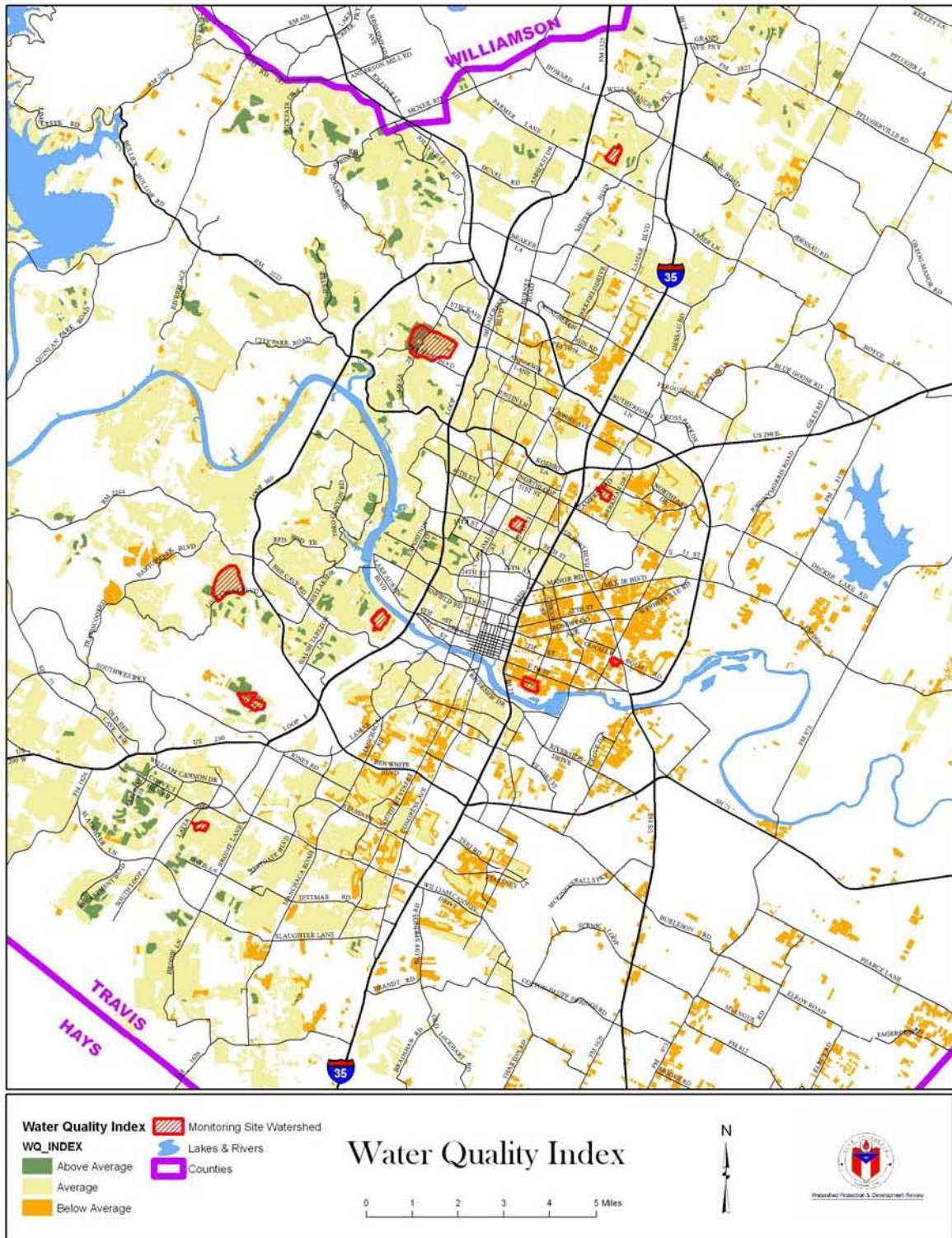


Figure 3: Water quality index model applied to demographics of Travis County, Texas.

Conclusions

Population demographics may be used to identify areas that may have water quality problems. Population density, owner occupancy, income and education are correlated to water quality. An equation was developed combining all these factors, which may be used for planning purposes. However, it is important to clarify that while correlation may exist among these factors, it may not be a causative relationship.

This study examined only the seventeen traditional stormwater pollutant listed previously and it appears these may be correlated to population demographics. Further, these results appear to indicate that better stormwater quality is associated with areas considered more affluent. This may be an erroneous interpretation when looking at individual pollutants or other pollutants not considered in this study. U.S. Geological Survey (Mahler, 2006a and 2006b) found levels of pesticides and PAHs were higher in areas generally considered more affluent. Additionally, surveys in North Carolina (Bartlett, 2006) found activities that may degrade stormwater quality in all demographic groups regardless of education or income. These studies taken together would indicate that demographics may be used as a tool to identify areas for more in-depth investigation, but the specific pollutants of concern should be considered as well.

References

- Bartlett, C. 2006. Outreach by the numbers. *Stormwater* 7(5):84-93
- City of Austin. 1990. *Stormwater pollution loading characteristics for various land uses in the Austin area*. Environmental Resource Management Division, Watershed Protection Department. Austin, TX 78767-1088.
- City of Austin. 1994. *Wet weather stormwater discharge characterization for the Austin, Texas, area*. Environmental Resource Management Division, Watershed Protection Department. Austin, TX 78767-1088.
- City of Austin. 1996a. *East Austin environmental initiative status report*. Environmental Resource Management Division, Watershed Protection Department. Austin, TX 78767-1088.
- City of Austin. 1996b. *Stormwater monitoring program descriptions, schedules, and site locations*. Environmental Resource Management Division, Watershed Protection Department. Austin, TX 78767-1088.
- City of Austin. 1997. *Evaluation of non-point source controls, an EPA/TNRCC section 319 grant report: Volume 1. Final Report*. Environmental Resource Management Division, Watershed Protection Department. Austin, TX 78767-1088.
- City of Austin. 2000. Block and block group demographic data from the 2000 census. Office of the City Demographer. Austin, TX 78767-1088.
- City of Austin. 2006. *Stormwater quality and quantity from small watersheds in Austin Texas*. Environmental Resource Management Division, Watershed Protection and Development Review Department. Austin, TX 78767-1088.
- Cochran, W.G. and G.M. Cox. 1957. *Experimental design*. John Wiley & Sons, Inc. New York.
- Gilbert, R.O. 1987. *Statistical methods for environmental pollution monitoring*. Van Nostrand-Reinhold. New York.
- Glick, R.H. 1992. *Native vegetation as nonstructural treatment of urban runoff*. Master's thesis. Texas A&M University. College Station, TX 77845.
- Lentner, M. and T. Bishop. 1986. *Experimental design and analysis*. Valley Book Co. Blacksburg, VA 24060.
- Mahler, B.J., et al. 2006a. *Concentrations, loads and yields of particle-associated contaminants in urban creeks, Austin, Texas, 1999-2004*. U.S. Geological Survey Scientific Investigation Report, in review.
- Mahler, B.J., et al. 2006b. *Historical (1975-2003) and recent (2003-2005) water quality of Barton Springs, Austin, Texas, and related conceptualization of the Barton Springs*

segment of the Edwards Aquifer. U.S. Geological Survey Scientific Investigation Report, in review.

SAS Institute, Inc. 1990. **SAS/STAT User's guide, Volume 2**. SAS Institute Inc. Cary NC 27513.

Appendix

Table A1. Duncan's test results for SFR sites, BOD.

Site	Number of EMCs	Geometric Mean (mg/l)	
EMA	27	28.06	a
EHA	31	19.37	ab
TPA	20	13.60	bc
HPA	16	10.66	cd
EBA	19	8.30	cde
TBA	31	7.90	cde
HLA	20	7.85	cde
MI	25	6.51	de
RO	14	5.69	e
LCA	22	5.26	e
TCA	20	4.57	e

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A2. Duncan's test results for SFR sites, Cd.

Site	Number of EMCs	Geometric Mean (ug/l)	
TBA	32	0.581	a
EHA	31	0.560	a
EMA	49	0.542	a
HPA	24	0.510	a
EBA	28	0.507	a
TPA	19	0.408	ab
TCA	19	0.321	b
HLA	1	0.306	b
LCA	12	0.306	b

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A3. Duncan's test results for SFR sites, COD.

Site	Number of EMCs	Geometric Mean (mg/l)	
EMA	49	118.80	a
EHA	33	105.04	a
TPA	22	65.06	b
HPA	25	64.31	b
EBA	30	57.51	b
TBA	31	53.83	b
LCA	22	43.71	bc
TCA	25	34.30	cd
MI	26	30.60	cde
RO	15	24.74	de
HLA	21	20.57	e

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A4. Duncan's test results for SFR sites, Cu.

Site	Number of EMCs	Geometric Mean (ug/l)	
EMA	49	11.86	a
HLA	20	11.21	a
EHA	31	10.17	a
LCA	19	7.27	ab
TPA	20	5.83	bc
HPA	24	5.81	bc
RO	14	5.70	bc
TBA	32	5.51	bc
MI	24	5.05	bc
EBA	28	4.89	bc
TCA	20	4.10	c

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A5. Duncan's test results for SFR sites, DP.

Site	Number of EMCs	Geometric Mean (mg/l)	
EHA	32	0.278	a
EMA	49	0.224	ab
HPA	25	0.209	ab
EBA	30	0.190	ab
TPA	18	0.179	abc
TCA	18	0.125	bc
TBA	30	0.096	cd
HLA	2	0.062	d
LCA	20	0.060	d

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A6. Duncan's test results for SFR sites, FCOL.

Site	Number of EMCs	Geometric Mean (colonies/100 ml)	
HPA	10	87125	a
EHA	23	74511	ab
EMA	21	54595	abc
EBA	16	51524	abc
TPA	15	49168	abc
MI	25	23471	bcd
TBA	25	17765	cd
LCA	19	17615	cd
TCA	15	14528	d
HLA	19	13745	d
RO	14	7379	d

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A7. Duncan's test results for SFR sites, FSTR.

Site	Number of EMCs	Geometric Mean (colonies/100 ml)	
EMA	24	388171	a
EHA	27	262446	a
HPA	12	187831	ab
EBA	16	105377	bc
TPA	17	98607	bc
TBA	26	67454	c
TCA	15	32471	d
RO	15	30804	d
MI	25	24788	de
LCA	18	21809	de
HLA	19	14307	e

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A8. Duncan's test results for SFR sites, NH₃.

Site	Number of EMCs	Geometric Mean (mg/l)	
EHA	32	0.254	a
TPA	22	0.223	ab
EBA	30	0.169	ab
EMA	49	0.152	abc
LCA	19	0.151	abc
TBA	29	0.150	abc
RO	15	0.148	abc
HLA	21	0.145	abc
MI	26	0.144	abc
HPA	22	0.116	bc
TCA	24	0.082	c

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A9. Duncan's test results for SFR sites, NO₃+ NO₂.

Site	Number of EMCs	Geometric Mean (mg/l)	
HLA	21	0.701	a
TPA	22	0.609	ab
EHA	32	0.606	ab
RO	15	0.602	abc
TBA	27	0.526	abc
LCA	21	0.500	abc
EMA	49	0.445	bc
EBA	30	0.441	bc
HPA	25	0.439	bc
TCA	23	0.409	bc
MI	26	0.401	c

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A10. Duncan's test results for SFR sites, Pb.

Site	Number of EMCs	Geometric Mean (ug/l)	
EHA	31	38.73	a
EMA	49	22.71	b
HLA	20	20.64	b
HPA	24	20.00	b
RO	14	11.29	c
TBA	32	9.16	c
EBA	28	9.11	c
TPA	20	8.42	cd
MI	24	7.38	cd
LCA	19	5.42	d
TCA	20	5.39	d

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A11. Duncan's test results for SFR sites, TKN.

Site	Number of EMCs	Geometric Mean (mg/l)	
EHA	32	3.09	a
EMA	48	2.38	ab
TPA	22	1.87	b
HPA	25	1.76	b
EBA	30	1.71	bc
TBA	31	1.13	cd
LCA	22	1.12	cd
TCA	25	0.85	de
RO	15	0.84	de
HLA	20	0.62	e
MI	26	0.59	e

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A12. Duncan's test results for SFR sites, TN.

Site	Number of EMCs	Geometric Mean (mg/l)	
EHA	31	3.698	a
EMA	48	2.914	ab
TPA	20	2.535	bc
HPA	25	2.276	bcd
EBA	30	2.253	bcd
TBA	27	1.908	cde
LCA	21	1.740	cde
RO	15	1.577	de
HLA	20	1.368	e
TCA	23	1.345	e

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A13. Duncan's test results for SFR sites, TOC.

Site	Number of EMCs	Geometric Mean (mg/l)	
EMA	49	20.25	a
EHA	33	17.16	ab
HPA	22	14.69	ab
EBA	30	11.92	bc
MI	26	11.74	bcd
RO	14	11.42	bcd
TPA	21	9.07	cde
LCA	18	7.71	cde
TCA	21	7.49	de
TBA	28	7.19	e
HLA	19	5.90	e

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A14. Duncan's test results for SFR sites, TP.

Site	Number of EMCs	Geometric Mean (mg/l)	
EHA	33	1.167	a
EMA	49	0.683	b
HPA	25	0.468	bc
EBA	30	0.460	bc
TPA	22	0.375	c
TBA	30	0.345	c
TCA	25	0.215	d
MI	26	0.214	d
LCA	22	0.163	d
RO	14	0.139	d
HLA	21	0.135	d

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A15. Duncan's test results for SFR sites, TSS.

Site	Number of EMCs	Geometric Mean (mg/l)	
EMA	48	229.8	a
EHA	33	202.1	a
MI	26	159.5	ab
RO	15	147.5	ab
TBA	31	130.0	ab
TPA	22	103.7	bc
LCA	20	94.9	bc
HPA	25	93.6	bc
HLA	21	89.3	bc
EBA	30	65.4	c
TCA	24	25.5	d

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A16. Duncan's test results for SFR sites, VSS.

Site	Number of EMCs	Geometric Mean (mg/l)	
EHA	33	55.33	a
EMA	48	55.11	a
LCA	17	39.30	ab
TPA	23	33.50	abc
HPA	24	31.61	abc
TBA	29	24.93	bc
EBA	29	22.90	bc
HLA	2	16.91	c
TCA	23	7.45	d

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A17. Duncan's test results for SFR sites, Zn.

Site	Number of EMCs	Geometric Mean (mg/l)	
EMA	49	133.74	a
EHA	31	115.22	a
HPA	24	96.70	a
TBA	32	59.62	b
LCA	19	45.39	bc
EBA	28	43.08	bc
TPA	20	40.57	bc
HLA	20	39.33	bc
RO	14	32.72	cd
MI	24	21.91	d
TCA	20	14.24	e

* Sites with a grouping letter in common are not significantly different at the 0.05 level.

Table A18. Duncan's test results for non-SFR sites, indicator variable.

Site	Number of EMCs	Standard Variable	
W5A	380	-0.667	a
GPI	233	-0.516	ab
LUA	421	-0.512	ab
CMI	348	-0.357	bc
BUA	257	-0.287	cd
WCI	482	-0.262	cd
E7A	418	-0.258	cd
ERA	306	-0.169	de
MBA	394	-0.054	ef
JVI	432	0.097	fg
S1M	439	0.150	gh
SWJ	225	0.191	ghi
WBA	442	0.196	ghi
OFA	256	0.236	ghi
BRI	310	0.326	hi
SWI	174	0.339	i
FPI	252	0.343	i
BNI	123	0.365	i
BSI	111	0.661	j
SI	308	0.670	j
BI	164	0.693	j
HI	274	0.802	j

* Sites with a grouping letter in common are not significantly different at the 0.05 level.