FINAL REPORT

PREDICTING EFFECTS OF URBAN DEVELOPMENT ON WATER QUALITY IN THE CITIES OF NEW BRAUNFELS, SAN MARCOS, SEGUIN AND VICTORIA

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PREDICTING EFFECTS OF URBAN DEVELOPMENT ON WATER QUALITY IN THE CITIES OF NEW BRAUNFELS, SAN MARCOS, SEGUIN AND VICTORIA

Prepared in Cooperation with the:
Guadalupe-Blanco River Authority
and the
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under the Authority of the Texas Clean Rivers Act

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EXECUTIVE SUMMARY

Over the last two decades there has been a growing interest in management of nonpoint source runoff. The US EPA has instituted urban runoff programs for larger cities, and efforts are underway to extend these programs to moderate sized communities via the Phase II regulations for Municipal Separate Storm Sewer Systems (MS4). While the concern with urban runoff is strong at the federal and state governmental levels, there is not yet a widespread public understanding of the processes involved and the methods of dealing with the concerns. This Clean Rivers Program report is an attempt to address the public understanding issue by applying the lessons learned in two decades of central Texas urban runoff study to specific watersheds in four growing cities in the Guadalupe River Basin. The intent is for city officials and concerned citizens to use the information developed here for their streams as a basis for taking effective action to avoid the predicted impacts.

The report focuses on four cities in the basin: Victoria, Seguin, New Braunfels, and San Marcos. These, together with Kerrville that was addressed earlier, are the cities in the basin that will be covered in the new Phase II MS4 regulations. The first part of the report reviews the urban runoff monitoring results from the City of Austin, and develops relationships between changes in urban development and the quality of runoff waters in urban streams. Consistent with other studies of the phenomena, the major finding was the effect of impervious cover causing increases in the amount of runoff. The greater quantity of runoff increases the amount of streambed scour that gives higher pollutant concentrations. Streams with higher development (greater impervious cover) exhibited higher average runoff concentrations of all parameters considered.

The next report section presents a quantification of changes in stream runoff quantity and quality in response to projected urban development in the four cities. Particular attention is devoted to differences in the receiving waters in each urban area. All the cities are growing and each watershed considered will have more impervious cover in the future. Based on the Austin experience, this will mean increases in runoff pollutant loads from each stream considered.

The final section puts the runoff load changes into context. It addresses the types of water quality effects that can be expected both in the urban streams and in the waters immediately downstream. The section also discusses the possible means that could be considered to manage the water quality effects. This includes a series of actions ranging from stream setbacks, impervious cover limitations and various types of runoff controls. Based on the Austin and national experience, the most important goal is to minimize the hydrologic changes that come with development. If new developments can include design features to retain and infiltrate rainwater in a similar fashion to the land before development, most of the impact on receiving streams can be avoided. This approach is known as Low Impact Development (LID). While LID may be the ultimate solution, it may be some time before it is widely accepted. In the meantime cities should begin now to address upcoming storm water regulations considering actual local effects expected and the values and priorities of their community.

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ACKNOWLEDGMENTS

This project was recommended and supported by the Texas Clean Rivers Program (CRP) Basin Steering Committee. Debbie Magin of the Guadalupe-Blanco River Authority was instrumental in organizing and supporting the effort.

The following agencies were very helpful in providing site-specific information in each city:

- Planning Department of the City of Victoria
- Public Works Department of the City of Seguin
- Planning Department of the City of New Braunfels
- Engineering Department of the City of San Marcos

Much of the report is drawn from work performed by the City of Austin. The City of Austin staff, particularly Dr. Roger Glick, was very helpful with data and technical assistance.

Karl McArthur contributed much in the development of percentage impervious cover using geographic information system technology. He and Jeff Kessel have provided thoughtful comments on an early draft of the report.

1.0 INTRODUCTION AND SUMMARY

Over the last two decades there has been a growing realization that with point source wastewater discharges now treated to very high levels, the primary water quality issues are with nonpoint source runoff. The US EPA has instituted urban runoff programs for the larger cities, and efforts are underway to extend these programs to moderate sized communities via the Phase II regulations for Municipal Separate Storm Sewer Systems (MS4).

While the concern with urban nonpoint source runoff is strong at the federal and state governmental levels, there is not yet a widespread public understanding of the processes involved and the methods of dealing with the concerns. The technical understanding of the issues and the types of controls that will be most effective, while substantial, is still evolving. In short, urban runoff concerns are poorly understood by the public, and the technical means to address these concerns effectively are still being developed.

This report is an attempt to address the first issue, public understanding and involvement, by applying the lessons learned in two decades of central Texas urban runoff study to specific watersheds in four growing cities in the Guadalupe River Basin. The intent is for city officials and concerned citizens to use the information developed here for their streams as a basis for taking effective action to avoid the predicted impacts.

The project was conceived and supported by the Texas Clean Rivers Program. The CRP was created in the 1991 legislative session to specifically address water quality concerns in the state's rivers and reservoirs. One of the main thrusts of the CRP is in developing public knowledge and support for dealing with water quality issues. In the Guadalupe River basin, the Guadalupe-Blanco River Authority (GBRA), together with the Upper Guadalupe River Authority (UGRA) have managed the CRP effort. One of the means they have employed to obtain public input and priorities has been through a Basin Steering Committee composed of community leaders throughout the basin.

With the support of the Basin Steering Committee, this project was designed to enhance public understanding of urban nonpoint source runoff issues by developing a preliminary quantification of urbanization effects. Recognizing that there has been essentially no urban runoff monitoring in the basin, the quantification is based on available data from other areas, primarily the City of Austin. The goal is to improve the level of public understanding of the issues that will provide a stronger basis for public action and support for efforts to manage and mitigate the effects of urbanization on water quality. The report focuses on four cities in the basin: Victoria, Seguin, New Braunfels, and San Marcos. These, together with

Kerrville that was addressed earlier, are the cities in the basin that will be covered in the new Phase II MS4 regulations.

Section 2.0 of this report reviews the urban runoff monitoring results from the City of Austin, and develops relationships between changes in urban development and the quality of runoff waters in urban streams. Consistent with other studies of the phenomena, the major finding was the effect of impervious cover causing increases in the amount of runoff. The greater quantity of runoff increases the amount of streambed scour. Streams with higher development (higher impervious cover percentage) exhibited higher average concentrations of all parameters considered.

The third report section presents a quantification of changes in stream runoff quantity and quality in response to projected urban development in the four cities. Victoria is described first, followed by San Marcos, New Braunfels and Seguin. Particular attention is devoted to differences in the receiving waters in each urban area. All the cities are growing and each watershed considered will have more impervious cover in the future. Based on the Austin experience, this will mean increases in runoff pollutant loads from each stream considered.

Section 4.0 attempts to put the changes in runoff loads into context. It addresses the types of water quality effects that can be expected both in the streams and in the waters that receive the urban runoff. The section also discusses briefly the possible means that could be considered to address or manage the water quality effects. This includes a series of actions ranging from stream setbacks, impervious cover limitations and various types of runoff controls. Based on the Austin experience, the most important goal appears to be to avoid or at least minimize the hydrologic changes that come with development. If new developments can include design features to retain and infiltrate rainwater in a similar fashion to the land before development, much of the impact on receiving streams can be avoided. This approach is called Low Impact Development (LID). While LID may be the ultimate solution, it is likely to take some time to be widely accepted and in some cases can be expensive. It is recommended that cities begin now to address upcoming storm water regulations considering actual local effects expected and the values and priorities of their community.

2.0 REVIEW OF CITY OF AUSTIN STREAM MONITORING DATA

The City of Austin has had a strong interest in analyzing urban water quality conditions for many decades and has had active monitoring programs dating back to the 1970s. This section summarizes work performed by the City and lays the groundwork for a methodology to assess development impacts.

The City has been responsible for two types of water quality monitoring activity. One is monitoring of the major creeks in the urban area under both runoff and base flow conditions. This is performed by the USGS under contract to the City. Figure 2-1 shows the locations of the USGS monitoring sites. The other major type of urban water quality monitoring is for smaller, typically single land use watersheds. City personnel perform this monitoring. Active monitoring stations run by the City are shown in Figure 2-2.

The creek monitoring performed by the USGS under contract to the City of Austin has included collecting flow-weighted averages of many parameters during rain events as well as non-rain periods. Table 2-1 describes the creek monitoring sites and the percentage that runoff flows represent of the overall creek flow. For example, with Barton Creek at Hwy 71, 36% of the total flow is rainfall runoff while the remaining 64% of the total flow is not associated with runoff. Almost all of these partly urbanized creeks in the Austin area are intermittent. However, they are large enough to have flows not associated with runoff, at least during relatively wet periods. Only during prolonged dry periods do most of the creeks cease flowing entirely.

As noted above, the City has been monitoring smaller, single land use sites with varying degrees of urbanization. Table 2-2 lists the smaller City sites that were included in the City's 1997 data report, along with the land use and impervious cover percentages for these smaller watersheds. The ID numbers for the sites that are currently being used (Figure 2-2) is included in the left column of Table 2-2. Note that the largest drainage area shown in Table 2-2 is 371 acres (ac), while the smallest creek site listed in Table 2-1 is 1,443 ac. All of the smaller sites are normally dry and are only sampled during runoff conditions.

One of the fundamental aspects of urban water quality conditions is the effect of impervious cover (streets, roofs, etc.) on increasing runoff volume. One measure is the Runoff Coefficient (Rv), defined as the ratio of total runoff depth to total rain depth for all runoff events in a normal rainfall year. Figure 2-3, reproduced from the City of Austin (1997) shows Rv plotted against the percentage of impervious cover in the non-recharge zone. The City (1997) notes that this relation is similar for the larger creek watersheds with the exception of two creeks where a recharge channel and stormwater detention basins act to reduce the average amount of runoff that would be predicted by the amount of impervious cover.

Figure 2-1
USGS Stream Monitoring Sites

USGS Stream Monitoring Sites

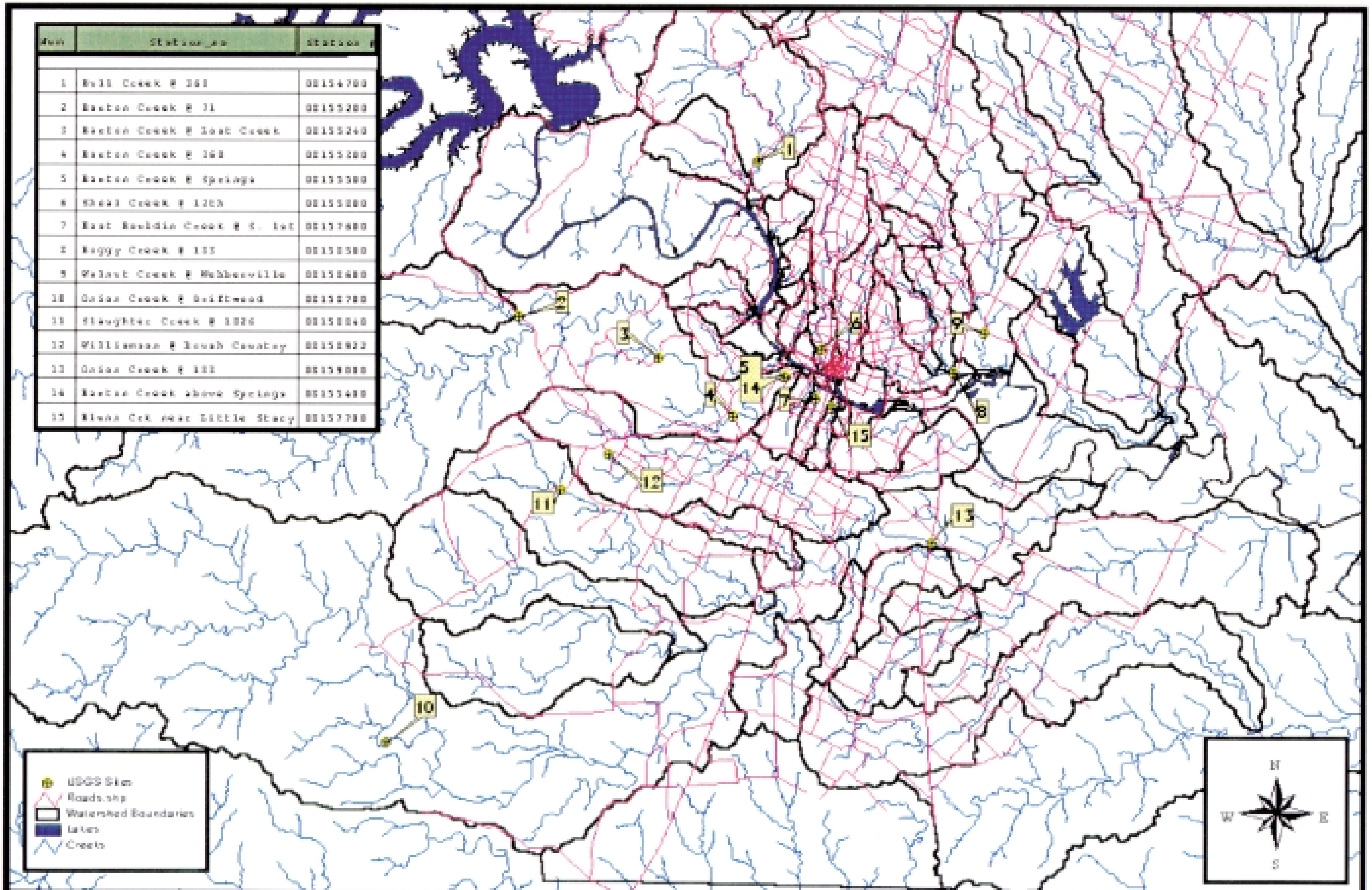


Figure 2-2
City of Austin Stormwater Sites

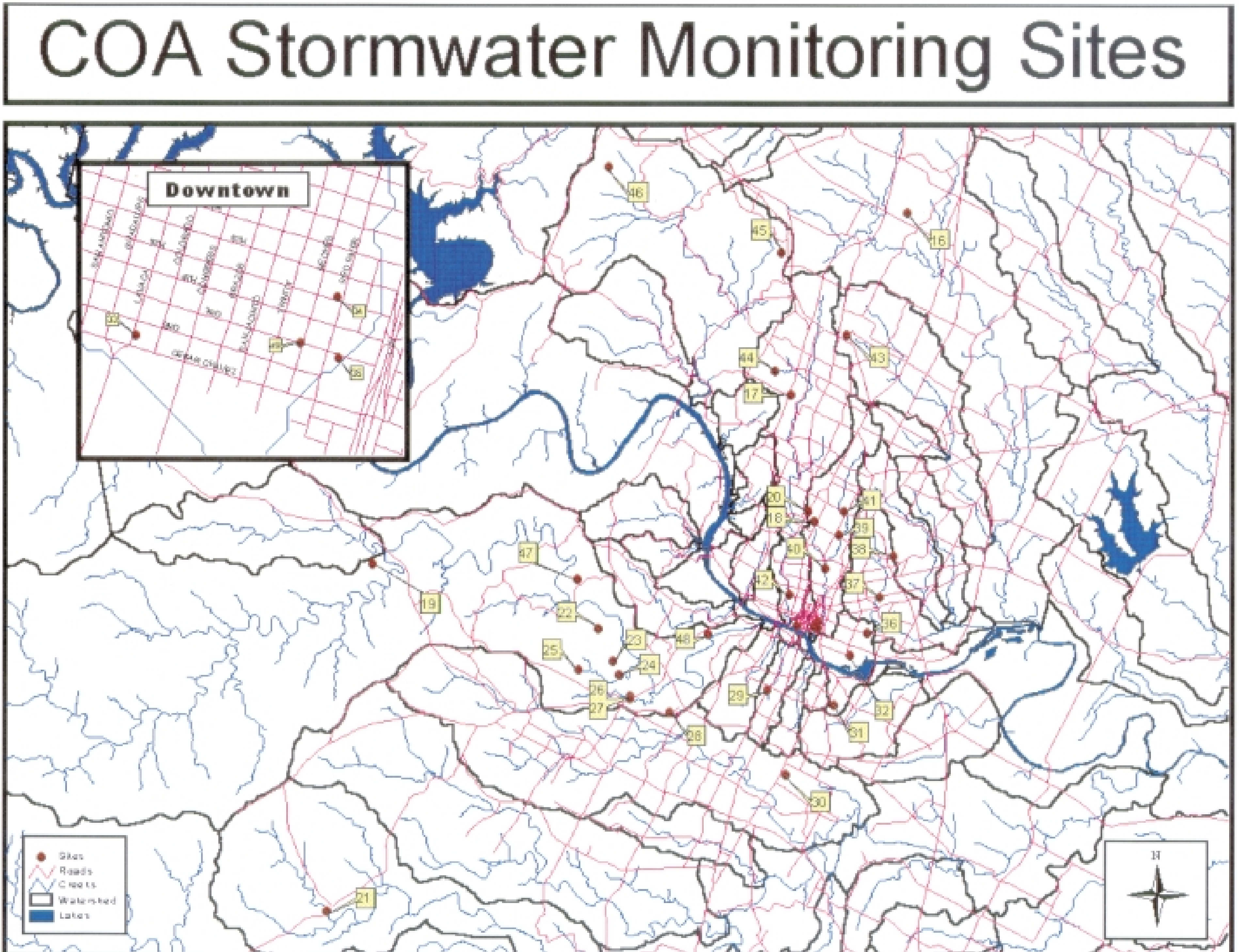


TABLE 2-1
USGS - CITY OF AUSTIN CREEK MONITORING DATA

ID Number[1]	Creek Monitoring Site	Drainage Area		Impervious Cover (%)	Landuse	Period of Record	Runoff to Streamflow (%)
		(Acres)	(Sq. Miles)				
1	Bull Creek @ Loop 360	14,272	22.3	16	Mixed	78-96	39
2	Barton Creek @ Hwy 71	57,408	89.7	3	Mixed	78-96	36
3	Barton Creek @ Lost Ck. Blvd.	68,480	107.0	4	Mixed	89-96	36
4	Barton Creek @ Loop 360	74,240	116.0	5	Mixed	78-96	51
6	Shoal Creek @ 12th St.	7,872	12.3	46	Mixed	75-96	87
	Waller Creek @ 38th St.	1,443	2.3	47	Mixed	92-95	89
	Waller Creek @ 23rd St.	2,624	4.1	49	Mixed	92-95	87
8	Boggy Creek @ Hwy 183	8,384	13.1	43	Mixed	75-96	92
9	Walnut Creek @ Webberville Rd	32,832	51.3	26	Mixed	78-96	59
10	Onion Creek near Driftwood	79,360	124.0	3	Mixed		
	Bear Creek @ FM 1826	7,808	12.2	5	Mixed	78-96	28
11	Slaughter Creek @ FM 1826	5,274	8.2	8	Mixed	78-96	35
	Williamson Creek @ Oak Hill	4,032	6.3	22	Mixed	78-96	54

Source: City of Austin, 1997, Evaluation of Non-point Source Controls, Volumes 1-2,
Report COA-ERM/WQM & WRE 1997-04

[1] Refer to Figure 2-1 USGS Stream Monitoring Sites

TABLE 2-2
CITY OF AUSTIN URBAN RUNOFF MONITORING SITES

ID Number[1]	Code Name	Site Name	Drainage Area (Acres)	Impervious Cover (%)	Landuse	No. of Measure-ments	Mean Rv
	AV	Alta Vista PUD	0.7	62	Manufactured	19	0.422
	BC	Bear Ck. Near Lake Travis	301.0	3	Undeveloped	23	0.014
	BCSM	Barton Creek Square Mall	47.0	86	Commercial	23	0.784
27	BNI	Roadway #6 BMP inflow	4.9	59	Transportation	8	
28	BRI	Barton Ridge Plaza	3.0	80	Commercial	17	0.765
26	BSI	Roadway BMP # 5 inflow	4.6	64	Transportation	5	0.662
31	BUA	Burton Road	12.0	82	Manufactured	17	
36	E7A	Seventh Street East	29.3	70	Industrial	10	
38	ERA	Municipal Airport	99.1	46	Industrial	15	0.365
19	FWU	Windago Way	50.0	1	Undeveloped	13	0.036
	HI	Highwood Apt.	3.0	50	Manufactured	25	
44	HL	Hart Lane	371.0	39	SF Residen.	33	0.163
45	JVI	Jollyville Rd	7.0	94	Transportation	28	0.711
47	LCA	Lost Creek Subdivision	209.9	23	SF Residential	18	0.102
33	LUA	Lavaca Street	13.7	97	Commercial	24	
43	MBA	Metric Blvd.	202.9	60	Industrial	22	0.511
	MI	Maple Run	27.8	36	SF Residential	25	
48	OFA	Spy Glass	3.0	88	Office	13	0.797
	RO	Rollingwood	62.8	21	SF Residential	19	0.05
30	SWI	St. Elmo St. East	16.4	60	Industrial	6	0.592
23	TCA	Travis Co. Ditch	40.7	37	SF Residential	22	0.178
24	TPA	Travis Co. Pipe	41.6	41	SF Residential	18	0.167
34	W5A	Waller Creek @ 5th St	4.0	95	Commercial	18	

Source: City of Austin, 1997, Evaluation of Non-point Source Controls, Volumes 1-2, Report COA-ERM/WQM & WRE 1997-04

[1] Refer to Figure 2-2 COA Stormwater Sites

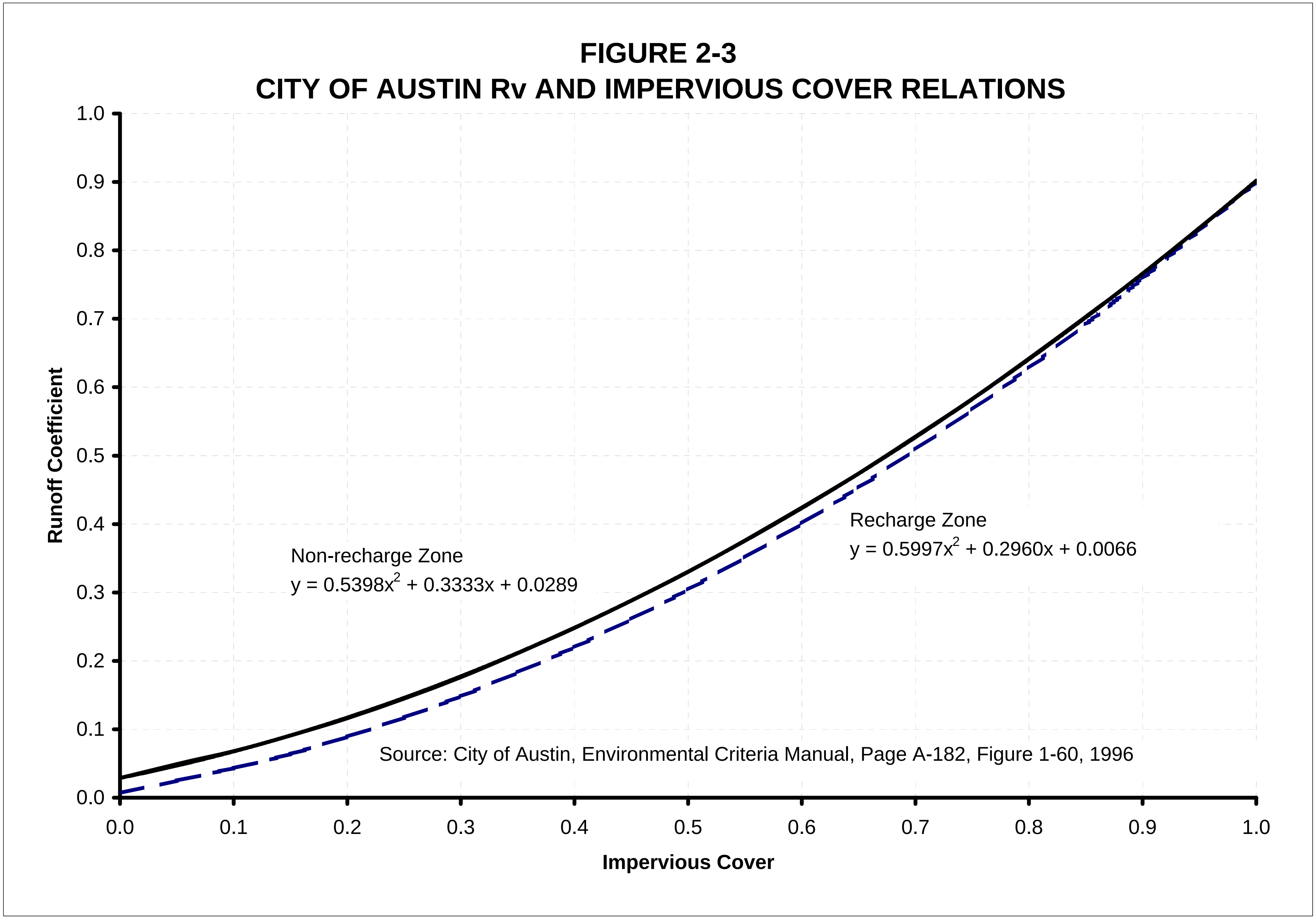


FIGURE 2-3
CITY OF AUSTIN Rv AND IMPERVIOUS COVER RELATIONS
Runoff Coefficient
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Non-recharge Zone
y = 0.5398x2 + 0.3333x + 0.0289
Recharge Zone
y = 0.5997x2 + 0.2960x + 0.0066
Source: City of Austin, Environmental Criteria Manual, Page A-182, Figure 1-60, 1996
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Impervious Cover

Another way to view the effect of impervious cover on runoff is use a runoff model. This is illustrated in Figure 2-4, taken from the Texas Nonpoint SourceBOOK; a web page developed for the Texas Public Works Association. For an example 1 square mile watershed and a given 3.8-inch rain, the figure shows how the runoff hydrograph changes in response to development. As the land is developed from woodland to paved surface, the amount of total runoff increases from about 1.37 inches to 3.5 inches, and the peak flow goes from about 600 cfs to nearly 2,000 cfs. An undeveloped parcel of land will have most of the rain either caught in vegetation and evaporated or soaked into the soil, while a fully developed site will have most of the rain leave the site as runoff.

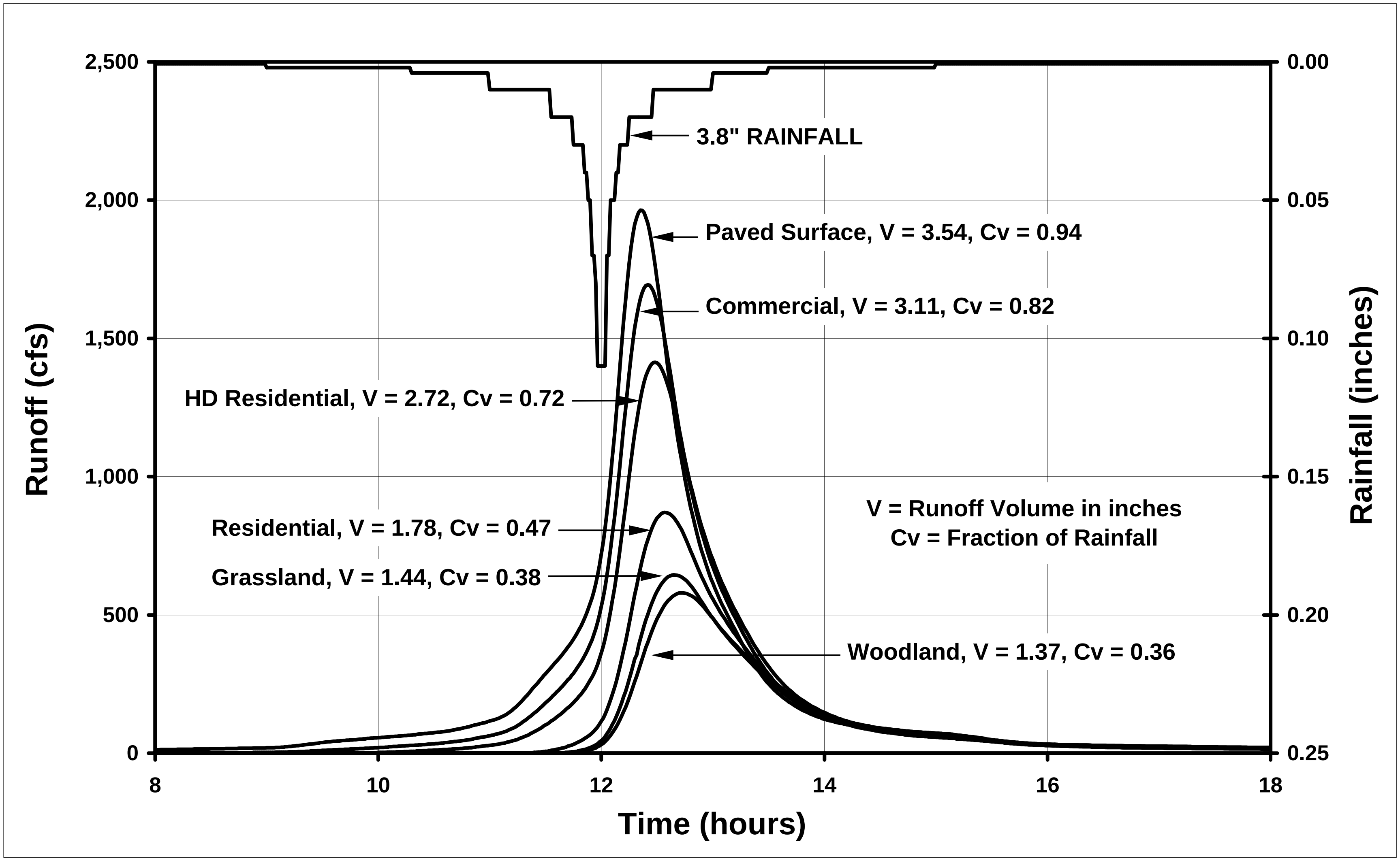
When discussing the quality of runoff samples, it is customary to employ a flow-weighted average, frequently called an Event Mean Concentration (EMC). This is necessary because the concentration of any parameter varies greatly during runoff events. A good example is the well-known first flush effect, where the initial concentration of dissolved and particulate matter in the runoff is markedly higher than in samples collected later in the event. Chang et al (1990) and (1994) note how this phenomenon is strongest for smaller watersheds with higher impervious cover percentages. An EMC is calculated from individual flow and concentration measurements taken during the course of the runoff event, considering the initial runoff and the trailing limb of the hydrograph.

Concentrations in stormwater are highly variable during a rain event and also vary substantially from one rain event to the next. Some of the reasons for the variability include differences in the size and intensity of the rain and differences in antecedent soil moisture conditions from one event to the next. Because of this variability the long-term concentration value for a site is an average or sometimes the median of a number of EMC values. With the data to be discussed, the City of Austin acceptance criteria was a minimum of 12 EMC values, with each consisting of at least three sets of flow and concentration for each parameter. Most sites have considerably more data.

Table 2-3 presents for the city stations the long-term flow-weighted average of Total Suspended Solids (TSS), Total Nitrogen (TN, the sum of Total Kjeldahl and Nitrate-Nitrite-N), Total Phosphorus (TP) and Fecal Coliform (FC). Also included are the medians of all the EMC observations for TSS and FC. Note that the flow-weighted average values are somewhat higher than the medians of the EMC observations.

Table 2-4 presents similar long-term average values for the same parameters for the USGS creek monitoring stations. With the USGS data the city computed the long-term average using empirical relations between flow and concentration for each site, using a method developed by the USGS. Also shown in Table 2-4 are the average concentrations collected under baseflow or non-runoff conditions. The non-runoff averages are substantially lower than the runoff data, as illustrated in Figure 2-5 for TSS and Figure 2-6 for FC. While the runoff concentrations are orders of magnitude larger than non-runoff data,

FIGURE 2-4
EFFECTS OF DEVELOPMENT ON RUNOFF VOLUMES



Source: Texas Nonpoint SourceBOOK, www.TXNPSbook.org

TABLE 2-3
CITY OF AUSTIN URBAN RUNOFF CONCENTRATION VALUES

Site Name	Impervious Cover (%)	Flow-weighted Mean				Median of All EMC Data			
		TSS (mg/L)	TN (mg/L)	TP (mg/L)	FC (cfu/dL)[1]	TSS (mg/L)	TN (mg/L)	TP (mg/L)	FC (cfu/dL)[1]
Alta Vista PUD	62	23	2.10	0.52		20	2.07	0.46	22,918
Bear Ck. Near Lake Travis	3	113	0.49	0.05	24,552	30	0.39	0.04	3,847
Barton Creek Square Mall	86	214	2.05	0.25		133	1.73	0.21	34,208
Roadway #6 BMP inflow	59	444	1.90	0.49		245	1.36	0.26	
Barton Ridge Plaza	80	224	2.23	0.33	12,482	183	1.94	0.27	1,737
Roadway BMP # 5 inflow	64	117	1.44	0.28		90			
Burton Road	82	267	2.36	0.52	84,797	127	2.10	0.42	42,117
Seventh Street East	70	123	2.07	0.67	83,866	98	1.86	0.54	29,082
Municipal Airport	46	51	2.02	0.70	11,378	42	1.74	0.55	6,939
Windago Way	1	254	1.61	0.15	15,729	105	1.30	0.14	3,776
Highwood Apt.	50	110	1.01	0.20	39,166	70	0.69	0.12	5,265
Hart Lane	39	187	2.06	0.29	48,097	93	1.65	0.20	9,474
Jollyville Rd	94	328	1.56	0.24		248	1.39	0.20	
Lost Creek Subdivision	23	117	1.68	0.29	28,149	70	1.55	0.13	12,377
Lavaca Street	97	162	2.37	0.45	58,726	136	2.51	0.46	33,568
Metric Blvd.	60	277	2.00	0.43	18,311	165	1.98	0.42	8,483
Maple Run	36	305	1.23	0.25	35,600	111	0.88	0.19	15,189
Spy Glass	88	43	2.12	0.18	14,815	35	2.10	0.16	8,945
Rollingwood	21	228	1.92	0.27	15,180	133	1.63	0.18	5,663
St. Elmo St. East	60	172	1.87	0.31	30,426	109	1.73	0.29	7,391
Travis Co. Ditch	37	40	1.45	0.23	46,041	18	1.35	0.19	14,510
Travis Co. Pipe	41	139	2.17	0.45	36,458	84	2.17	0.38	34,615
Waller Creek @ 5th St	95	142	3.30	0.59	53,650	118	3.03	0.55	42,359

Source: City of Austin, 1997, Evaluation of Non-point Source Controls, Volumes 1-2, Report COA-ERM/WQM & WRE 1997-04

[1] (Colony forming unit/deciLiter)

TABLE 2-4

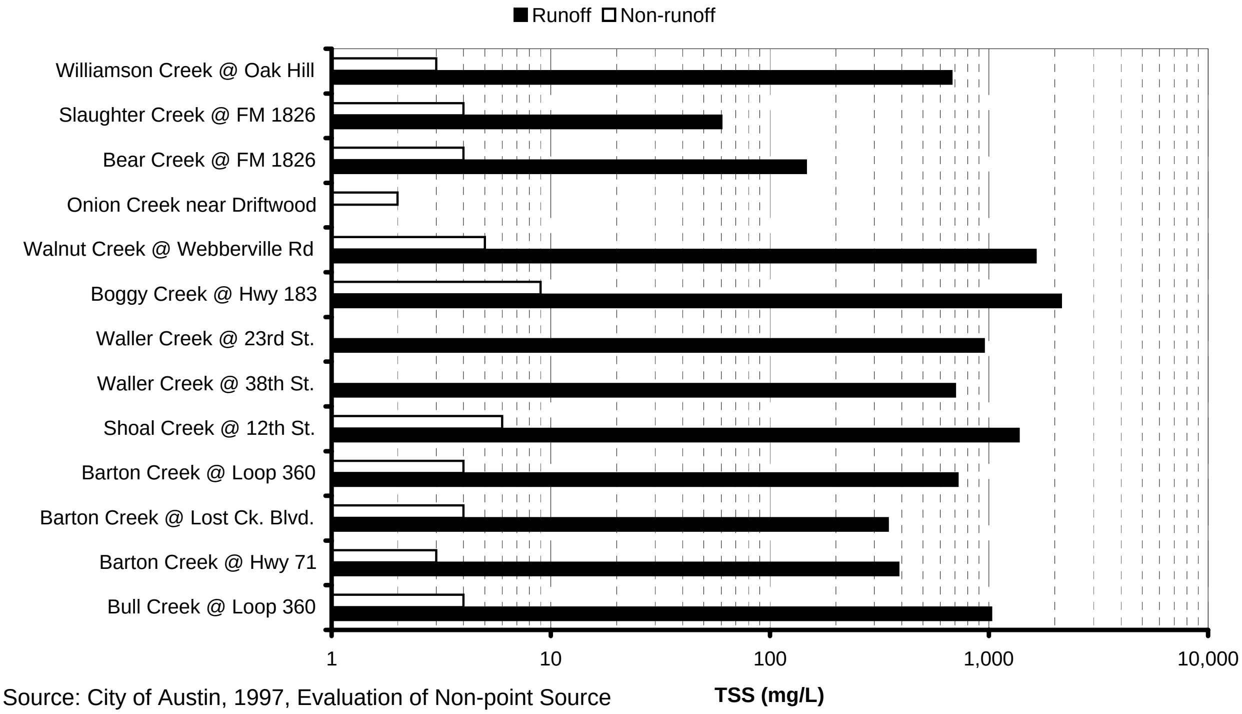
LARGE CREEK FLOW WEIGHTED AVERAGE RUNOFF AND NON-RUNOFF CONCENTRATION VALUES

Creek Monitoring Site	Impervious Cover (%)	Runoff				Non-runoff			
		TSS (mg/L)	TN (mg/L)	TP (mg/L)	FC (cfu/dL)[1]	TSS (mg/L)	TN (mg/L)	TP (mg/L)	FC (cfu/dL)[1]
Bull Creek @ Loop 360	16	1,023	2.90	0.28	29,426	4	0.55	0.02	564
Barton Creek @ Hwy 71	3	386	1.09	0.11	13,625	3	0.37	0.02	67
Barton Creek @ Lost Ck. Blvd.	4	345	1.05	0.13	12,381	4	0.39	0.03	80
Barton Creek @ Loop 360	5	719	2.08	0.18	22,940	4	0.62	0.01	38
Shoal Creek @ 12th St.	46	1,364	3.29	0.92	155,398	6	1.04	0.05	9,450
Waller Creek @ 38th St.	47	700	3.86	0.95	67,599				
Waller Creek @ 23rd St.	49	947	3.94	1.15	102,609				
Boggy Creek @ Hwy 183	43	2,131	3.74	1.35	190,441	9	0.82	0.05	3,023
Walnut Creek @ Webberville Rd	26	1,632	2.17	0.75	53,133	5	1.05	0.03	533
Onion Creek near Driftwood	3					2	0.42	0.02	85
Bear Creek @ FM 1826	5	146	1.09	0.05	5,217	4	0.52	0.02	112
Slaughter Creek @ FM 1826	8	60	1.00	0.06	20,131	4	0.51	0.02	94
Williamson Creek @ Oak Hill	22	674	2.91	0.51	71,197	3	0.56	0.17	251

Source: City of Austin, 1997, Evaluation of Non-point Source Controls, Volumes 1-2, Report COA-ERM/WQM & WRE 1997-04

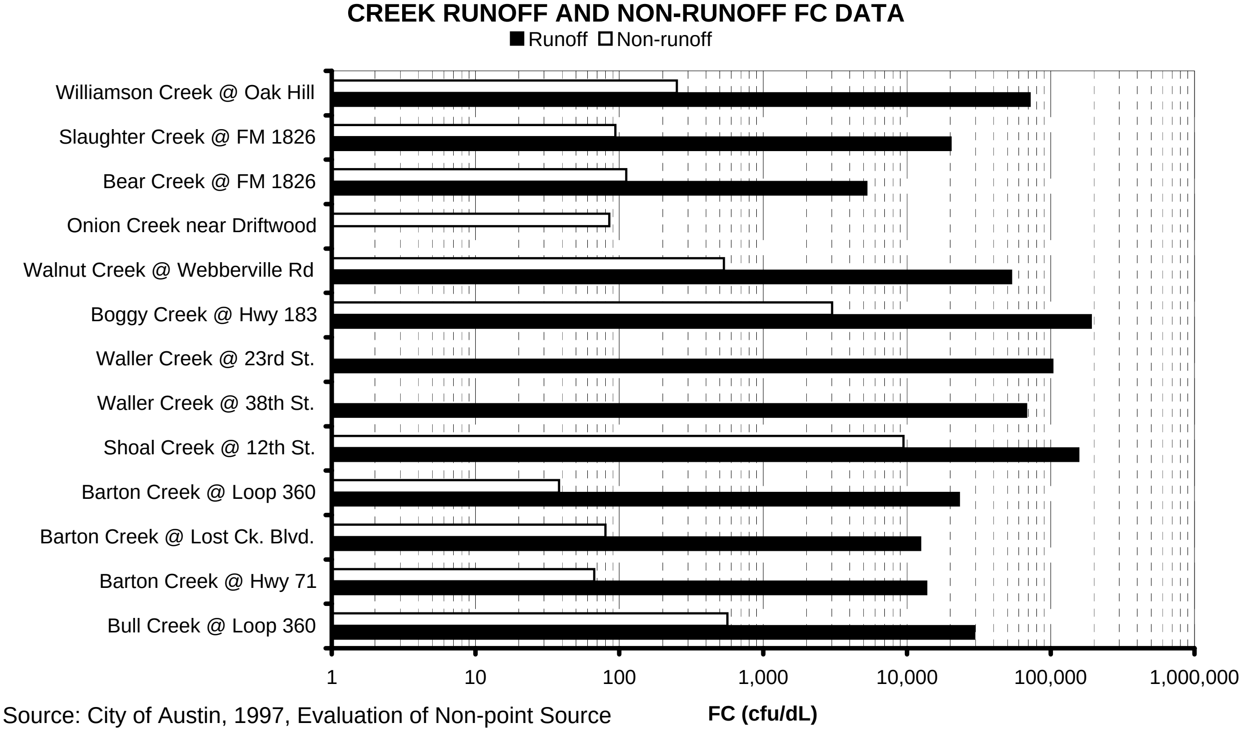
[1] (Colony forming unit/deciLiter)

FIGURE 2-5
CREEK RUNOFF AND NON-RUNOFF TSS DATA



Source: City of Austin, 1997, Evaluation of Non-point Source Controls, Volumes 1-2, Report COA-ERM/WQM & WRE 1997-04

FIGURE 2-6
CREEK RUNOFF AND NON-RUNOFF FC DATA



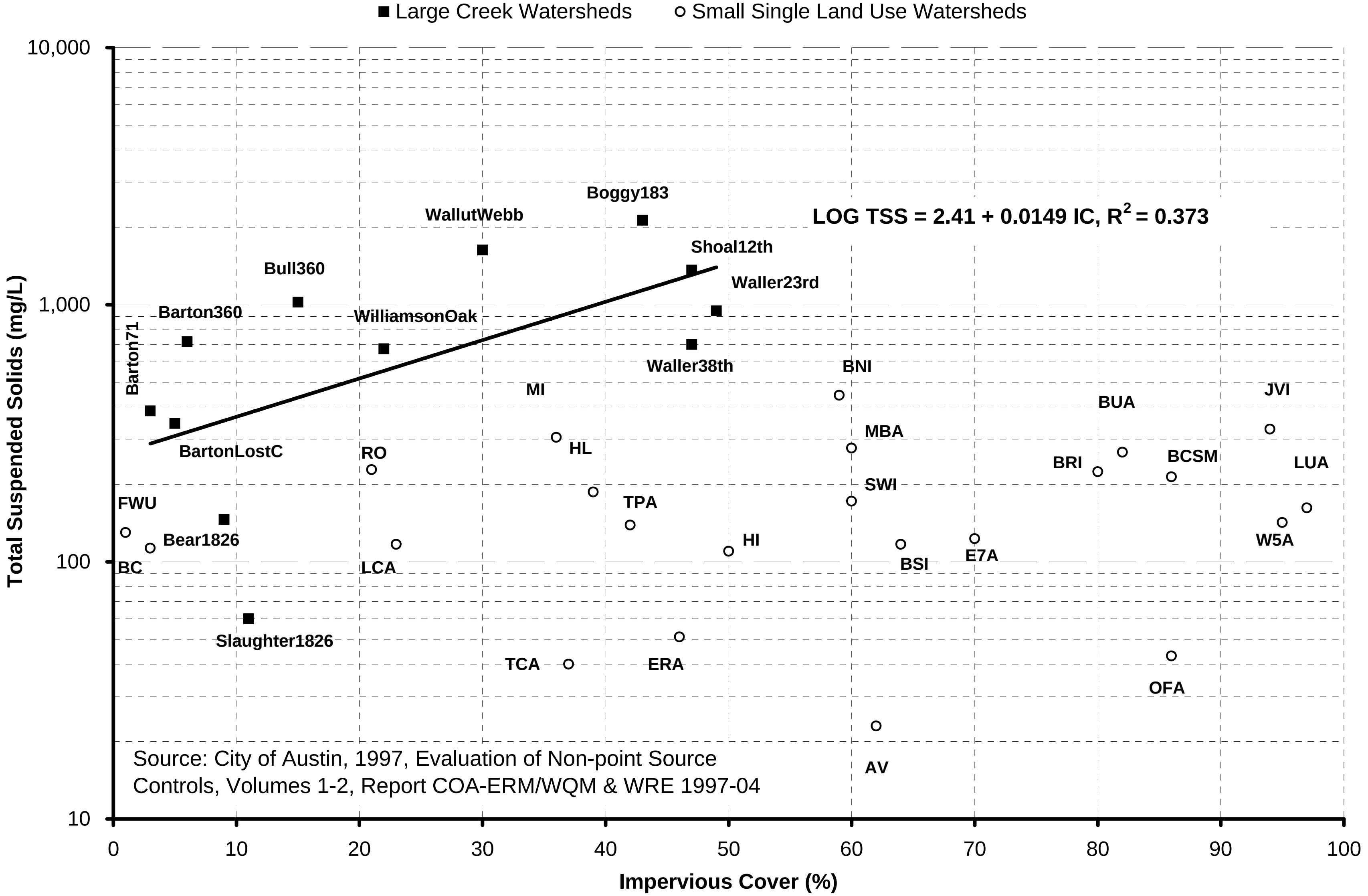
Source: City of Austin, 1997, Evaluation of Non-point Source Controls, Volumes 1-2, Report COA-ERM/WQM & WRE 1997-04 the runoff conditions are relatively rare, lasting only a matter of hours each month. With FC, the runoff data are much higher than the geometric mean level of 200 cfu/dL the state water quality criterion for contract recreation use. The sites that have water and can be sampled during non-runoff periods (the creek stations) have much lower FC levels at these times. Accordingly, there appears to be little doubt that a major factor in stream FC bacteria levels is the presence of runoff. Landuse may not be as important a factor in the concentration of bacteria in runoff, but it is clearly a major factor in runoff flows, which appear to be a major factor in creek scour and the resultant concentrations of most parameters.

Figure 2-7 shows the long-term average EMCs for TSS for both the smaller sites and the larger creek sites listed in Tables 2-3 and 2-4, plotted versus impervious cover percentage in the contributing watershed. One observation from Figure 2-7 is that there is a major difference between the TSS levels in the smaller city sites and the larger creek sites. While the smaller sites are tributaries to the larger creek sites, the values appear to be substantially lower than the creek sites. The major reason for the difference noted by the City (1990) is erosion of the creek beds and banks due to greater flow energy. The smaller sites are almost always in a drainage structure such as a culvert or grassed channel where erosion is not a factor, while the creek sites are in streams that have a natural bottom. During runoff events, the creeks with a much larger volume of flow experience scour of the streambed, putting sediment into suspension at concentrations considerably higher than that of the small tributary inflows. This streambed scour is accelerated by larger amounts of runoff flows produced by higher impervious cover in some of the watersheds. In contrast, the smaller sites do not have established and erodable channels, and contribute relatively low TSS concentrations whether they have low or high impervious cover.

The other major observation from Figure 2-7 is the different responses of the smaller and larger watersheds to impervious cover. For the smaller urban sites, there does not appear to be a relation between the intensity of landuse, as indicated by impervious cover percentage, and the long-term average runoff concentrations of TSS. With the larger creek sites in Figure 2-7, there does appear to be somewhat higher TSS concentrations with greater impervious cover. The regression line and equation fitted to the creek data has a correlation coefficient of 0.61.

A similar pattern can be seen for TN in Figure 2-8, TP in Figure 2-9, and FC in Figure 2-10. In some cases there may be a relation for the smaller sites, but if a relation exists, it is not strong. In general, increasing the amount of paved or roofed impervious surface in smaller watersheds does not generate additional erodable particulate matter or associated nutrients or bacteria so there is little change in the concentrations of these parameters with increasing impervious cover. In the smaller watersheds, say a parking lot, the amount of particulate matter that can be washed off in a rain is finite. In the creeks however, increasing impervious cover in the watershed increases the amount of runoff and stream flow, which

FIGURE 2-7
TSS MEAN EMCs FOR CITY OF AUSTIN STORMWATER RUNOFF



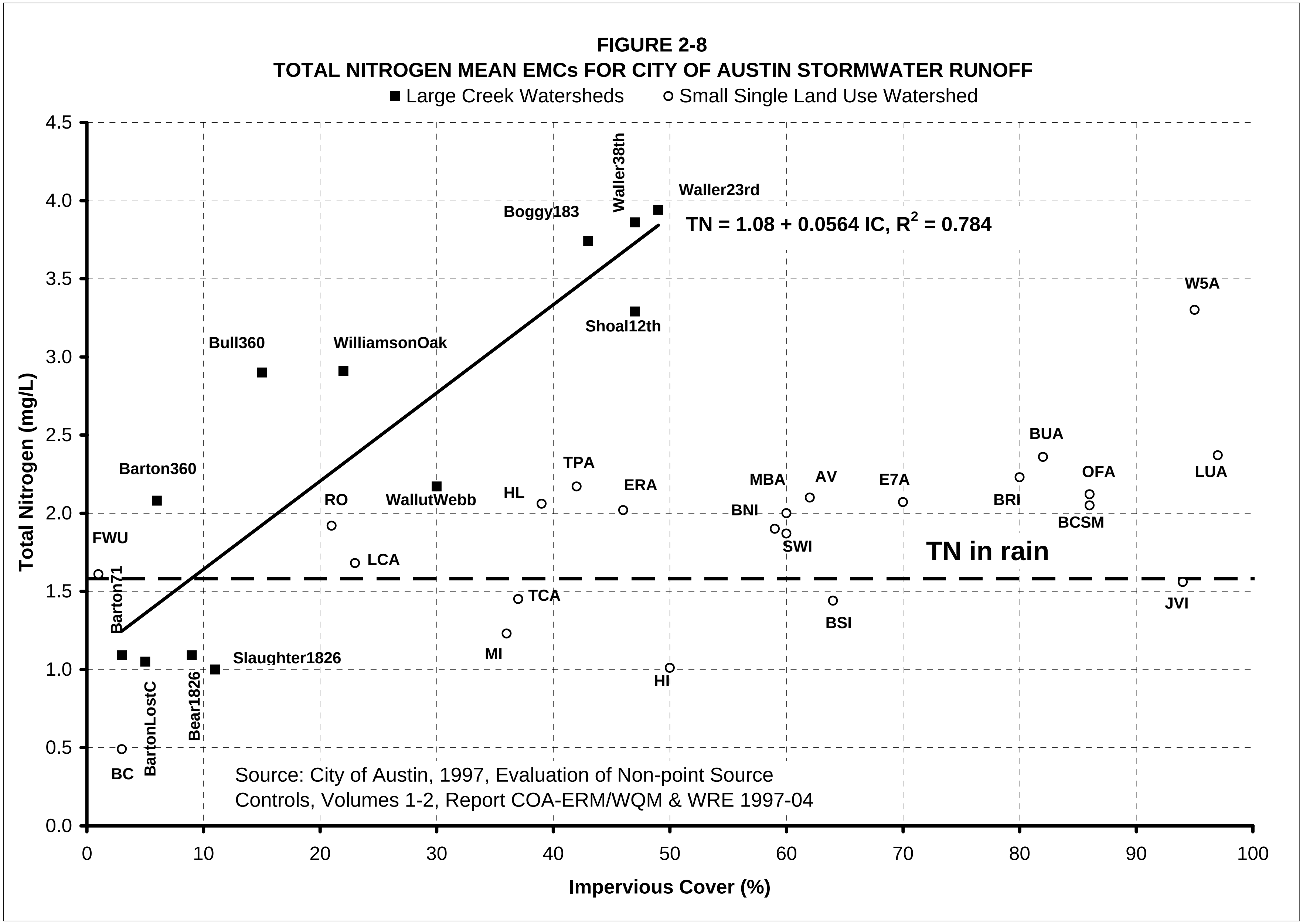


FIGURE 2-8
TOTAL NITROGEN MEAN EMCs FOR CITY OF AUSTIN STORMWATER RUNOFF
Large Creek Watersheds
Small Single Land Use Watershed
TN = 1.08 + 0.0564 IC, R2 = 0.784
TN in rain
Total Nitrogen (mg/L)
Impervious Cover (%)
Waller38th
Waller23rd
Boggy183
Shoal12th
Bull360
WilliamsonOak
Barton360
WallutWebb
Barton71
BartonLostC
Bear1826
Slaughter1826
FWU
BC
RO
LCA
HL
TPA
ERA
TCA
MI
HI
MBA
AV
BNI
SWI
BSI
E7A
BUA
BRI
OFA
BCSM
W5A
LUA
JVI
Source: City of Austin, 1997, Evaluation of Non-point Source Controls, Volumes 1-2, Report COA-ERM/WQM & WRE 1997-04

FIGURE 2-9

TOTAL PHOSPHORUS MEAN EMCs FOR CITY OF AUSTIN STORMWATER RUNOFF

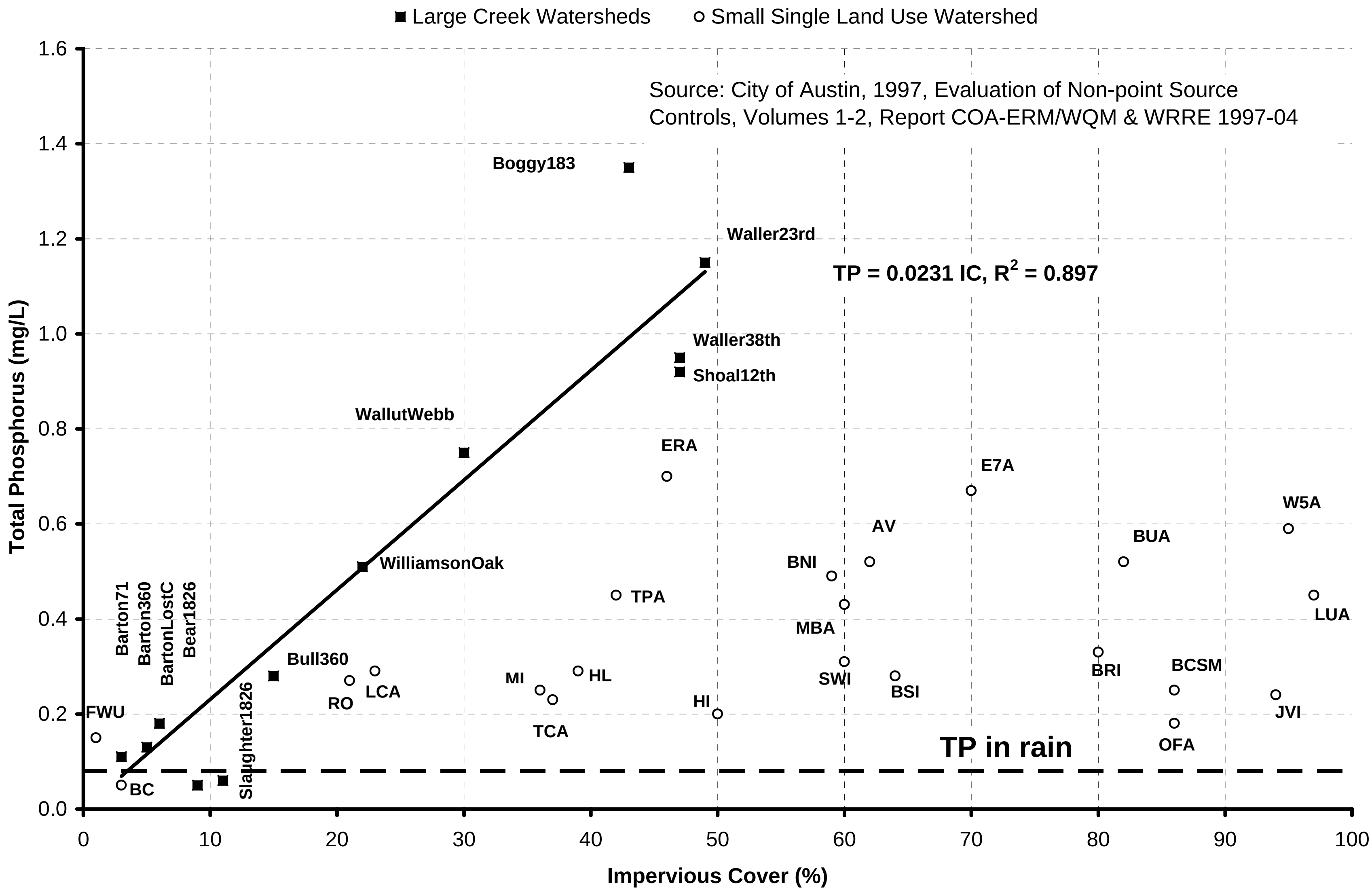
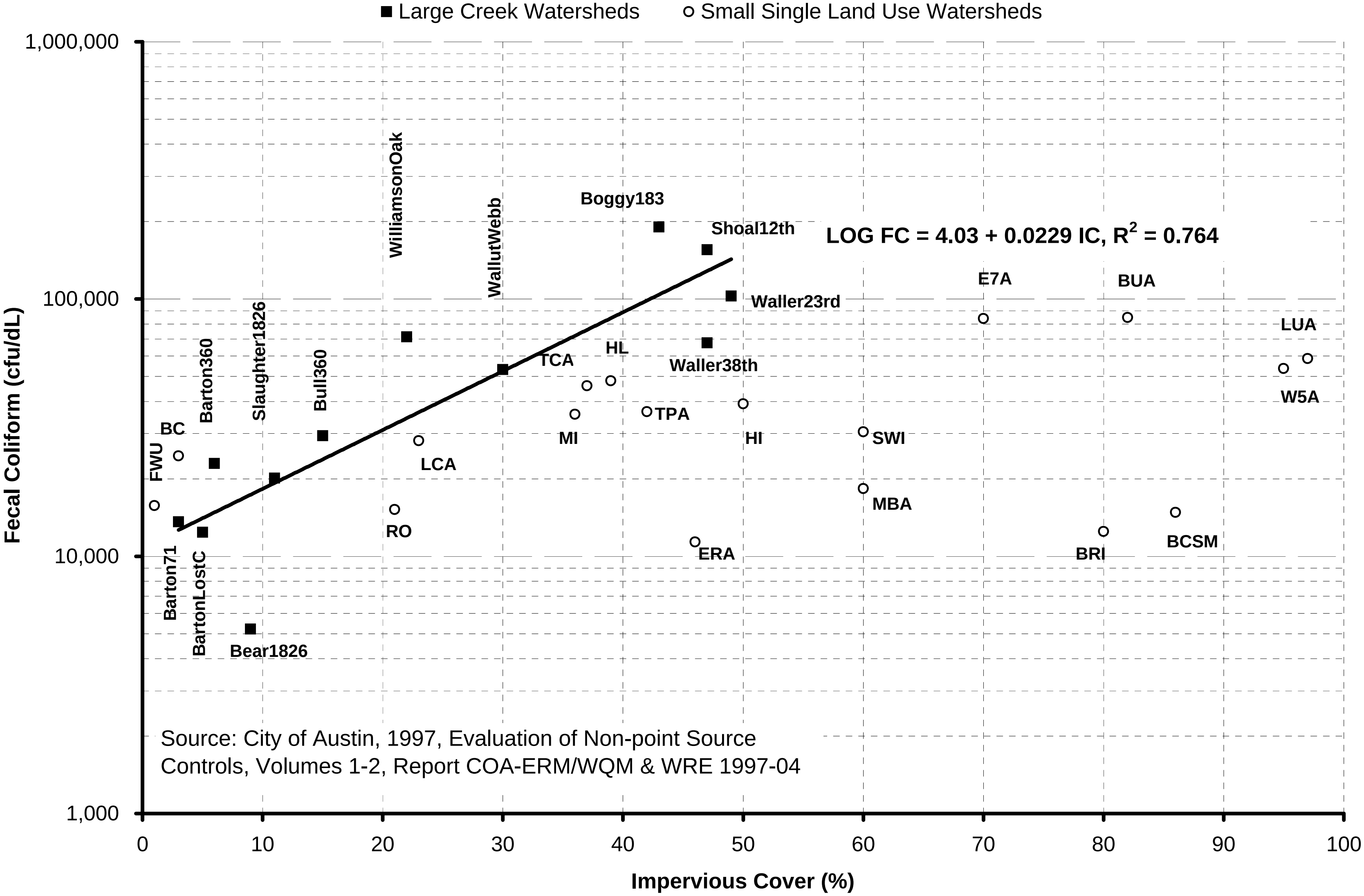


FIGURE 2-10
FECAL COLIFORM MEAN EMCs FOR CITY OF AUSTIN STORMWATER RUNOFF



increases the amount of streambed erosion, which increases the amount of sediment, nutrients and bacteria in suspension.

All of the runoff data start with rain. While rain does not contain much particulate matter or bacteria, with nitrogen and phosphorus there is a substantial contribution in the rain itself. Figures 2-8 and 2-9 show the average concentrations in Austin rainfall in relation to the runoff data. It can be seen that rainfall explains most of the TN in the runoff, while it only represents about a third of the TP in runoff.

Another factor that must be considered in assessing urban runoff data is the contribution from sanitary sewer leakage or overflows. While not an everyday event, unintended releases can occur particularly as wastewater collection systems age. This undoubtedly plays some role in the observed stormwater data. For example, the creeks in Austin that drain older and more developed areas, Shoal, Boggy, Waller, and Walnut, all have higher runoff FC values and also tend to show higher non-runoff values than do the creeks in newer and less developed areas. How much of this difference can be attributed to sanitary sewer leakage and how much is simply a result of greater urban density and higher impervious cover would be very difficult to quantify. While it may not be easily quantifiable, the sewer leakage potential in older urban areas must be recognized.

3.0 QUANTIFICATION OF DEVELOPMENT EFFECTS

Changes in runoff quantity and quality as a result of urban development are estimated for the Cities of Victoria, San Marcos, New Braunfels and Seguin. This section describes the method used to estimate the changes in impervious cover that have occurred since 1960 and that are projected to occur in the future to the year 2020. With the information in Section 2.0, these changes in impervious cover are related to changes in runoff quantity and quality.

The calculations for the City of Victoria will be described in detail to illustrate the analytical approach that is basically the same for the four communities. Results for the other three areas are then presented with details specific to the individual communities. Note that the regression equations in Section 2.0 between constituent concentrations and percentage impervious cover were developed from creek monitoring data in the Austin area and should only be applied to watersheds drained by creeks of similar size. Drainage areas that involve overland flow or flows through storm sewer systems directly into the Guadalupe River are not considered in this study.

3.1 CITY OF VICTORIA

Figure 3-1 shows the watersheds and the city limits for the City of Victoria delineated in the City's Storm Drainage Master Plan (PBS&J, 1999). Of the watersheds shown, the Spring Creek watershed is likely to be affected by growth. It includes the subwatersheds of Mockingbird Outfall, Whispering Creek and North Outfall. Lone Tree Creek and Marcado Creek do not drain to the Guadalupe River and will not be considered. The Second Street Outfall discharges to the Guadalupe River through a system of storm sewers rather than an open creek channel. The analysis focuses on streams that exhibit changes in both quality and quantity with development. As discussed in Section 2.0, watersheds served by storm sewers are typical of the smaller City of Austin sites that do not exhibit significant runoff concentration changes with higher levels of development, and are not considered here.

Population growth was used as the key factor to reflect development in each city. The population data for the four communities are shown in Table 3-1. Population data for 1960 to 1990 were obtained from the U.S. Bureau of Census. For 2000 to 2020, projected population data based on the most likely growth scenario were obtained from the Texas Water Development Board.

The first step in the analysis was to estimate the present level (2000) of impervious cover in the studied watersheds. This task was facilitated by the use of Geographic Information System (GIS) technology. The USGS Digital Orthophoto Quarter Quadrangles (DOQQ) were used as base maps for delineation of land uses. Various sources of information were used to generate the land use data for the four

FIGURE 3-1
WATERSHEDS OF THE CITY OF VICTORIA

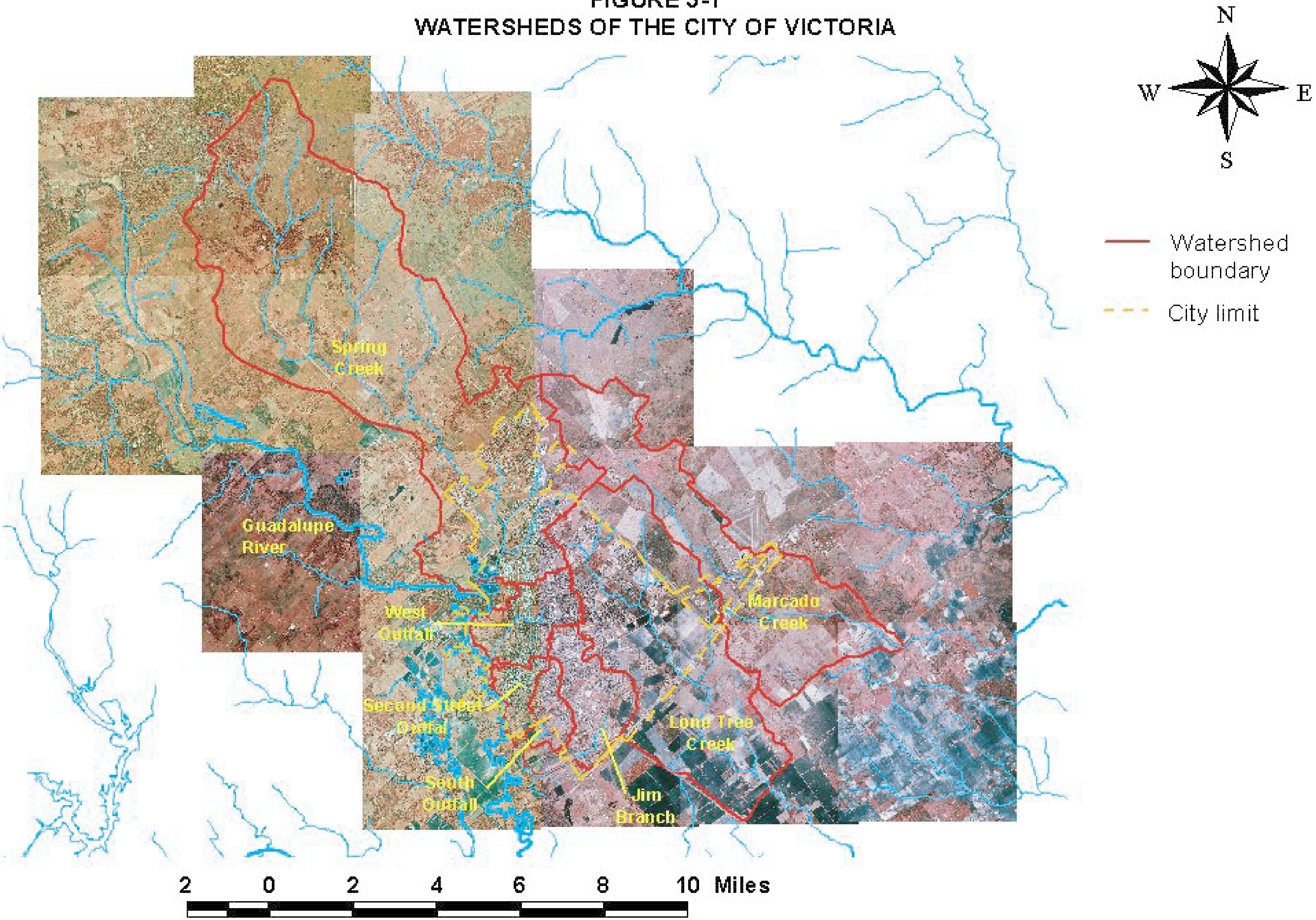


TABLE 3-1
POPULATION DATA

City	1960	1970	1980	1990	2000	2010	2020
Victoria	33,047	41,349	50,695	55,076	61,305	67,537	73,496
San Marcos	12,713	18,860	23,420	28,743	33,751	40,281	47,370
New Braunfels	15,631	17,859	22,404	27,334	38,404	50,207	65,417
Seguin	14,299	15,934	17,854	18,853	20,364	21,983	27,040

Sources:
United States Bureau of the Census 1961, 1971, 1981, 1991.
Texas Water Development Board, 1996 Consensus Texas Water Plan, Scenario M_ML (most likely growth scenario).

communities including city parcel map, city zoning map, drainage master plan and city planning reports. Section 5.0 presents a complete list of the referenced materials. Impervious cover percentages for various land uses were obtained from USDA (1986). The total impervious area for each watershed considered in Victoria is presented in Table 3-2.

For each watershed, the impervious area and the population within the city were estimated. Then the per capita impervious cover was calculated for each watershed for the area within the city limit. The population distribution between watersheds is an estimate based on observed density of development on DOQQ maps. For 2010 and 2020, a judgement was made as to where additional population would locate. In general, areas that are already highly developed were assigned smaller percentages of the total population increase, and vice versa. A demographic projection for the City of Victoria (Wilbur Smith Associates, 1997) indicated that the major area of growth would be in the northern part of the city. The estimated city populations in each watershed for different years are shown in Table 3-3.

To relate impervious cover to population, the values for each watershed were computed and shown in Table 3-2. These values ranged from 0.09 to 0.12 ac/capita in Victoria, but were up to 0.20 in other communities. The overall value employed for this study was 0.16 ac/capita, based on City of Austin (1995) impervious cover and population data for the same area. For calculation of growth effects, it was assumed that the per capita impervious cover would remain constant over time. This value multiplied by the change in population gives an estimate of the change in impervious area for the watershed. Using the population projections, the percentage of impervious cover for each watershed was calculated for each year. These are also shown in Table 3-3.

After developing estimates of the changes in the percentage of impervious cover for each watershed, the next step is to calculate the changes in runoff quantity and quality associated with the impervious cover changes. This is done using the results from the City of Austin developed in Section 2.0.

The runoff coefficient is the average percentage of the rain that falls on a watershed that leaves as runoff. The City of Austin has derived a relationship between impervious cover and runoff coefficient (Figure 2-3 in Section 2.0). Table 3-3 shows the runoff coefficients estimated with this relationship. Note however that soils in the Victoria area tend to have a higher clay content and are less permeable than those in the Austin. As a result runoff from undeveloped land will tend to be higher than shown, and the relative effect of impervious cover may be somewhat less.

Table 3-4 presents calculations of the long-term average stormwater runoff EMCs for the four selected parameters described in Section 2.0: TSS, TN, TP, and FC (Total Suspended Solids, Total Nitrogen, Total Phosphorus and Fecal Coliform). The concentrations of the water quality parameters were

TABLE 3-2
DATA FOR SELECTED WATERSHEDS OF THE CITY OF VICTORIA

Watershed	Watershed area (acres)	% Impervious cover	Impervious area (acres)	Assumed population distribution [2]	Assumed distribution of population change [3]	% Impervious cover of watershed within city [4]	Impervious area within city (acres)	2,000 Population	2000 per capita imp cover (ac/capita)
Jim Branch	2,971	33.4%	992	15%	15%	33.0%	980	9,196	0.107
South Outfall	1,020	33.0%	337	5%	5%	32.0%	326	3,065	0.106
West Outfall	2,299	38.1%	876	15%	5%	38.1%	876	9,196	0.095
Spring Creek [1]	30,034	7.6%	2,283	25%	50%	6.0%	1,802	15,326	0.118

[1] Spring Creek includes Mockingbird Outfall, Whispering Creek and North Outfall.
[2] Assumed distribution for 1960 to 2000 city population.
[3] Assumed distribution of city population change of 2010 and 2020 from 2000.
[4] Impervious area of the part of the watershed within city as a percentage of the total area of the watershed.

TABLE 3-3
ESTIMATION OF PERCENTAGE IMPERVIOUS COVER AND RUNOFF COEFFICIENTS FOR THE CITY OF VICTORIA

Watershed	1960	1970	1980	1990	2000	2010	2020
Population							
Jim Branch	4,957	6,202	7,604	8,261	9,196	10,131	11,024
South Outfall	1,652	2,067	2,535	2,754	3,065	3,377	3,675
West Outfall	4,957	6,202	7,604	8,261	9,196	9,507	9,805
Spring Creek [1]	8,262	10,337	12,674	13,769	15,326	18,442	21,422
Total city population	33,047	41,349	50,695	55,076	61,305	67,537	73,496
Impervious area (acres) [2, 3]							
Jim Branch	314	513	738	843	992	1,142	1,285
South Outfall	111	177	252	287	337	386	434
West Outfall	198	397	621	726	876	926	973
Spring Creek [1]	1,152	1,484	1,858	2,033	2,283	2,781	3,258
Percentage impervious cover							
Jim Branch	10.6%	17.3%	24.8%	28.4%	33.4%	38.4%	43.2%
South Outfall	10.8%	17.3%	24.7%	28.1%	33.0%	37.9%	42.6%
West Outfall	8.6%	17.3%	27.0%	31.6%	38.1%	40.3%	42.3%
Spring Creek [1]	3.8%	4.9%	6.2%	6.8%	7.6%	9.3%	10.8%
Runoff coefficient [4]							
Jim Branch	7.0%	10.3%	14.5%	16.7%	20.0%	23.7%	27.4%
South Outfall	7.1%	10.3%	14.4%	16.5%	19.8%	23.3%	26.9%
West Outfall	6.2%	10.3%	15.8%	18.8%	23.4%	25.1%	26.7%
Spring Creek [1]	4.2%	4.7%	5.2%	5.4%	5.7%	6.4%	7.1%

[1] Spring Creek includes Mockingbird Outfall, Whispering Creek and North Outfall.
[2] Change in impervious cover is estimated from the change in population and impervious area per capita.
[3] Used 0.16 ac/capita.
[4] Values calculated from regression developed in Section 2.0.

TABLE 3-4
CALCULATED RUNOFF EMCs OF SELECTED PARAMETERS FOR THE CITY OF VICTORIA [1]

Watershed	1960	1970	1980	1990	2000	2010	2020
TSS (mg/L)							
Jim Branch	369	465	602	680	808	961	1133
South Outfall	373	466	599	674	797	943	1107
West Outfall	345	465	650	760	950	1023	1099
Spring Creek [2]	293	305	318	324	334	353	373
TN (mg/L)							
Jim Branch	1.68	2.05	2.48	2.68	2.96	3.25	3.52
South Outfall	1.69	2.06	2.47	2.67	2.94	3.22	3.48
West Outfall	1.57	2.05	2.60	2.86	3.23	3.35	3.47
Spring Creek [2]	1.30	1.36	1.43	1.46	1.51	1.60	1.69
TP (mg/L)							
Jim Branch	0.24	0.40	0.57	0.66	0.77	0.89	1.00
South Outfall	0.25	0.40	0.57	0.65	0.76	0.88	0.98
West Outfall	0.20	0.40	0.62	0.73	0.88	0.93	0.98
Spring Creek [2]	0.09	0.11	0.14	0.16	0.18	0.21	0.25
FC (cfu/dL)							
Jim Branch	18,712	26,650	39,681	47,822	62,353	81,310	104,804
South Outfall	18,974	26,747	39,367	47,187	61,052	79,001	101,079
West Outfall	16,864	26,633	44,550	56,700	79,890	89,568	99,916
Spring Creek [2]	13,118	13,905	14,848	15,312	15,997	17,460	18,985

[1] Values calculated from impervious cover and regressions developed in Section 2.0.
[2] Spring Creek includes Mockingbird Outfall, Whispering Creek and North Outfall.

estimated using the relationships between impervious cover and constituent concentration derived in Section 2.0.

Significant increases over time in runoff concentrations of the selected parameters can be seen as a result of development. A large portion of the Spring Creek watershed is outside the city limit and as a whole, the watershed is relatively undeveloped. Therefore, the runoff concentrations are substantially lower than those of the other watersheds.

The runoff loads from the all the studied watersheds combined for selected parameters are presented in Table 3-5 and depicted in Figure 3-2 as percentages of the year 2000 loads. In this case, the runoff load is defined as the product of the runoff coefficient and the average runoff concentration. In estimating the runoff load, the contributions from the watersheds have been weighted according to their areas. The percentage increases in the loads reflect both an increase in the amount of runoff with more impervious cover, and the increase in event average concentrations. The calculated runoff loads have increased by 3 to 6 times from 1960 to 2000 and are expected to increase by 43% to 79% from 2000 to 2020.

3.2 CITY OF SAN MARCOS

Figure 3-3 shows the City of San Marcos and the contributing urban watersheds to the San Marcos River. The San Marcos River is fed by springs in the immediate area. The primary springs are impounded to form Spring Lake that is the headwaters of the San Marcos River. Downstream several small dams maintain pools in the river suitable for swimming and tubing.

Sink Creek, Purgatory Creek and Willow Spring Creek are the major urban tributary creeks of the San Marcos River. Storm drains serve other parts of the urban watershed. The area to the northeast of the city drains to the Blanco River that does not join with the San Marcos River until well below the city. The Sink Creek watershed flows into Spring Lake. Purgatory and Willow Spring creeks flow directly into the impounded sections of the San Marcos River. Because the receiving water for Sink Creek is Spring Lake, it may be viewed as substantially different from the other two creeks. Because of this difference, it will be treated separately and the other two will be combined in the calculations.

Table 3-6 presents the estimated existing impervious area and population for both the Sink Creek and Purgatory and Willow Spring creek watersheds. Sink Creek watershed is relatively undeveloped at this time, and is not estimated to receive the bulk of future growth. Of the total change in population, it is estimated that the Sink Creek watershed will receive 10% while the other two creeks receive 45%. The

TABLE 3-5
RUNOFF LOAD CHANGES FOR SELECTED PARAMETERS FROM THE CITY OF VICTORIA

Parameter	1960	1970	1980	1990	2000	2010	2020
Jim Branch							
TSS	16%	29%	54%	70%	100%	140%	192%
TN	20%	35%	61%	75%	100%	129%	162%
TP	11%	26%	54%	71%	100%	136%	177%
FC	11%	22%	46%	64%	100%	154%	230%
South Outfall							
TSS	17%	30%	55%	71%	100%	139%	189%
TN	21%	36%	61%	76%	100%	129%	161%
TP	12%	27%	54%	71%	100%	135%	175%
FC	11%	23%	47%	65%	100%	152%	225%
West Outfall							
TSS	10%	21%	46%	64%	100%	115%	132%
TN	13%	28%	55%	71%	100%	111%	122%
TP	6%	20%	48%	67%	100%	113%	127%
FC	6%	15%	38%	57%	100%	120%	142%
Spring Creek [1]							
TSS	65%	74%	86%	91%	100%	119%	139%
TN	64%	73%	85%	91%	100%	119%	140%
TP	37%	53%	73%	84%	100%	137%	178%
FC	61%	71%	83%	90%	100%	123%	148%
Total [2]							
TSS	30%	42%	62%	75%	100%	126%	156%
TN	35%	48%	69%	80%	100%	121%	143%
TP	15%	30%	56%	72%	100%	128%	160%
FC	20%	31%	52%	67%	100%	134%	179%

[1] Spring Creek includes Mockingbird Outfall, Whispering Creek and North Outfall.
[2] Runoff loads are calculated as area-weighted averages of the watersheds.

FIGURE 3-2
PROJECTED PERCENTAGE INCREASES IN URBAN RUNOFF LOADS OF SELECTED PARAMETERS FROM THE CITY OF VICTORIA

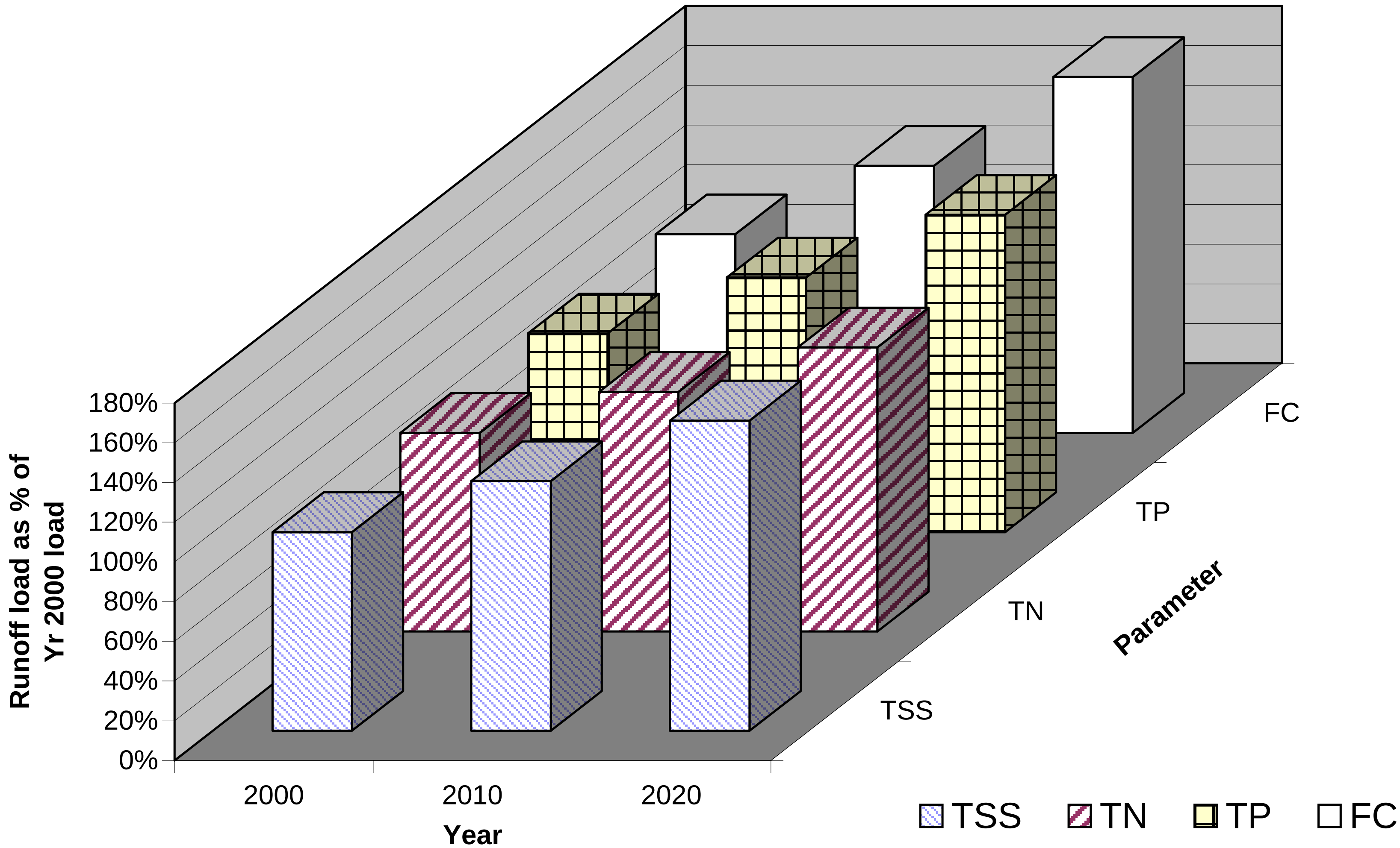


FIGURE 3-3
WATERSHEDS OF THE CITY OF SAN MARCOS

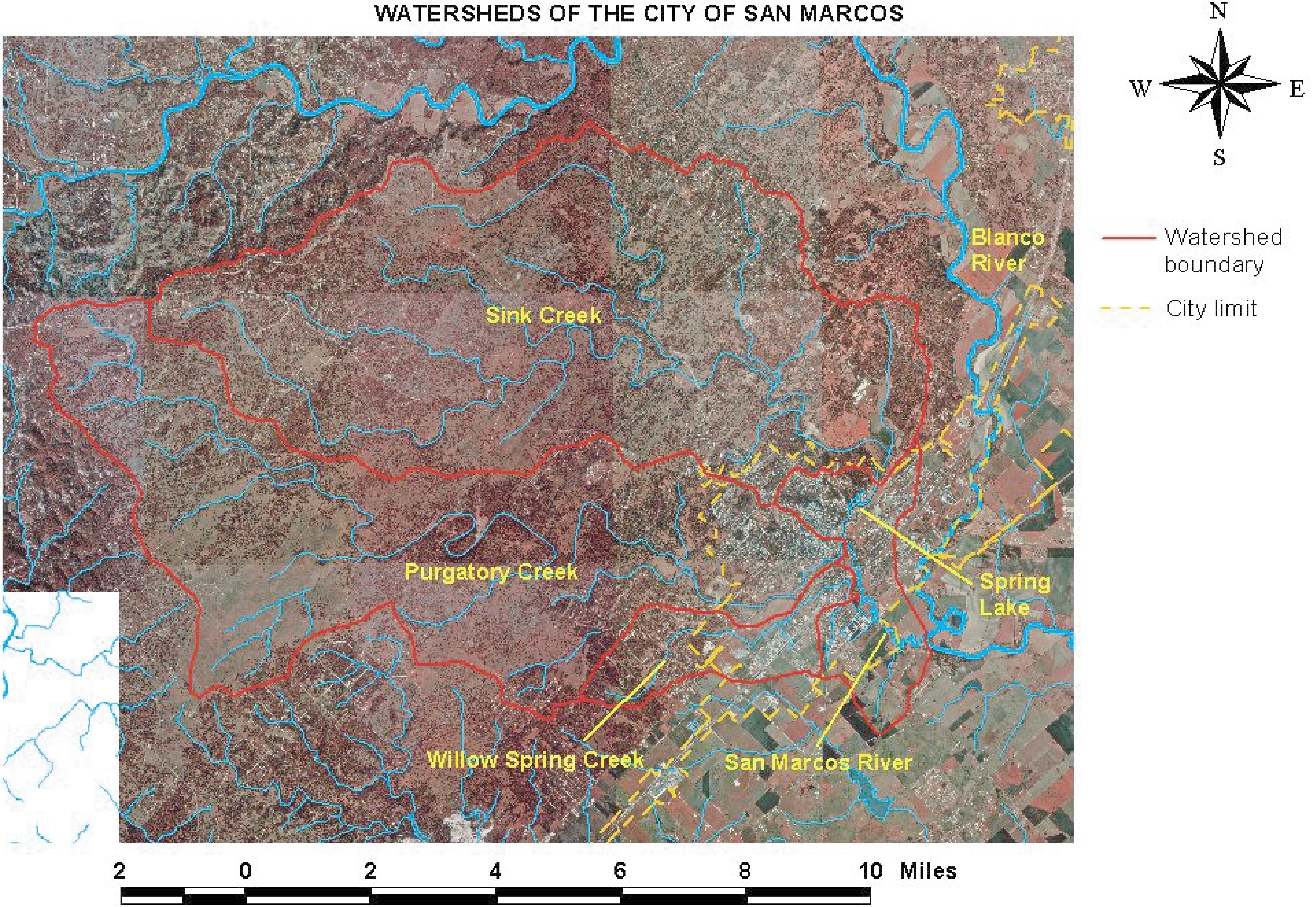


TABLE 3-6
DATA FOR SELECTED WATERSHEDS OF THE CITY OF SAN MARCOS

Watershed	Watershed area (acres)	% Impervious cover	Impervious area (acres)	Assumed population distribution [1]	Assumed distribution of population change [2]
Sink Creek	30,445	3.7%	1,126	8%	10%
Purgatory Creek & Willow Spring Creek	26,562	6.4%	1,700	35%	45%

[1] Assumed distribution for 1960 to 2000 city population.
[2] Assumed distribution of city population change of 2010 and 2020 from 2000.

remaining 55% of population growth is estimated to occur in the immediate urban watershed served by storm drains and to the northeast along the IH-35 corridor.

Calculations for estimating impervious cover and runoff changes are shown in Table 3-7. Table 3-8 presents the changes in runoff quality while Table 3-9 presents the changes in runoff load. Between 1960 and 2000, the calculated runoff loads have been increased by as little as 10% for TSS in Sink Creek to over 400% for TP on the other creeks. From 2000 to 2020, load increases for TP are predicted to range from 27% for Sink Creek to 105% for Purgatory and Willow Spring creeks. Figure 3-4 shows the projected percentage increases in the runoff loads for all parameters for the total of the Sink Creek and combined Purgatory and Willow creeks.

3.3 CITY OF NEW BRAUNFELS

Figure 3-5 shows the City of New Braunfels and the urbanizing watersheds in the area. Dry weather or non-runoff flow in the Guadalupe River at New Braunfels is a combination of river flows (regulated by releases from Canyon Lake) and Comal spring flows which enter via the Comal River. Dry Comal Creek and Blieders Creek are tributaries of the Comal River. Blieders Creek enters the Comal River upstream of the major concentration of springs at Landa Lake and the Dry Comal Creek enters the Comal River just downstream of Landa Lake.

The calculation for estimating the runoff quality changes was performed for Blieders and Dry Comal creeks, the entire Comal River watershed, and the watershed of an unnamed tributary on the southwest side of the Guadalupe River. The northeast side of the river has no substantial tributaries in the urban area because the watershed of Geronimo Creek, which enters the river downstream of Seguin, is nearby. Most of the drainage on the northeast side of the river enters from smaller storm drainage systems that are not considered.

All of the urban drainage from New Braunfels goes to the Guadalupe River upstream of Lake Dunlap, a run-of-river impoundment that provides both hydroelectric power and recreational uses. A short distance downriver is Lake McQueeney that provides a similar function.

The calculations are shown in tables 3-10 to 3-13. Table 3-10 provides the watershed areas and estimated present impervious cover. Also shown are the assumed present distribution of population between watersheds and the assumed distribution of population changes. The basic assumption is that in the future slightly more of the development will occur in the Blieders Creek watershed than has been the case in the past.

TABLE 3-7
ESTIMATION OF PERCENTAGE IMPERVIOUS COVER AND RUNOFF COEFFICIENT
FOR THE CITY OF SAN MARCOS

Watershed	1960	1970	1980	1990	2000	2010	2020
Population							
Sink Creek	1,017	1,509	1,874	2,299	2,700	3,353	4,062
Purgatory Creek & Willow Spring Creek	4,450	6,601	8,197	10,060	11,813	14,751	17,941
Total city population	12,713	18,860	23,420	28,743	33,751	40,281	47,370
Impervious area (acres) [1]							
Sink Creek	857	936	994	1,062	1,126	1,231	1,344
Purgatory Creek & Willow Spring Creek	522	866	1,121	1,420	1,700	2,170	2,681
Percentage impervious cover							
Sink Creek	2.8%	3.1%	3.3%	3.5%	3.7%	4.0%	4.4%
Purgatory Creek & Willow Spring Creek	2.0%	3.3%	4.2%	5.3%	6.4%	8.2%	10.1%
Runoff coefficient [2]							
Sink Creek	3.9%	4.0%	4.0%	4.1%	4.2%	4.3%	4.5%
Purgatory Creek & Willow Spring Creek	3.6%	4.0%	4.4%	4.8%	5.2%	6.0%	6.8%

[1] Change in impervious cover is estimated from the change in population and impervious area per capita.
[2] Values calculated from regression developed in Section 2.0.

TABLE 3-8

CALCULATED RUNOFF EMCs OF SELECTED PARAMETERS FOR THE CITY OF SAN MARCOS [1]

Watershed	1960	1970	1980	1990	2000	2010	2020
TSS (mg/L)							
Sink Creek	283	286	288	290	292	295	299
Purgatory Creek & Willow Spring Creek	275	287	297	309	320	340	363
TN (mg/L)							
Sink Creek	1.24	1.25	1.26	1.28	1.29	1.31	1.33
Purgatory Creek & Willow Spring Creek	1.19	1.26	1.32	1.38	1.44	1.54	1.65
TP (mg/L)							
Sink Creek	0.07	0.07	0.08	0.08	0.09	0.09	0.10
Purgatory Creek & Willow Spring Creek	0.05	0.08	0.10	0.12	0.15	0.19	0.23
FC (cfu/dL)							
Sink Creek	12,430	12,601	12,729	12,880	13,024	13,261	13,524
Purgatory Creek & Willow Spring Creek	11,885	12,725	13,387	14,203	15,016	16,485	18,243

[1] Values calculated from impervious cover and regressions developed in Section 2.0.

TABLE 3-9
RUNOFF LOAD CHANGES FOR SELECTED PARAMETERS FROM THE CITY OF SAN MARCOS

Parameter	1960	1970	1980	1990	2000	2010	2020
Sink Creek							
TSS	89%	92%	95%	97%	100%	104%	109%
TN	89%	92%	94%	97%	100%	105%	110%
TP	70%	78%	85%	93%	100%	113%	127%
FC	88%	91%	94%	97%	100%	105%	111%
Purgatory Creek & Willow Spring Creek							
TSS	58%	69%	78%	89%	100%	121%	147%
TN	56%	67%	77%	88%	100%	122%	148%
TP	21%	39%	55%	77%	100%	145%	205%
FC	54%	65%	75%	87%	100%	125%	158%
Total [1]							
TSS	73%	80%	85%	93%	100%	113%	130%
TN	71%	78%	85%	92%	100%	114%	131%
TP	38%	53%	66%	82%	100%	134%	178%
FC	69%	77%	83%	91%	100%	116%	137%

[1] Runoff loads are calculated as area-weighted averages of the watersheds.

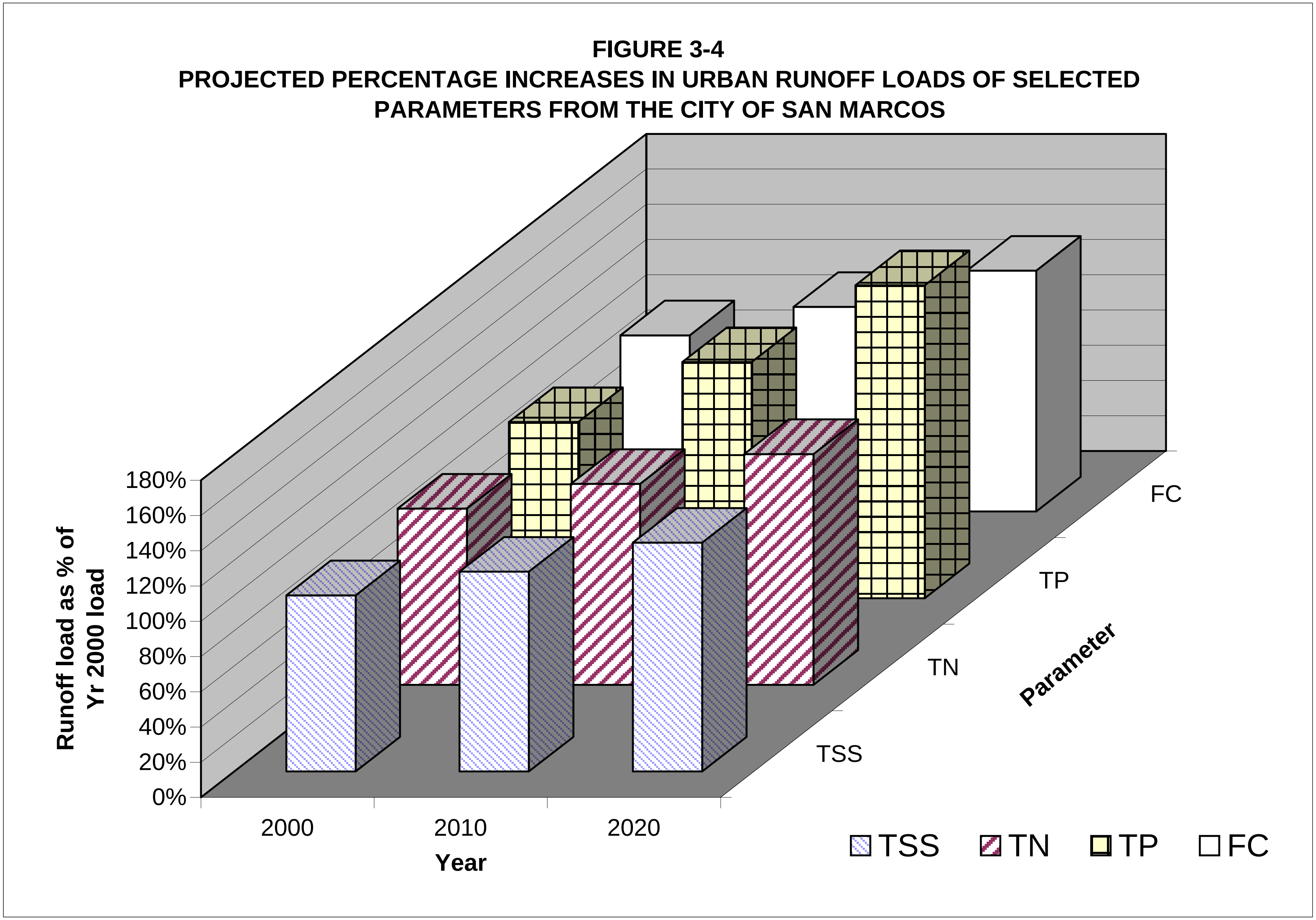


FIGURE 3-4
PROJECTED PERCENTAGE INCREASES IN URBAN RUNOFF LOADS OF SELECTED PARAMETERS FROM THE CITY OF SAN MARCOS
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
Runoff load as % of Yr 2000 load
2000
2010
2020
Year
FC
TP
TN
TSS
Parameter
TSS
TN
TP
FC

FIGURE 3-5
WATERSHEDS OF THE CITY OF NEW BRAUNFELS

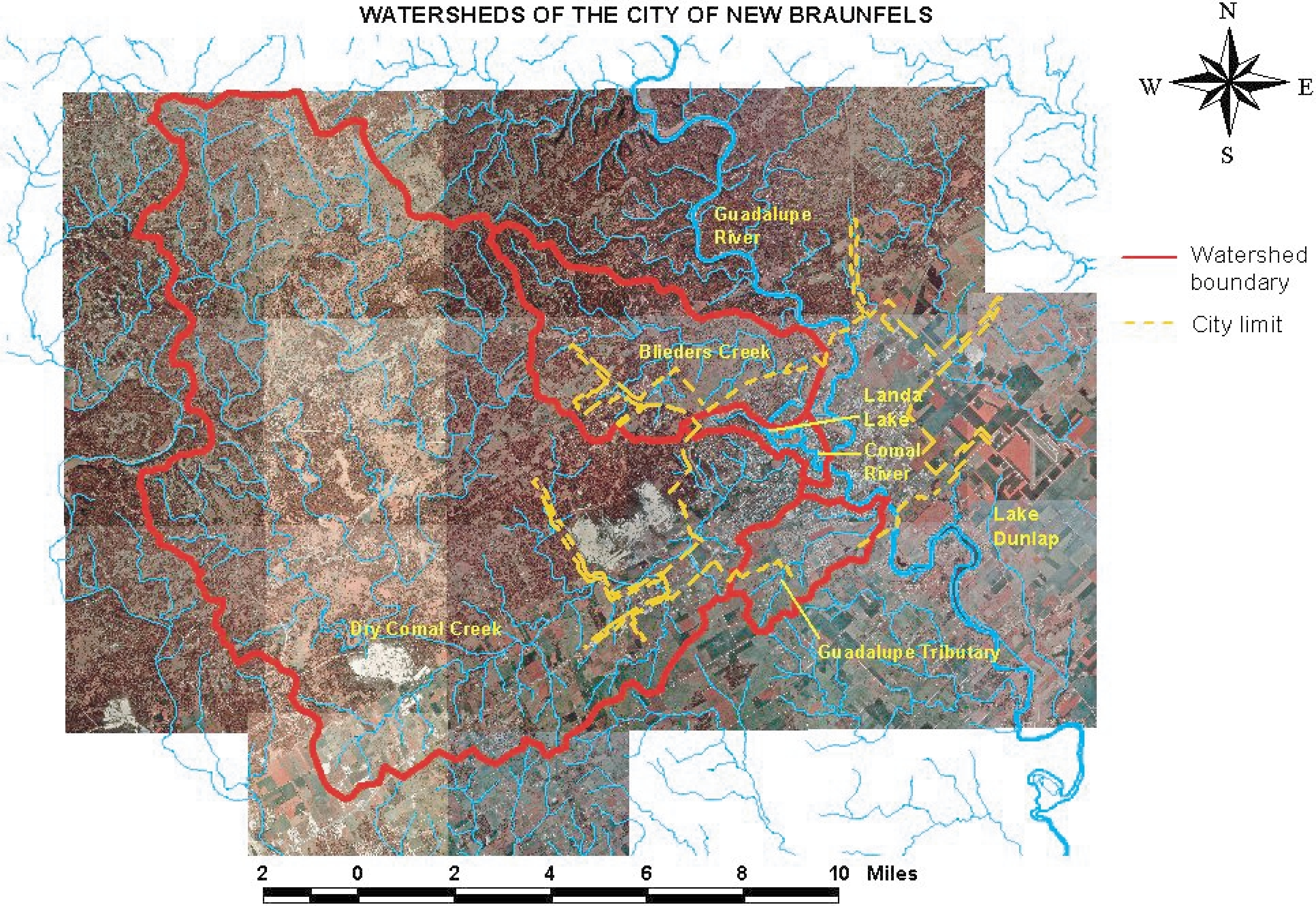


TABLE 3-10
DATA FOR SELECTED WATERSHEDS OF THE CITY OF NEW BRAUNFELS

Watershed	Watershed area (acres)	% Impervious cover	Impervious area (acres)	Assumed population distribution [2]	Assumed distribution of population change [3]
Dry Comal Creek	71,414	7.6%	5,427	30%	20%
Blieders Creek	10,525	16.2%	1,705	15%	20%
Comal River [1]	83,063	9.2%	7,610	55%	45%
Tributary of Guadalupe River	3,093	34.5%	1,067	15%	15%

[1] Includes Dry Comal Creek and Blieders Creek watersheds.
[2] Assumed distribution for 1960 to 2000 city population.
[3] Assumed distribution of city population change of 2010 and 2020 from 2000.

TABLE 3-11
ESTIMATION OF PERCENTAGE IMPERVIOUS COVER AND RUNOFF COEFFICIENT
FOR THE CITY OF NEW BRAUNFELS

Watershed	1960	1970	1980	1990	2000	2010	2020
Population							
Dry Comal Creek	4,689	5,358	6,721	8,200	11,521	13,882	16,924
Blieders Creek	2,345	2,679	3,361	4,100	5,761	8,121	11,163
Comal River [1]	8,597	9,822	12,322	15,034	21,122	26,434	33,278
Tributary of Guadalupe River	2,345	2,679	3,361	4,100	5,761	7,531	9,813
Total city population	15,631	17,859	22,404	27,334	38,404	50,207	65,417
Impervious area (acres) [2]							
Dry Comal Creek	4,334	4,441	4,659	4,896	5,427	5,805	6,292
Blieders Creek	1,158	1,212	1,321	1,439	1,705	2,083	2,569
Comal River [1]	5,606	5,802	6,202	6,636	7,610	8,460	9,555
Tributary of Guadalupe River	521	574	683	801	1,067	1,350	1,715
Percentage impervious cover							
Dry Comal Creek	6.1%	6.2%	6.5%	6.9%	7.6%	8.1%	8.8%
Blieders Creek	11.0%	11.5%	12.6%	13.7%	16.2%	19.8%	24.4%
Comal River [1]	6.7%	7.0%	7.5%	8.0%	9.2%	10.2%	11.5%
Tributary of Guadalupe River	16.8%	18.6%	22.1%	25.9%	34.5%	43.7%	55.5%
Runoff coefficient [3]							
Dry Comal Creek	5.1%	5.2%	5.3%	5.4%	5.7%	6.0%	6.2%
Blieders Creek	7.2%	7.4%	7.9%	8.5%	9.7%	11.6%	14.2%
Comal River [1]	5.4%	5.5%	5.7%	5.9%	6.4%	6.8%	7.4%
Tributary of Guadalupe River	10.0%	10.9%	12.9%	15.1%	20.8%	27.7%	38.0%

[1] Includes Dry Comal Creek and Blieders Creek watersheds.

[2] Change in impervious cover is estimated from the change in population and impervious area per capita.

[3] Values calculated from regression developed in Section 2.0.

TABLE 3-12

CALCULATED RUNOFF EMCs OF SELECTED PARAMETERS FOR THE CITY OF NEW BRAUNFELS [1]

Watershed	1960	1970	1980	1990	2000	2010	2020
TSS (mg/L)							
Dry Comal Creek	317	318	322	325	334	340	348
Blieders Creek	375	382	395	411	448	507	594
Comal River [2]	324	327	332	338	352	365	381
Tributary of Guadalupe River	458	486	548	625	840	1150	1723
TN (mg/L)							
Dry Comal Creek	1.42	1.43	1.45	1.47	1.51	1.54	1.58
Blieders Creek	1.70	1.73	1.79	1.85	1.99	2.20	2.46
Comal River [2]	1.46	1.47	1.50	1.53	1.60	1.65	1.73
Tributary of Guadalupe River	2.03	2.13	2.33	2.54	3.03	3.54	4.21
TP (mg/L)							
Dry Comal Creek	0.14	0.14	0.15	0.16	0.18	0.19	0.20
Blieders Creek	0.25	0.27	0.29	0.32	0.37	0.46	0.56
Comal River [2]	0.16	0.16	0.17	0.18	0.21	0.24	0.27
Tributary of Guadalupe River	0.39	0.43	0.51	0.60	0.80	1.01	1.28
FC (cfu/dL)							
Dry Comal Creek	14,757	14,874	15,115	15,382	15,997	16,449	17,051
Blieders Creek	19,145	19,665	20,770	22,038	25,176	30,420	38,820
Comal River [2]	15,295	15,487	15,885	16,329	17,370	18,333	19,653
Tributary of Guadalupe River	26,025	28,509	34,336	42,009	66,077	107,098	199,548

[1] Values calculated from impervious cover and regressions developed in Section 2.0.

[2] Includes Dry Comal Creek and Blieders Creek watersheds.

TABLE 3-13

RUNOFF LOAD CHANGES FOR SELECTED PARAMETERS FROM THE CITY OF NEW BRAUNFELS

Parameter	1960	1970	1980	1990	2000	2010	2020
Dry Comal Creek							
TSS	85%	86%	89%	92%	100%	106%	114%
TN	84%	86%	89%	92%	100%	106%	114%
TP	71%	74%	79%	85%	100%	111%	126%
FC	82%	84%	87%	91%	100%	107%	116%
Blieders Creek							
TSS	62%	65%	72%	80%	100%	135%	195%
TN	63%	67%	73%	81%	100%	132%	181%
TP	50%	55%	63%	74%	100%	146%	221%
FC	57%	60%	67%	76%	100%	144%	226%
Comal River [1]							
TSS	78%	80%	84%	89%	100%	111%	126%
TN	77%	79%	83%	88%	100%	111%	126%
TP	62%	65%	72%	80%	100%	119%	146%
FC	74%	76%	81%	87%	100%	113%	132%
Tributary of Guadalupe River							
TSS	26%	30%	40%	54%	100%	182%	375%
TN	32%	37%	48%	61%	100%	156%	254%
TP	24%	28%	40%	55%	100%	169%	293%
FC	19%	23%	32%	46%	100%	216%	551%
Total [2]							
TSS	66%	69%	74%	81%	100%	127%	182%
TN	69%	71%	77%	83%	100%	119%	150%
TP	50%	54%	62%	72%	100%	135%	192%
FC	57%	59%	66%	74%	100%	145%	264%

[1] Includes Dry Comal Creek and Blieders Creek watersheds.

[2] Runoff loads are calculated as area-weighted averages of the watersheds (Comal River and Tributary of Guadalupe River).

Using those estimates of where population growth will occur, and the value of 0.16 ac of impervious cover per capita, the projected percentage increases in impervious area, runoff coefficients and concentrations are shown in tables 3-11 and 3-12. Table 3-13 shows the calculated runoff load changes for each of the watersheds for each parameter. The largest changes are calculated for the small tributary on the southwest side of the city. This is a consequence of assuming the same distribution of future population change in a watershed that is of modest size and already substantially developed. With additional development the watershed gets to 55% impervious cover, with corresponding higher runoff and concentration values. Whether this level of development will occur in this watershed remains to be seen, but it does serve to illustrate the sensitivity of the results to increases in development. The runoff loads from Blieders Creek, which drains to Landa Lake and the main areas of Comal Springs, are projected to increase by a factor of two.

Figure 3-6 presents the percentage changes in all the parameters for the entire area considered. Between 1960 and 2000, the runoff loads in the selected creeks are shown to have been increased by a factor of 1.6 to 2.0. From 2000 to 2020, further load increases of 50% to 164% are predicted.

3.4 CITY OF SEGUIN

Figure 3-7 shows the City of Seguin, just downriver from New Braunfels, and the major urban tributary watersheds. Walnut Branch drains a significant area of the city, while Little Mill Creek and Mays Creek each drain a relatively small area of the city. Geronimo Creek on the eastern side of the city is relatively large and substantially undeveloped. Because of its size and the relatively small portion of its watershed projected for urban development, no calculations are performed for Geronimo Creek. Also, a substantial area of the city drains to the Guadalupe River without going through a creek. This area is also not included in the calculations.

With a small exception, all of the urban tributaries in the Seguin area drain to the Guadalupe River and thence into Meadow Lake (TP-5). Meadow Lake is a run-of-river impoundment that provides hydroelectric power at Nolte Dam and recreational uses. At this time it is not as heavily developed as Lakes Dunlap and McQueeney further upstream.

Table 3-14 shows the watersheds with existing area and present and estimated future population distribution. It is estimated that the Walnut Branch watershed now has about 30% of the present city population, and that 25% of the future growth in population would take place in that watershed. The other two creeks considered represent small fractions of the existing population and are not expected to be major growth areas. Most of the future growth in the area is estimated to be along the I-10 corridor and the SH-123 area.

FIGURE 3-6
PROJECTED PERCENTAGE INCREASES IN URBAN RUNOFF LOADS OF SELECTED PARAMETERS FROM THE CITY OF NEW BRAUNFELS

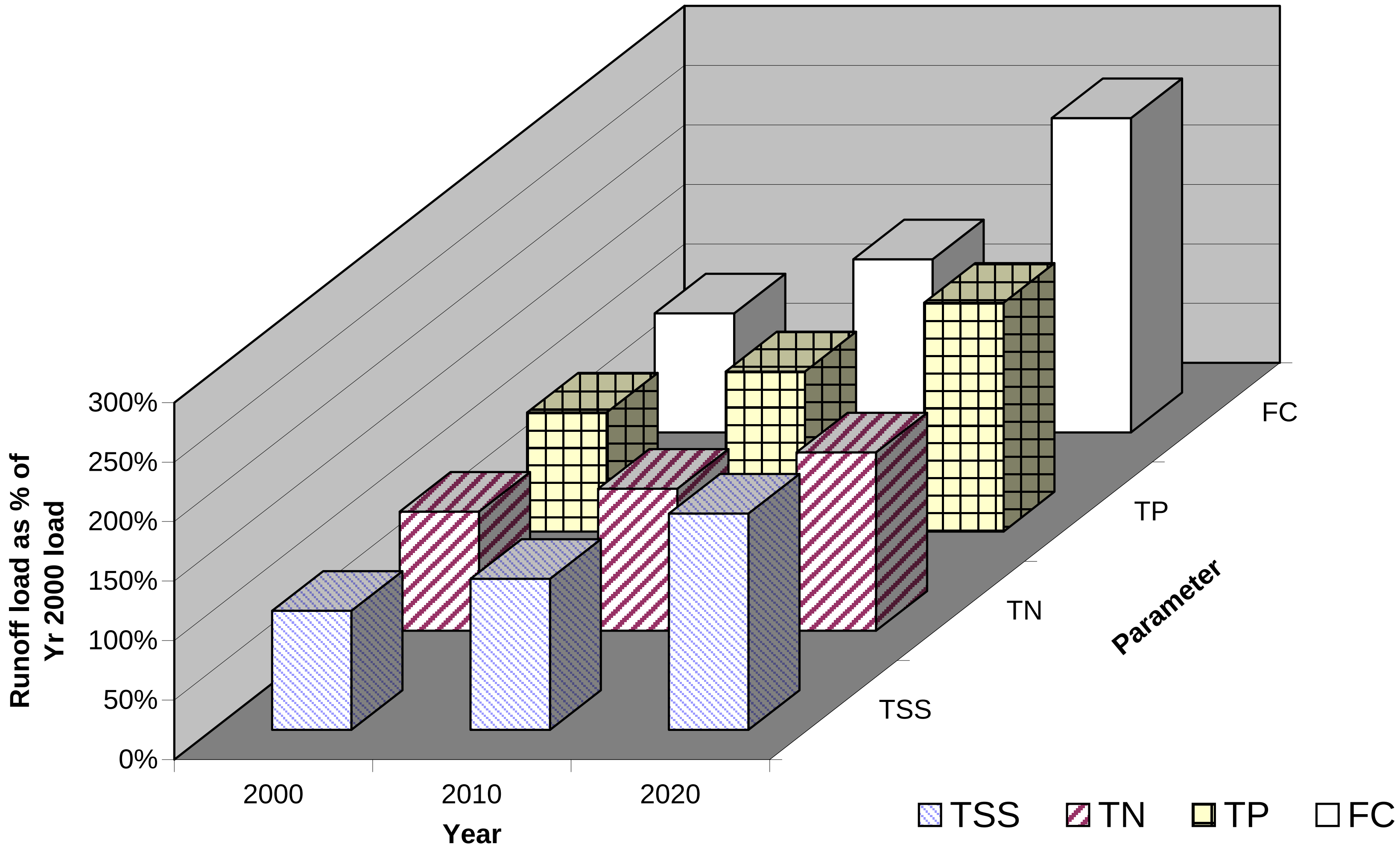


FIGURE 3-7
WATERSHEDS OF THE CITY OF SEGUIN

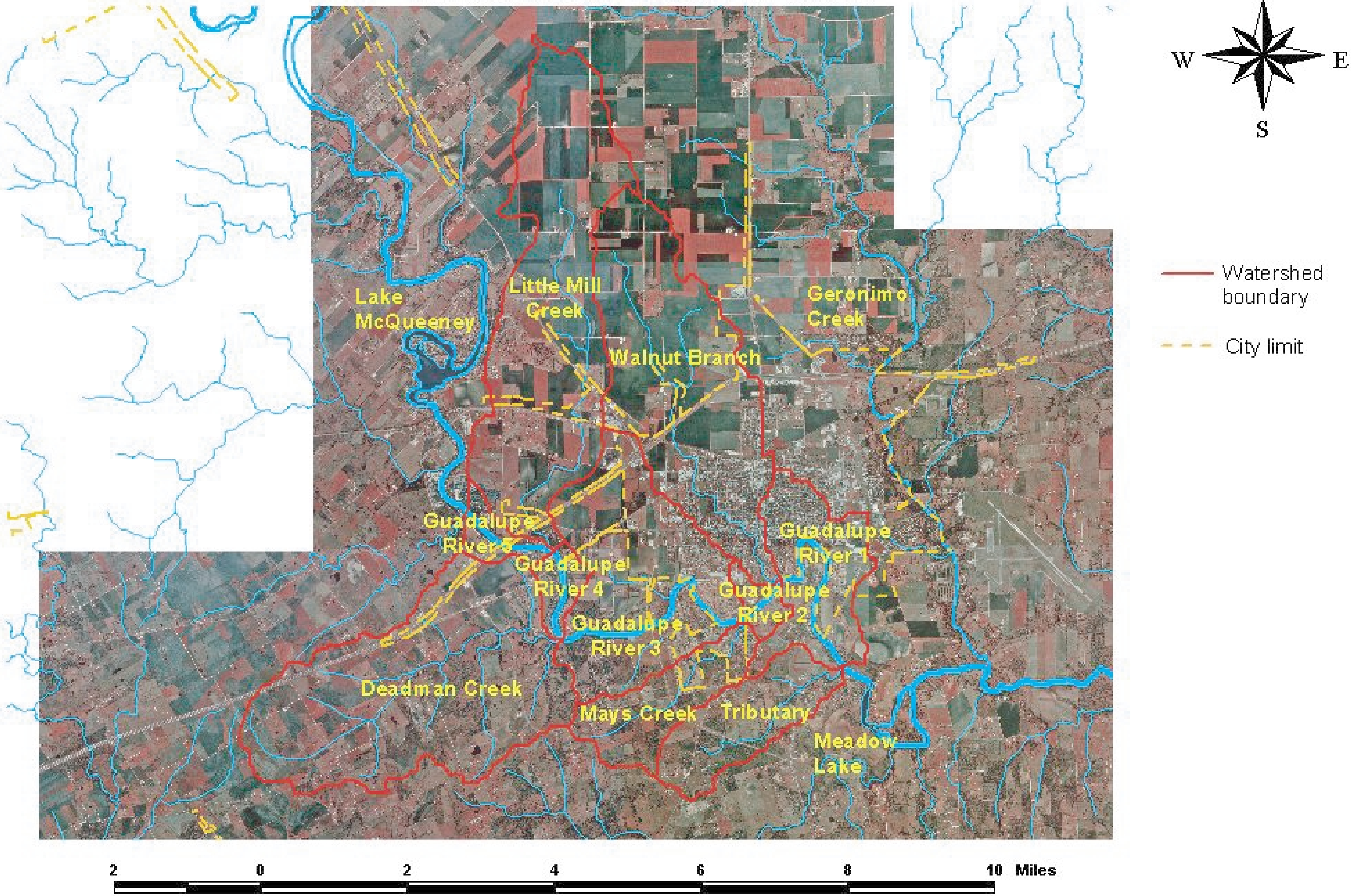


TABLE 3-14
DATA FOR SELECTED WATERSHEDS OF THE CITY OF SEGUIN

Watershed	Watershed area (acres)	% Impervious cover	Impervious area (acres)	Assumed population distribution [1]	Assumed distribution of population change [2]
Walnut Branch	4,740	16.8%	796	30%	25%
Mays Creek	1,337	5.4%	72	2%	5%
Little Mill Creek	5,553	5.3%	294	2%	2%

[1] Assumed distribution for 1960 to 2000 population.
[2] Assumed distribution of population change of 2010 and 2020 from 2000.

Table 3-15 shows the population, impervious cover and runoff coefficient values while Table 3-16 shows the runoff concentration values. Table 3-17 presents the percentage changes in the runoff loads for the watersheds of Walnut Branch, Little Mill and Mays creeks and the weighted total of the creeks. Figure 3-8 shows the projected percentage increases in the runoff loads. Between 1960 and 2000, the calculated loads have been increased by a factor of 1.4 to 1.9. From 2000 to 2020, load increases of 39% to 67% are predicted. These percentage changes are somewhat smaller than obtained for the other cities, primarily because most of the growth in Seguin is expected to occur outside of defined creeks.

TABLE 3-15
ESTIMATION OF PERCENTAGE IMPERVIOUS COVER AND RUNOFF COEFFICIENT
FOR THE CITY OF SEGUIN

Watershed	1960	1970	1980	1990	2000	2010	2020
Population							
Walnut Branch	4,290	4,780	5,356	5,656	6,109	6,514	7,778
Mays Creek	286	319	357	377	407	488	741
Little Mill Creek	286	319	357	377	407	440	541
Total city population	14,299	15,934	17,854	18,853	20,364	21,983	27,040
Impervious area (acres) [1]							
Walnut Branch	505	584	676	724	796	861	1,063
Mays Creek	53	58	64	67	72	85	126
Little Mill Creek	275	280	286	289	294	299	316
Percentage impervious cover							
Walnut Branch	10.7%	12.3%	14.3%	15.3%	16.8%	18.2%	22.4%
Mays Creek	3.9%	4.3%	4.8%	5.0%	5.4%	6.4%	9.4%
Little Mill Creek	5.0%	5.0%	5.2%	5.2%	5.3%	5.4%	5.7%
Runoff coefficient [2]							
Walnut Branch	7.1%	7.8%	8.7%	9.2%	10.0%	10.7%	13.1%
Mays Creek	4.3%	4.4%	4.6%	4.7%	4.8%	5.2%	6.5%
Little Mill Creek	4.7%	4.7%	4.8%	4.8%	4.8%	4.8%	5.0%

[1] Change in impervious cover is estimated from the change in population and impervious area per capita
[2] Values calculated from regression developed in Section 2.0.

TABLE 3-16

CALCULATED RUNOFF EMCs OF SELECTED PARAMETERS FOR THE CITY OF SEGUIN [1]

Watershed	1960	1970	1980	1990	2000	2010	2020
TSS (mg/L)							
Walnut Branch	371	392	419	434	457	479	555
Mays Creek	294	298	303	306	309	320	355
Little Mill Creek	305	306	307	307	308	309	312
TN (mg/L)							
Walnut Branch	1.68	1.77	1.88	1.94	2.03	2.10	2.35
Mays Creek	1.30	1.32	1.35	1.36	1.38	1.44	1.61
Little Mill Creek	1.36	1.36	1.37	1.37	1.38	1.38	1.40
TP (mg/L)							
Walnut Branch	0.25	0.28	0.33	0.35	0.39	0.42	0.52
Mays Creek	0.09	0.10	0.11	0.12	0.12	0.15	0.22
Little Mill Creek	0.11	0.12	0.12	0.12	0.12	0.12	0.13
FC (cfu/dL)							
Walnut Branch	18,796	20,511	22,725	23,971	25,985	27,926	34,973
Mays Creek	13,195	13,470	13,801	13,976	14,245	14,991	17,585
Little Mill Creek	13,911	13,981	14,062	14,105	14,170	14,240	14,460

[1] Values calculated from impervious cover and regressions developed in Section 2.0.

TABLE 3-17
RUNOFF LOAD CHANGES FOR SELECTED PARAMETERS FROM THE CITY OF SEGUIN

Parameter	1960	1970	1980	1990	2000	2010	2020
Walnut Branch							
TSS	57%	67%	80%	88%	100%	112%	159%
TN	58%	68%	81%	88%	100%	111%	151%
TP	45%	57%	74%	84%	100%	116%	174%
FC	51%	62%	76%	85%	100%	115%	176%
Mays Creek							
TSS	84%	88%	93%	96%	100%	112%	154%
TN	83%	88%	93%	96%	100%	112%	156%
TP	65%	74%	85%	91%	100%	127%	233%
FC	82%	87%	92%	95%	100%	114%	165%
Little Mill Creek							
TSS	96%	97%	98%	99%	100%	101%	105%
TN	96%	97%	98%	99%	100%	101%	105%
TP	91%	93%	96%	98%	100%	103%	111%
FC	95%	97%	98%	99%	100%	101%	105%
Total [1]							
TSS	69%	76%	86%	91%	100%	109%	144%
TN	70%	77%	86%	92%	100%	109%	139%
TP	52%	63%	78%	86%	100%	114%	167%
FC	63%	71%	82%	89%	100%	112%	160%

[1] Runoff loads are calculated as area-weighted averages of the watersheds.

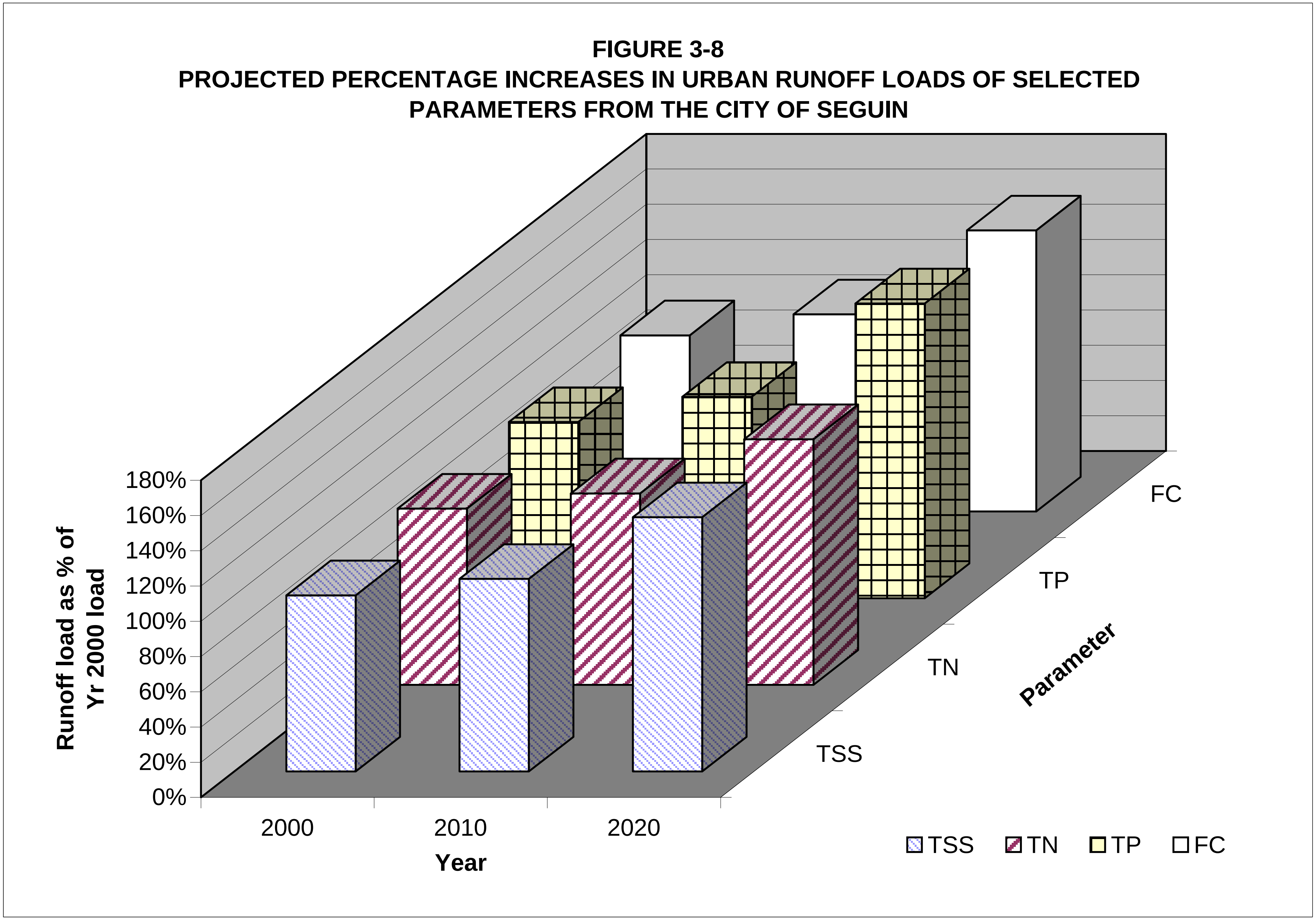


FIGURE 3-8
PROJECTED PERCENTAGE INCREASES IN URBAN RUNOFF LOADS OF SELECTED PARAMETERS FROM THE CITY OF SEGUIN
Runoff load as % of Yr 2000 load
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
2000
2010
2020
Year
TSS
TN
TP
FC
Parameter
TSS
TN
TP
FC

4.0 DISCUSSION AND RECOMMENDATIONS

The preceding section describes the calculation of increases in runoff loads from urbanizing creeks in four Guadalupe River basin communities (New Braunfels, San Marcos, Seguin, and Victoria) assuming that no actions are taken by local government or private entities to mitigate these increases. The calculations are based on a substantial amount of experience gained by the City of Austin with stormwater runoff monitoring in urban creeks similar to those considered.

All four communities are projected to grow and all of the urban creeks considered show increases in runoff loads, although the percentage changes vary substantially. There are also substantial differences in the receiving waters of these creeks. For example, Spring Lake and the San Marcos River tend to retain runoff inputs in impoundments while they simply flow downstream in the Guadalupe River at Victoria. This section attempts to put the calculated changes into context and address some differences that might be important to the local communities in the future as decisions are made on stormwater management.

The first consideration is to put these runoff loads into proper context. Runoff events last a matter of hours and typically occur 10 to 15 times per year during larger and more intense rains. Small or low intensity rains generally do not produce significant runoff. The differences in the amount and concentrations in the runoff that have been calculated would take time to detect with specialized monitoring procedures, but would be almost impossible for the public to notice during the runoff events.

While differences in runoff loads of TSS or other parameters would not be obvious or even detectable by the public <u>during the events</u>, there are potential longer-term or chronic effects that are (or at least should be) of legitimate public concern. These chronic effects can occur both in the streams and in the receiving waters of the streams. In the streams the major impact of increased runoff flows and loads is a change in the physical nature and aquatic habitat characteristics. In the receiving water the changes include increased accumulation of sediments and nutrients and reduced opportunities for swimming.

The physical nature of streams and the quality and quantity of aquatic habitats can be altered in two ways. First, the larger volume of flow produced by increased impervious cover runoff tends to scour the streambed. This is the mechanism that produces the higher TSS and other parameter concentrations in stream runoff flows. This scour has the potential to drastically modify the aquatic habitat in the stream. It can also be a threat to structures near the stream and may lead to the need to armor the channel to control erosion. The second mechanism is diminished dry weather flows, a direct consequence of increased runoff flows. Because more of the land in the watershed has impervious cover, less of the rain can soak into the ground and sustain baseflow in the stream during dry periods. The effect is for the stream to be dry for longer periods. A worst-case scenario would involve changing the stream from a continuously flowing sediment channel with diverse aquatic and riparian vegetation and a rich benthic and fish community into a barren rock or concrete drainage channel that only has water during and immediately after a rain. Because such a worst-case scenario usually takes a substantial amount of time to develop, it is important to have in place some form of monitoring to evaluate and document the current quality of streams in each community.

Effects on receiving waters can also be dramatic, but tend to vary substantially depending on the nature of the receiving water. If the mouth of the tributary stream feeds into an impounded area like Spring Lake in San Marcos or Lake Dunlap in New Braunfels, the greater loads of sediment, nutrients and indicator bacteria will tend to be retained in the impoundment. In that case the impoundment will tend to fill more rapidly with sediment, will be exposed to higher nutrient loads and thus be more susceptible to nuisance vegetation, and will encounter longer periods of elevated indicator bacteria levels. On the other hand, if the tributary stream feeds into another larger stream like the Guadalupe River at Victoria, the greater loads will not be retained in the immediate area but flow downriver. As a consequence, there may be little noticeable effects in the immediate area of the community. While the effect may not be easily seen in the community itself, downstream interests will still be affected to some degree.

In the past the effects described above have been considered to be an unavoidable consequence of urban development. Examples of streams converted from natural to concrete-lined drainage structures are available in most urban areas of Texas including Brays and White Oak bayous in Houston and portions of the San Antonio River in San Antonio. Impacts to receiving impoundments are not as obvious but also exist.

Gradually the situation is changing. Concern over downstream flooding in the last two decades has prompted requirements for flood peak detention. This detention minimizes increases in peak runoff rates. However, it does not address the overall volume of runoff flow that is the major contributor to stream scour, because flood detention facilities have to drain quickly to be able to accommodate another rain. In cities such as Austin there are requirements for water quality features for new development. These include stream set backs or buffers, density limits and control measures. Stream buffers prevent most types of development in the immediate area of a stream and thus protect riparian vegetation. Another common approach is to limit the amount of impervious cover in a watershed from new development. This is effective in limiting runoff flow increases, but it is expensive if property values are high as it limits the use of the land. It also tends to disperse development over a broader area, and that has some negative implications with regard to traffic and urban sprawl. A third major tool to deal with water quality effects of new development are structural controls such as sedimentation-filtration ponds that act to reduce the concentrations of TSS and other parameters but do not make a major difference in total volume of runoff flows.

Whatever regulatory requirements evolve in the coming years, the Austin data and experience suggests that a major objective should be to avoid an increase in the amount of total site runoff as development occurs. This is an ambitious goal that is gaining a degree of acceptance. A major proponent of the approach has been Prince George's County, MD. This is an area that has seen extensive suburban growth in last several decades, and that has devoted considerable effort into managing the effects of that growth. They have produced several documents on Low-Impact Development (LID) (PGC, 2000a, 2000b, 1997) that detail many of the methods required to maintain predevelopment stormwater runoff volume, peak runoff flow rates and frequencies. The LID methods include a combination of site planning to minimize impervious cover, and landscape and drainage features to retain and infiltrate runoff. Essentially, the goal is to control runoff changes at the source, rather than using measures such as sedimentation and filtration ponds that are expensive, must be maintained, and have a limited degree of effectiveness (PGC, 1997). If LID could be implemented in these developing Guadalupe River basin communities, most of the water quality impacts predicted in the previous section could be avoided. In addition, most of the downstream flooding effects would be addressed at the source, minimizing the need for additional flood detention structures.

While LID appears to be the ultimate solution to the water quality problem addressed here, it is a significant change that can be expensive in some cases and it may not be viewed as necessary by all parties involved. Communities will need to make individual decisions considering both external mandates (federal and state regulations), and local interests and desires. While the external mandates are still evolving, the communities have time to assess their particular situations, considering the uses made of streams and receiving waters in their area and develop a consensus on priorities and the alternatives available.

All of the communities discussed in this report are likely to be subject to emerging Phase II Stormwater regulations enacted by the US EPA and to be implemented by the TNRCC. How this program will ultimately be structured in Texas is still being developed, but it is safe to assume that some form of administrative responsibility for stormwater will be placed on these cities. The challenge to be faced will be to structure an effort that is appropriate and effective for the specific situations faced by each city.

The goal of this report is to encourage involvement in water quality efforts by providing quantitative information on the effects of urbanization in each community, and by suggesting ways that could be used to deal with development. For additional information, the following web sites are a good place to start:

www.TXNPSBOOK.org Website prepared by the Texas Public Works Association targeted to helping city officials deal with runoff issues.
www.tnrcc.state.tx.us/water/quality/tpdes/index/ The official TNRCC TPDES web site.
www.epa.gov/owm/sw/index/ Official EPA web site for storm water issues.
www.lowimpactdevelopment.org/ Website of the Low Impact Development Center.

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