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CALCULATIONS OF URBAN RUNOFF WATER QUALITY EFFECTS IN KERR COUNTY

Prepared for:

Texas Clean Rivers Program
Guadalupe-Blanco River Authority
and
Upper Guadalupe River Authority

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1.0 INTRODUCTION AND SUMMARY

Over the last two decades there has been a gradually growing realization that with point source wastewater discharges having been 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.

While the recognition of the concern with urban nonpoint source runoff is strong at the governmental level, there is not yet a widespread public understanding of the processes involved and the magnitude and nature of the concerns. Furthermore, there is an evolving technical understanding of the issues and the types of controls that will be most effective in many situations. In short, urban runoff concerns are poorly understood by the public, and the means to address these concerns effectively are still being evolved.

The Texas Clean Rivers Program 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 the urbanization effects. Recognizing that there has been no urban runoff monitoring in Kerr County, 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.

Section 2 of this report describes the historical growth patterns in Kerr County in terms of population and incorporated areas. The section also includes recent projections of population growth in the area. Briefly, the population doubled in the 30 years between 1960 and 1990, and is projected to almost double again in the 30-year period between 1990 and 2020. Much of this growth has been and will continue to be in urban areas of the county.

The next report section 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.

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. Creeks with higher development (higher impervious cover percentage) exhibited higher average concentrations of all parameters considered, despite there being no apparent difference in the quality of runoff waters feeding the creeks.

The fourth report section presents the actual quantification of changes in runoff quantity and quality in response to the urban development changes. In the rural areas upstream of Kerrville the changes predicted are quite small. In the metropolitan area however, the combined effects of higher total runoff and higher creek runoff concentrations produced substantial increases in the calculated loads of suspended solids, nitrogen, phosphorus, and indicator bacteria. While the changes calculated for the urban area are substantial, the effect further downriver at Comfort is more modest. This is because even in 2020 the projected total amount of urban development in Kerr County is still small.

Finally, section 5 addresses briefly the possible means that could be considered to address or manage the potential water quality concerns. 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.

2.0 DEVELOPMENT IN KERR COUNTY

This section briefly summarizes data on development patterns in Kerr County and the metropolitan Kerrville area. Changes in urbanized area and population are related to changes in land use, using data from the City of Austin. In the next major section, additional City of Austin data are used to estimate changes in the quality and quantity of water entering the Guadalupe River in Kerr County.

2.1 POPULATION CHANGES

Table 2-1 summarizes U.S. Census data for the county and City of Kerrville from 1960 through 1990.

TABLE 2-1

REGIONAL POPULATION DATA

Year	Kerrville	Kerr County
1960	8,901	16,800
1970	12,672	19,454
1980	15,276	28,780
1990	17,384	36,304

Substantial growth during the period is evident. The population of the City almost doubled during the 30-year period and the County population more than doubled. The average increase in population per decade was over 2,800 in the City and over 6,500 in the County.

The 1990 population in Kerr County was determined for nine areas shown in Figure 2-1. Table 2-2 lists the population for those areas and the projections made through the year 2020 in the recent Regional Water and Wastewater Planning Study (HDR, 1997).

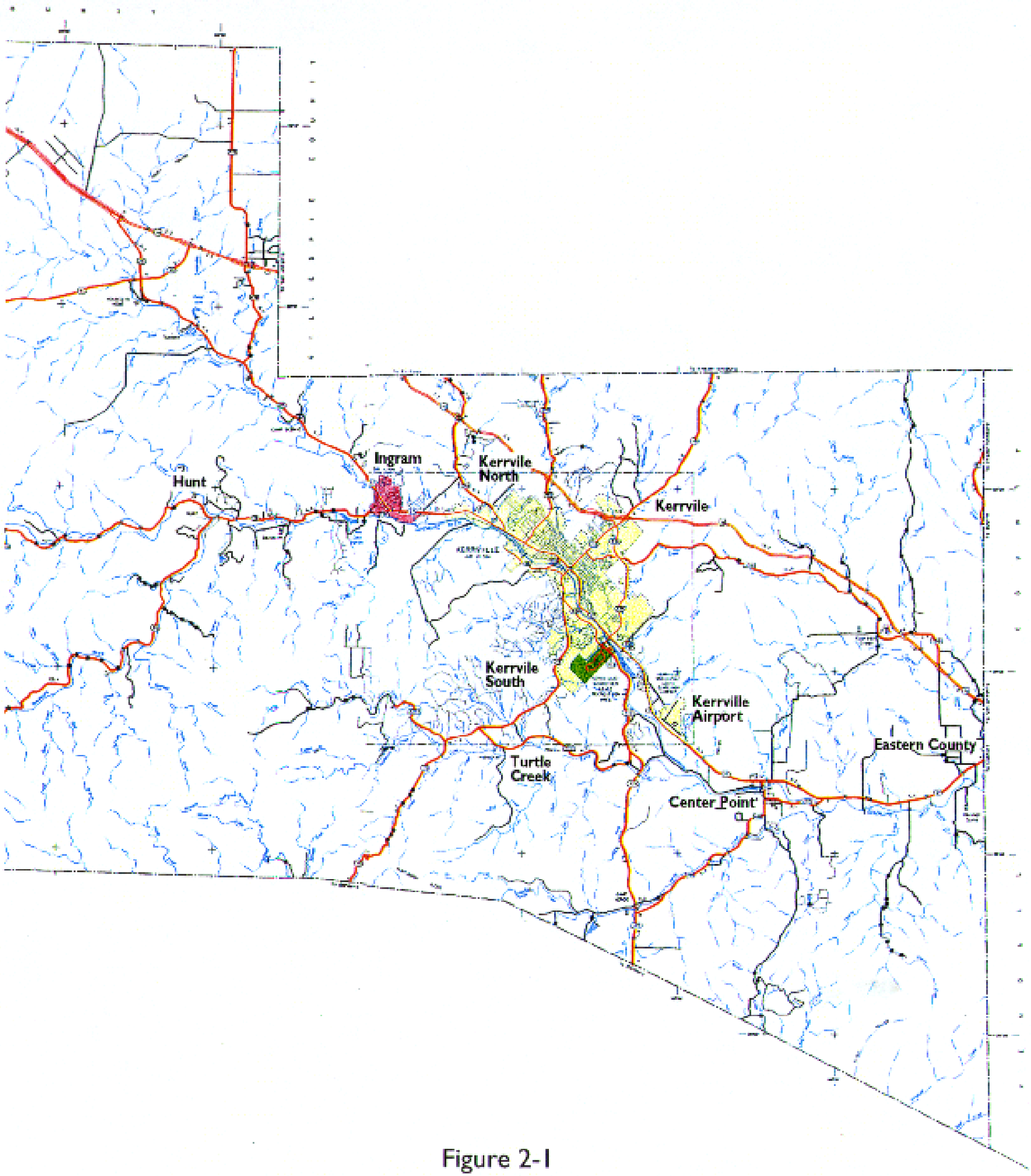

Figure 2-1
Population Concentrations in Kerr County

TABLE 2-2

KERR COUNTY POPULATION PROJECTIONS

Area	Year 1990	2000	2010	2020
Kerrville	17,384	21,191	25,580	30,425
near Kerrville	420	420	420	420
Ingram area	5,618	6,745	7,934	9,004
Kerrville North	742	891	1,048	1,189
Kerrville South	3,892	4,673	5,497	6,238
Turtle Creek	2,076	2,492	2,931	3,326
Kerrville Airport	910	1,093	1,285	1,459
Center Point	2,738	3,287	3,866	4,388
Eastern County	936	1,124	1,322	1,500
Hunt	583	700	823	934
Other	1,005	1,206	1,419	1,610
Kerr County Total	36,304	43,822	52,125	60,493

Source: Regional Water and Wastewater Study, HDR, 1997

2.2 LANDUSE CHANGES

Data on landuse in the City and County has not been developed in any detail. One measure of the growth in the urban area is the size of incorporated area of the City of Kerrville. Figure 2-2 shows how the mapped area of the City has increased over approximately the same period of time as the population data discussed above. Table 2-3 shows the approximate City of Kerrville area at several times during the analysis period.

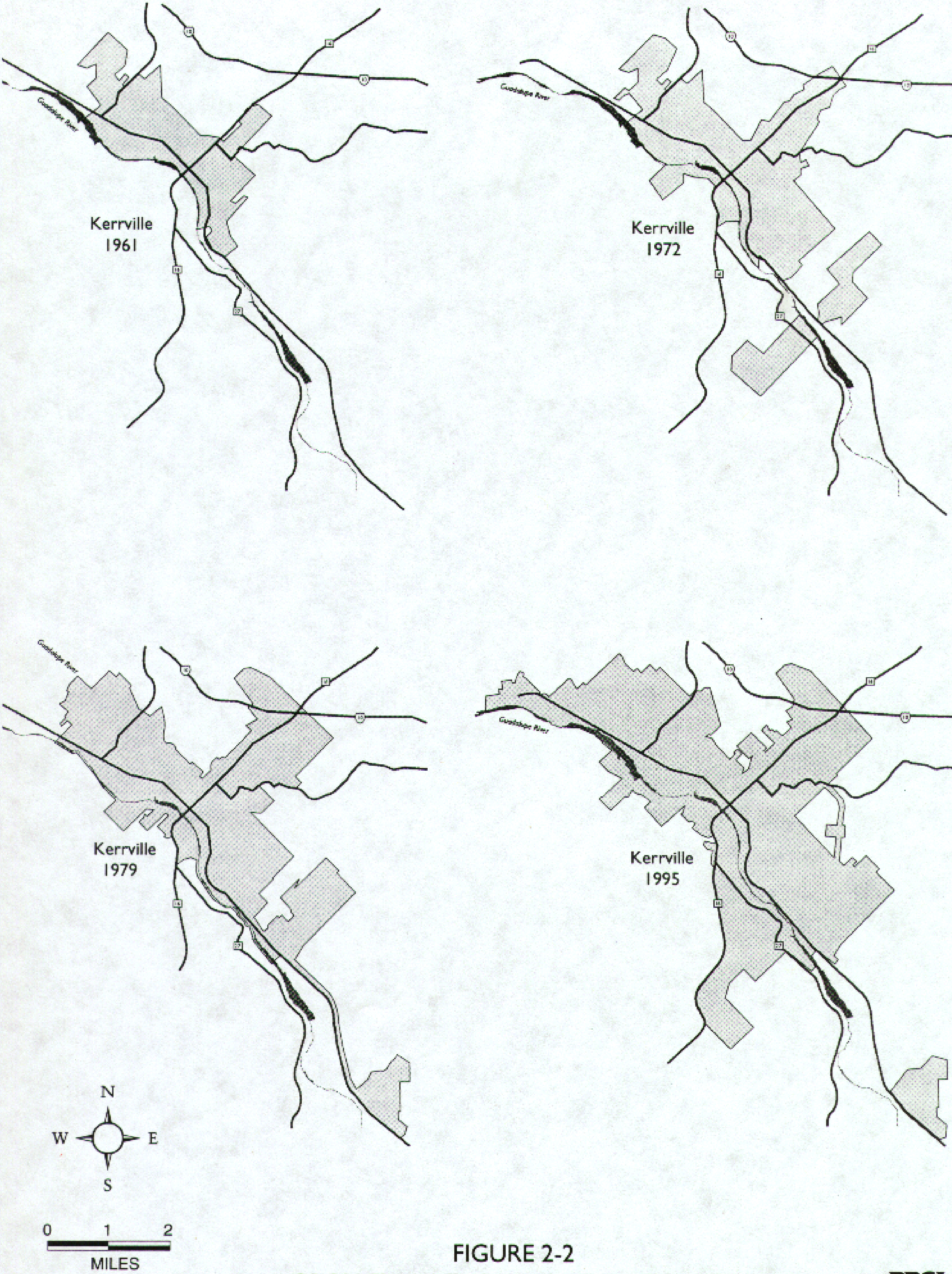

FIGURE 2-2
GROWTH IN THE KERR COUNTY AREA

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TABLE 2-3

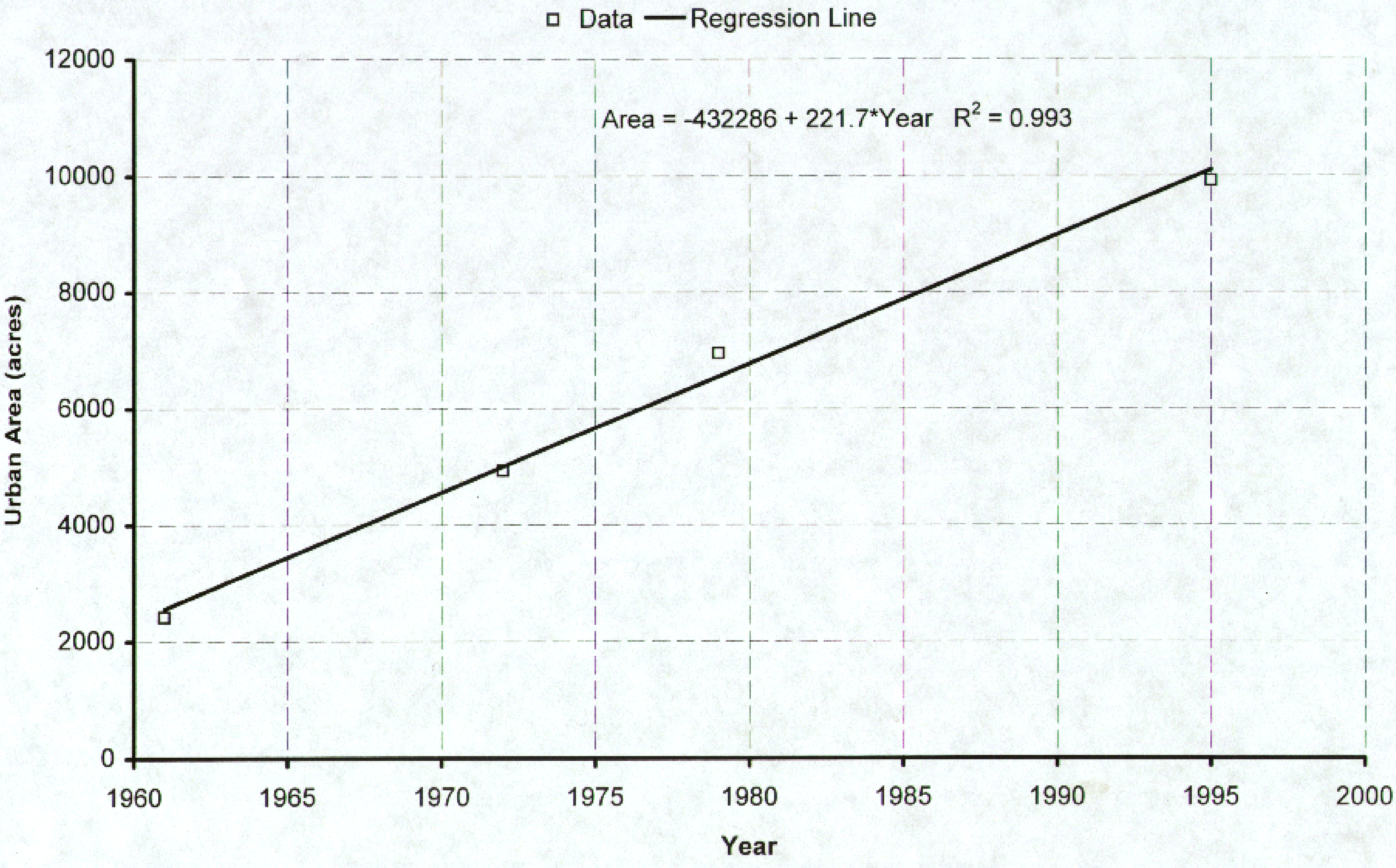
CITY OF KERRVILLE AREAS

Year	Acreage	Square Miles
1961	2421	3.8
1972	4934	7.7
1979	6953	10.9
1995	9913	15.5

Recognizing that the date of publishing a map of the City boundary may not correspond to the actual time when that boundary was established, the general pattern of growth of the area within the City has been approximately matched the rate of population growth. Figure 2-3 plots the areas against time and includes a regression line that is surprisingly linear. Using the regression line to smooth the variations and provide values at decade intervals, the average acreage per capita in the City has increased from 0.25 in 1960 to 0.51 in 1990.

While population and incorporated areas are the parameters that are routinely quantified, the major factor from a water quality perspective is the amount of impervious cover such as roofs and paved areas. Data from many years of urban runoff monitoring from the City of Austin has indicated that impervious cover plays a major role in the amount and quality of runoff. The relation between impervious cover and water quantity-quality is developed in section 3.0 of this report.

FIGURE 2-3
GROWTH IN THE URBAN AREA OF THE CITY OF KERRVILLE



3.0 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.

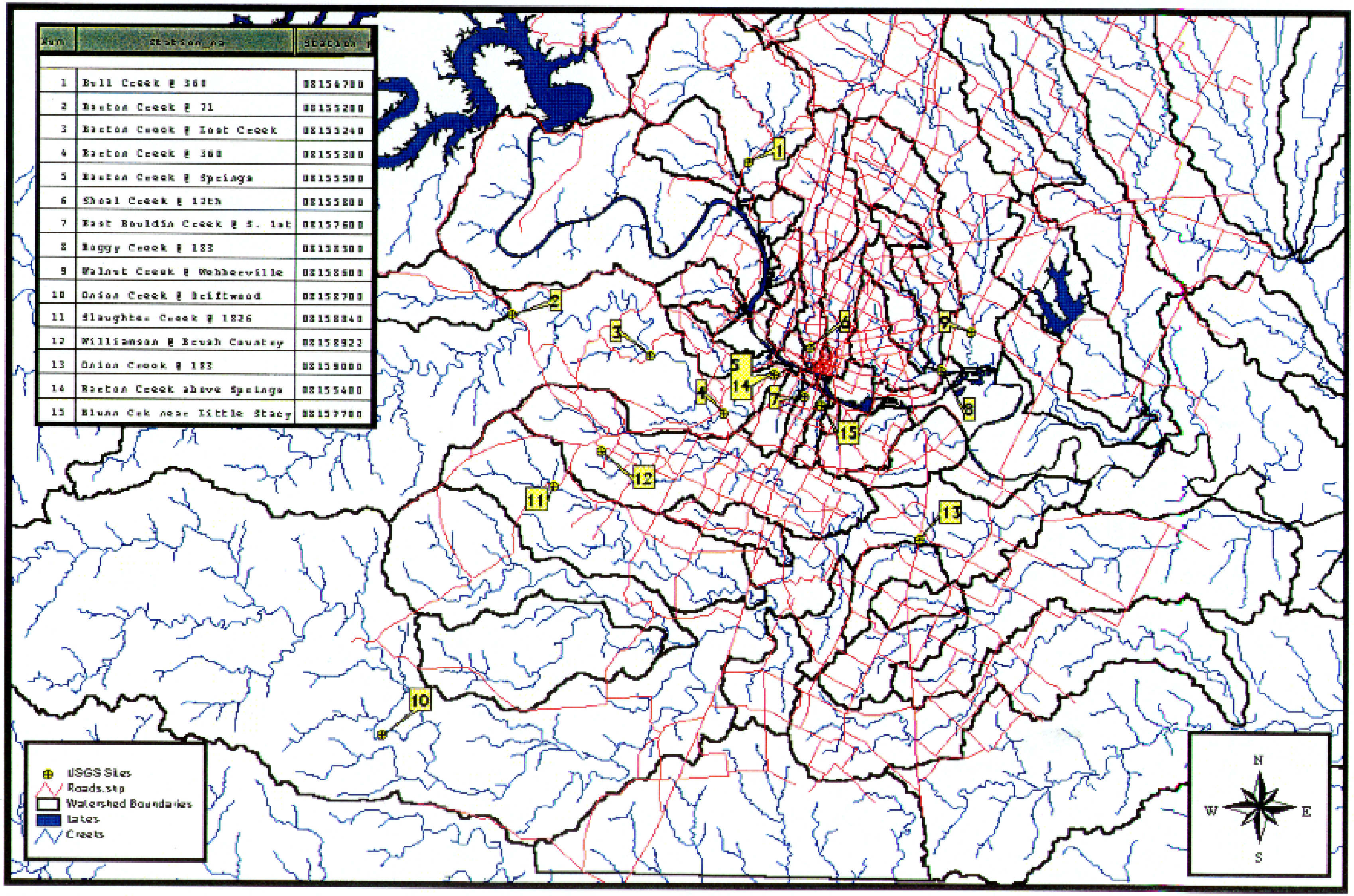
The City has been responsible for two types of water quality monitoring activity. One is monitoring of the major creeks in the urban area under both runoff and base flow conditions. This is performed by the USGS under contract to the City. Figure 3-1 shows the locations of the USGS monitoring sites. The other major type of urban water quality monitoring is for smaller, typically single land use watersheds. This monitoring is performed by City personnel.

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 3-1 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. Figure 3-2 shows the location of the sites currently monitored by the City. Table 3-2 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 3-2) is included in the left column of Table 3-2. Note that the largest drainage area shown in Table 3-2 is 371 acres, while the smallest creek site listed in Table 3-1 is 1,443 acres. All of the smaller sites are normally dry and are only sampled during runoff conditions.

One of the fundamental points about urban water quality conditions is the effect of impervious cover (streets, roofs, etc.) on increasing runoff. 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 3-3, 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.

USGS Stream Monitoring Sites



Num	Station_na	Station_
1	Bull Creek @ 360	08154700
2	Barton Creek @ 71	08155200
3	Barton Creek @ Lost Creek	08155240
4	Barton Creek @ 360	08155300
5	Barton Creek @ Springs	08155500
6	Shoal Creek @ 12th	08156800
7	East Bouldin Creek @ S. 1st	08157600
8	Boggy Creek @ 183	08158300
9	Walnut Creek @ Webberville	08158600
10	Onion Creek @ Driftwood	08158700
11	Slaughter Creek @ 1826	08158840
12	Williamson @ Brush Country	08158922
13	Onion Creek @ 183	08159000
14	Barton Creek above Springs	08155400
15	Blunn Crk near Little Stacy	08157700

Figure 3-1
USGS Stream Monitoring Sites

TABLE 3-1
USGS - CITY OF AUSTIN CREEK MONITORING DATA

Creek Monitoring Site	Drainage Area		Impervious Cover (%)	Landuse	Period of Record	Runoff to Streamflow (%)
	(Acres)	(Sq. Miles)				
Bull Creek @ Loop 360	14,272	22.3	16	Mixed	78-96	39
Barton Creek @ Hwy 71	57,408	89.7	3	Mixed	78-96	36
Barton Creek @ Lost Ck. Blvd.	68,480	107.0	4	Mixed	89-96	36
Barton Creek @ Loop 360	74,240	116.0	5	Mixed	78-96	51
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
Boggy Creek @ Hwy 183	8,384	13.1	43	Mixed	75-96	92
Walnut Creek @ Webberville Rd	32,832	51.3	26	Mixed	78-96	59
Onion Creek near Driftwood	79,360	124.0	3	Mixed		
Bear Creek @ FM 1826	7,808	12.2	5	Mixed	78-96	28
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: Characterization of Stormwater Pollution for the Austin, TX Area-COA-ERM/WQM, 1997

COA Stormwater Monitoring Sites

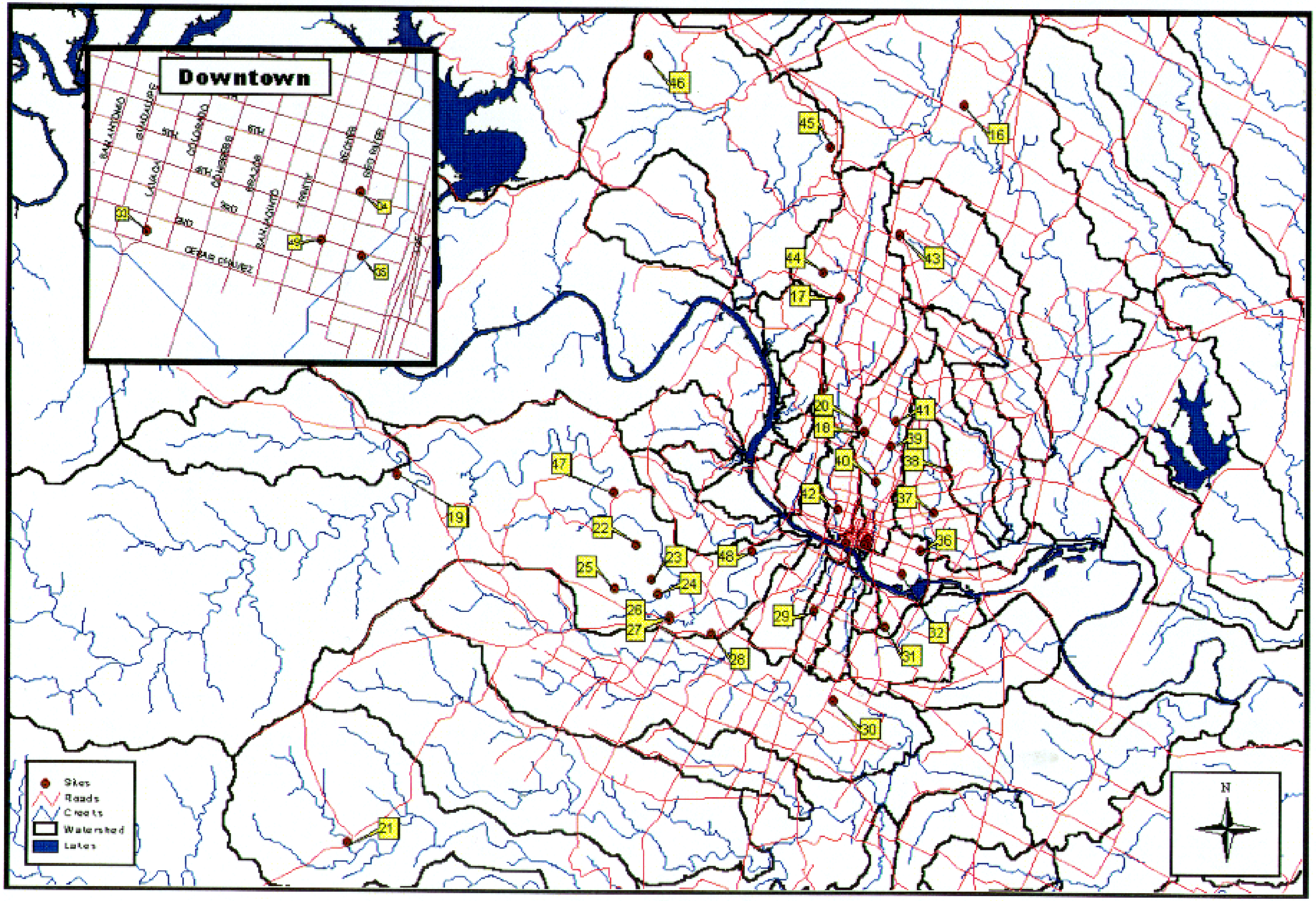


Figure 3-2
City of Austin Stormwater Sites

TABLE 3-2
CITY OF AUSTIN URBAN RUNOFF MONITORING SITES

ID Number[1]	Code Name	Site Name	Drainage Area (Acres)	Impervious Cover (%)	Landuse	No. of Measurements	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: Characterization of Stormwater Pollution for the Austin, TX Area-COA-ERM/WQM, 1997

[1] Refer to Figure 3-2 COA Stormwater Sites

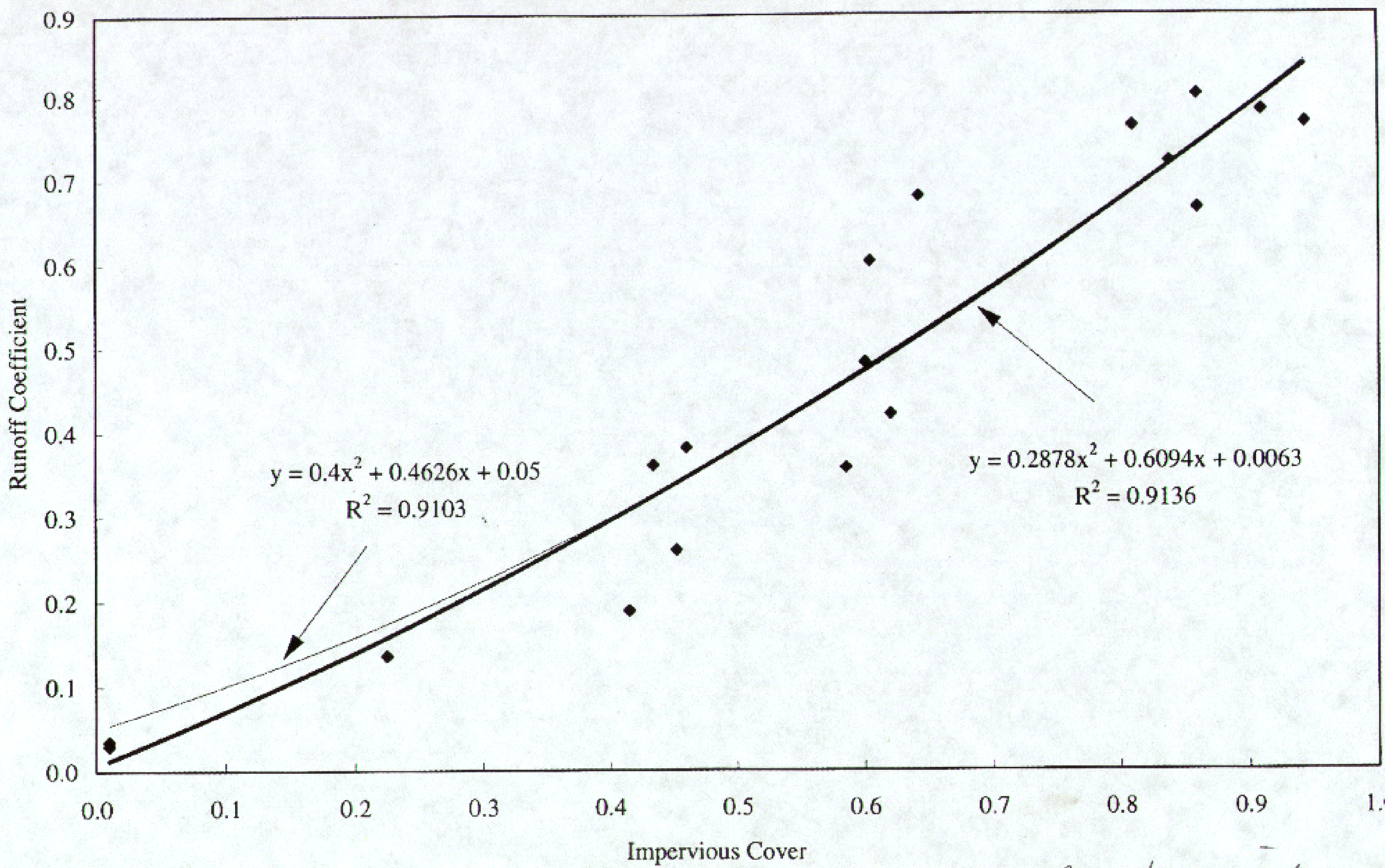


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Figure 3-3
Rv and impervious cover for non-recharge zones

Source: Characterization of Stormwater Pollution for the Austin, Texas Area, City of Austin, 1997

Another way to view the effect of impervious cover on runoff is use a runoff model. This is illustrated in Figure 3-4, 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 soak into the soil, while a fully developed site will have most of the rain leave the site as runoff.

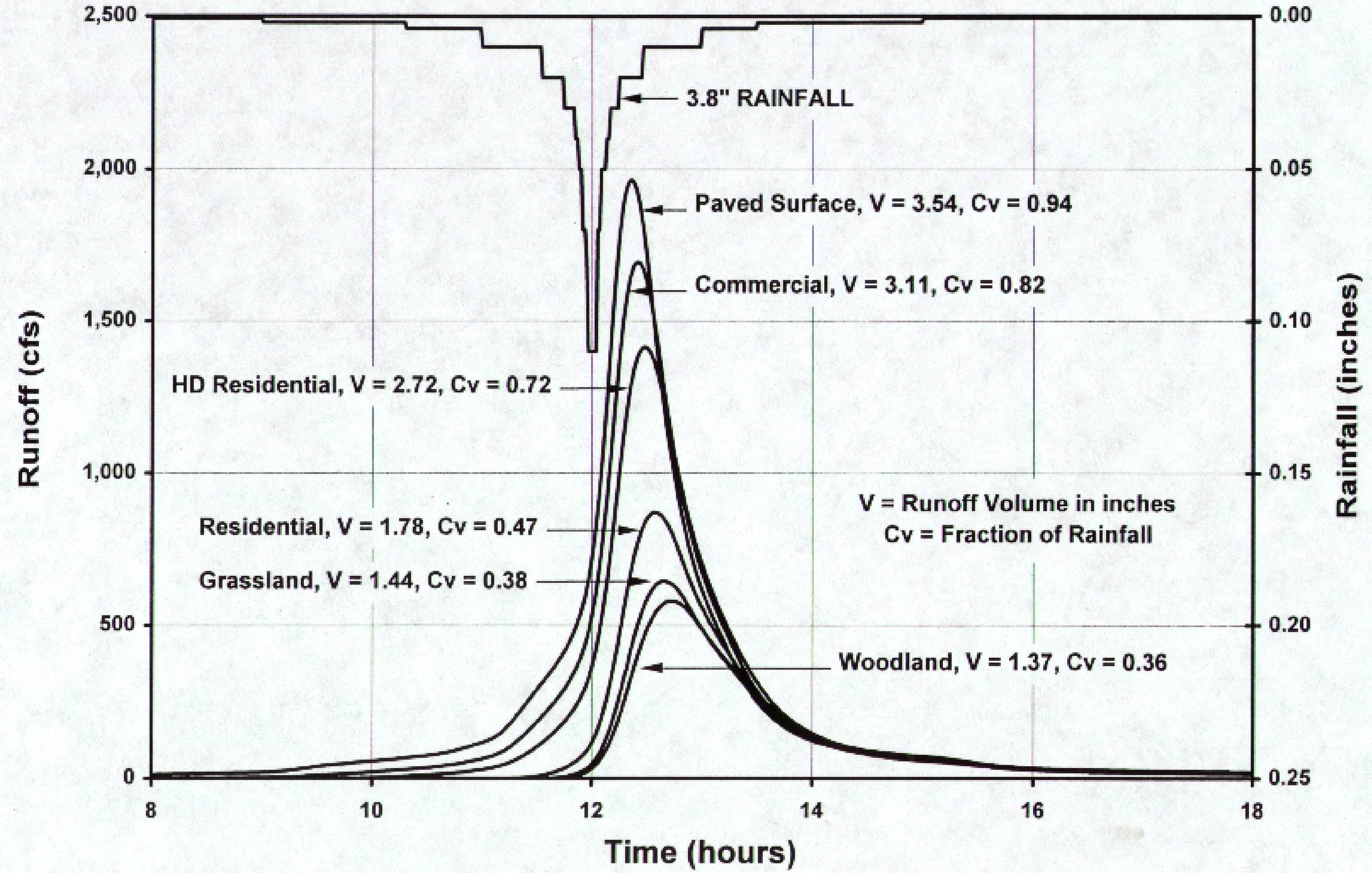
When discussing the quality of runoff samples, it is customary to employ a flow-weighted average, frequently called an Event Mean Concentration (EMC). This is necessary because the concentration of any parameter varies greatly during runoff events. A good example is the well-known first flush effect, 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 3-3 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 3-4 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 3-4 are the concentrations collected under baseflow or non-runoff conditions. Typically the non-runoff averages are substantially lower than the runoff data.

FIGURE 3-4
EFFECTS OF DEVELOPMENT ON RUNOFF VOLUMES



Source: Texas Nonpoint SourceBOOK, www.TXNPSbook.org

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TABLE 3-3
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: Appendix E3, Characterization of Stormwater Pollution for the Austin, TX Area-COA-ERM/WQM, 1997

[1] (Colony forming unit/deciLiter)

TABLE 3-4

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: Appendix E4 and E5, Characterization of Stormwater Pollution for the Austin, TX Area-COA-ERM/WQM, 1997

[1] (Colony forming unit/deciLiter)

Figure 3-5 shows the long-term average EMCs for TSS for both the smaller sites and the larger creek sites listed in Tables 3-3 and 3-4, plotted versus impervious cover percentage in the contributing watershed. One observation from Figure 3-5 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 Figures 3-5 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 3-5, there does appear to be somewhat higher TSS concentrations with greater impervious cover.

Figure 3-6 presents similar information taken from earlier City of Austin reports (CoA, 1990, 1994). In this case the City employed medians of USGS data for the creeks and city monitoring sites instead of flow-weighted means. Comparing Figures 3-5 and 3-6, the small single land use sites have similar TSS values, in the range of 100 to 200 mg/L. The major difference is in the creek sites, where more of the stations have somewhat higher TSS concentrations. The earlier City reports using medians of the data has the overall effect of producing a somewhat stronger delineation between the larger and smaller sites, but the same overall pattern. There is little change in runoff quality with impervious cover at the smaller sites, but significant changes with impervious cover on the creeks.

A similar pattern can be seen for TN in Figure 3-7, TP in Figure 3-8, and FC in Figure 3-9. 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 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, the amount of small 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 increases the amount of streambed erosion, which increases the amount of sediment, nutrients and bacteria in suspension.

FIGURE 3-5

TSS MEAN EMCs FOR CITY OF AUSTIN STORMWATER RUNOFF

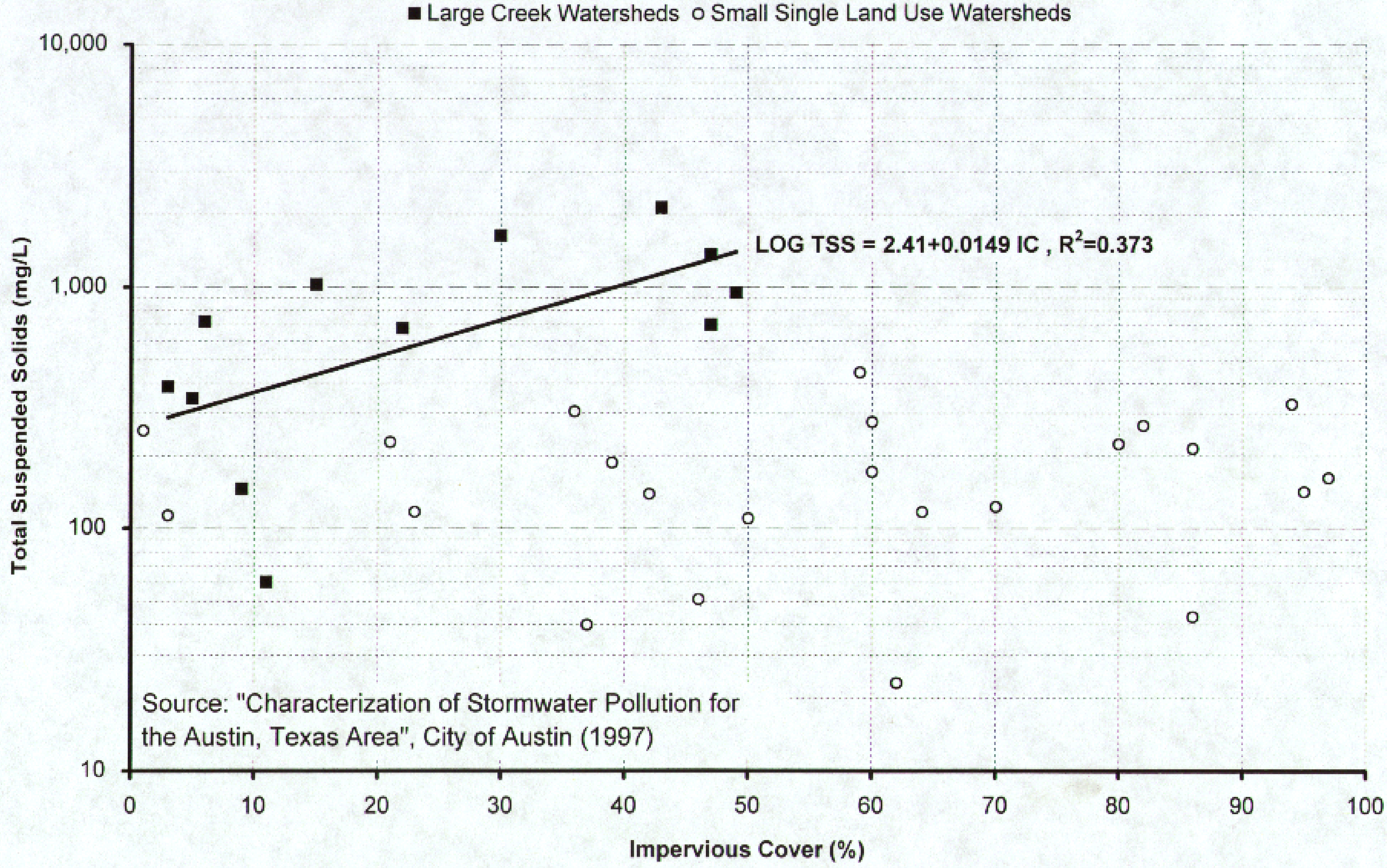

FIGURE 3-6

MEDIAN TSS EMCs FOR CITY OF AUSTIN STORMWATER RUNOFF

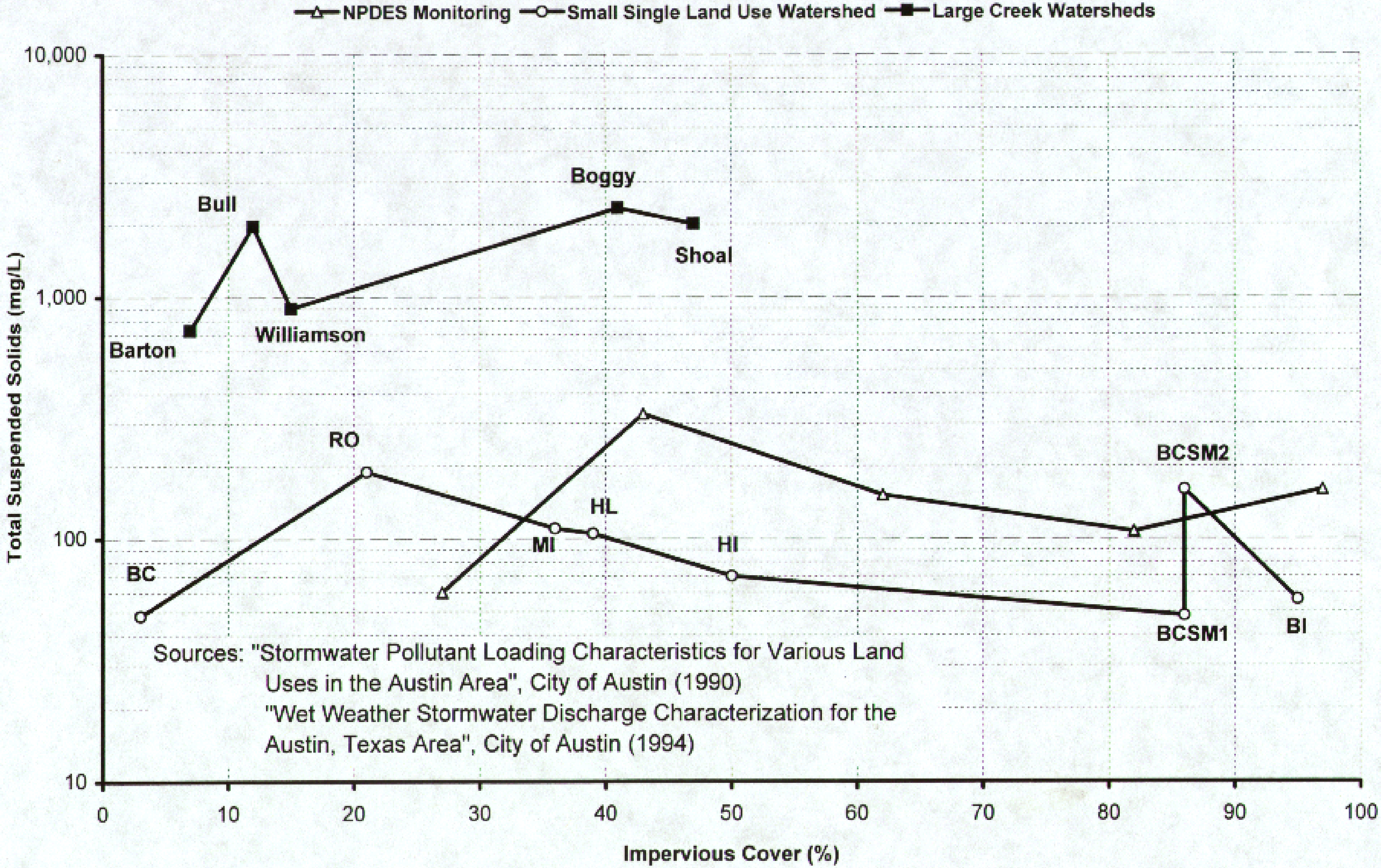

FIGURE 3-7

TOTAL NITROGEN MEAN EMCs FOR CITY OF AUSTIN STORMWATER RUNOFF

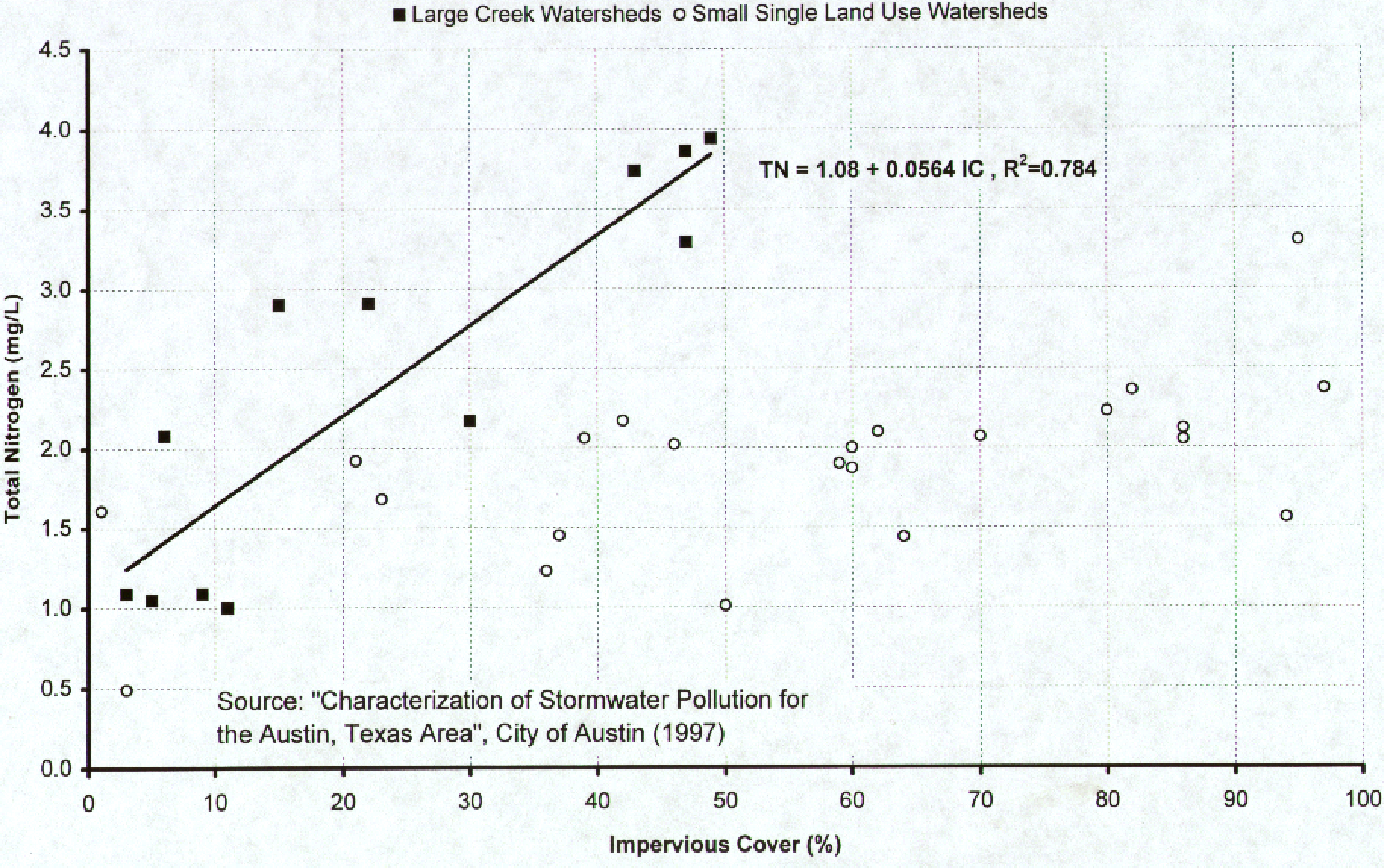

FIGURE 3-8

TOTAL PHOSPHORUS MEAN EMCs FOR CITY OF AUSTIN STORMWATER RUNOFF

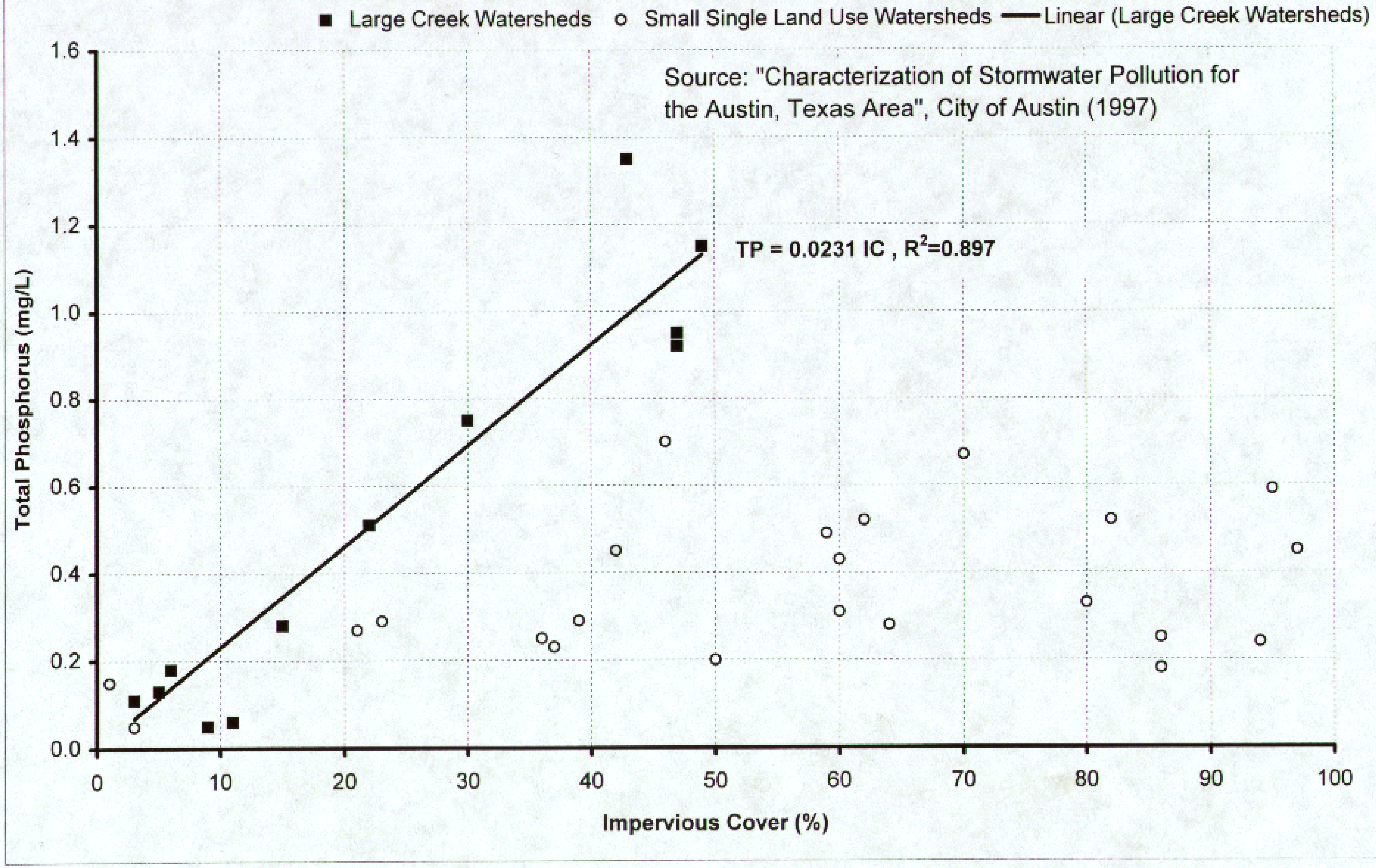

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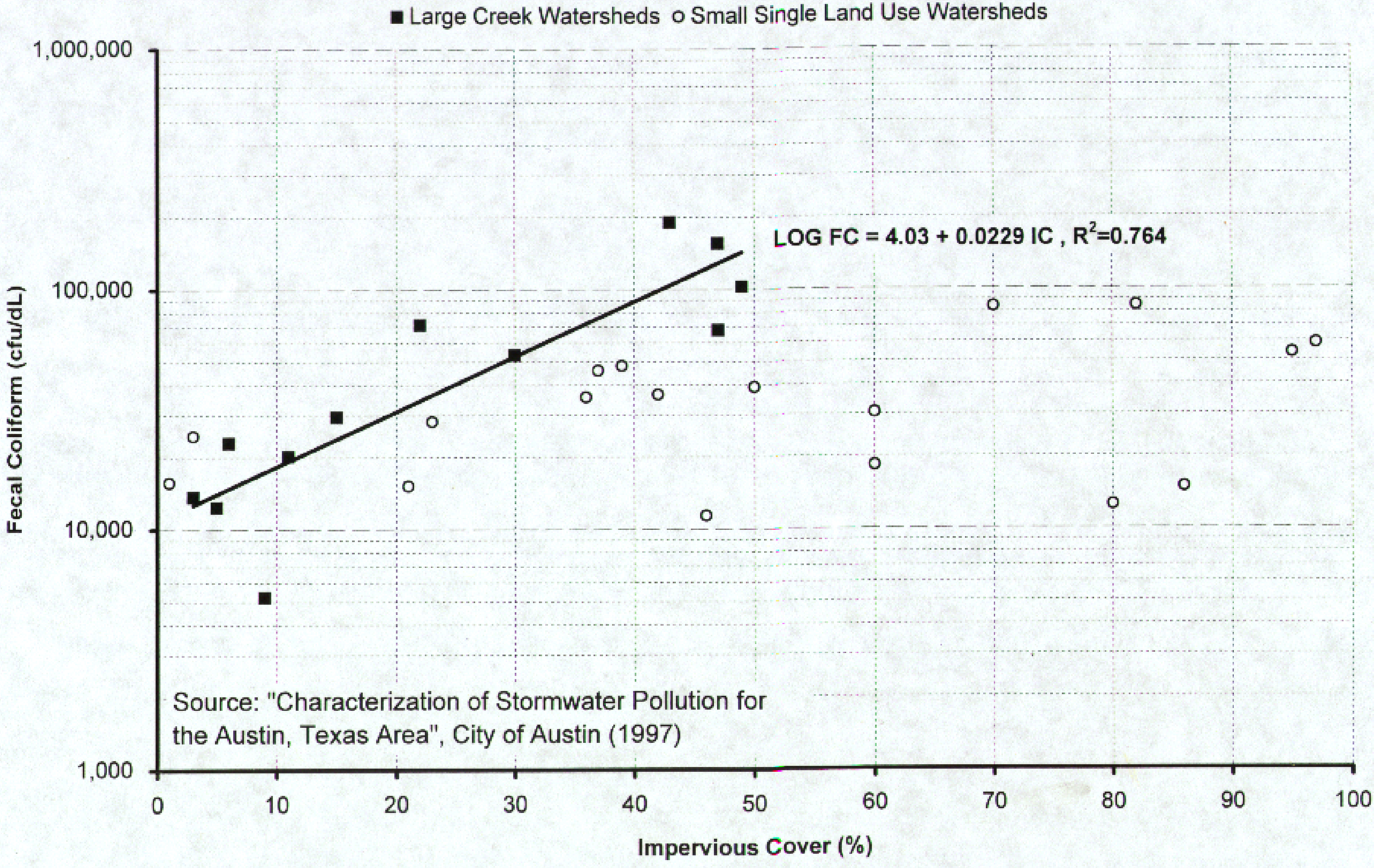
FIGURE 3-9

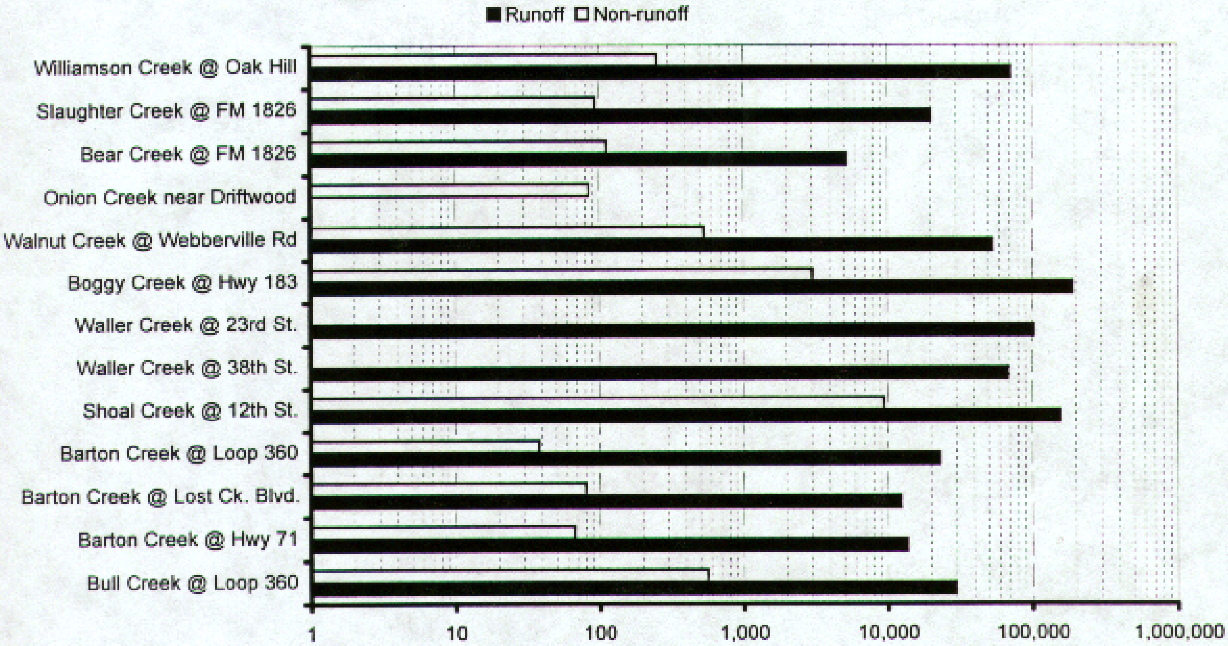
FECAL COLIFORM MEAN EMCs FOR CITY OF AUSTIN STORMWATER RUNOFF



The effect of streambed scour is important to the differences between the urban creek and smaller watersheds, and highlights the differences between runoff and non-runoff conditions. Figure 3-10 plots the creek runoff and non-runoff FC data together, and Figure 3-11 plots the runoff and non-runoff TSS data. The runoff data are one to three orders of magnitude higher than the dry weather data. With FC, the runoff data are much higher than the geometric mean level of 200 cfu/dL specified for contract recreation use. The sites that 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.

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.

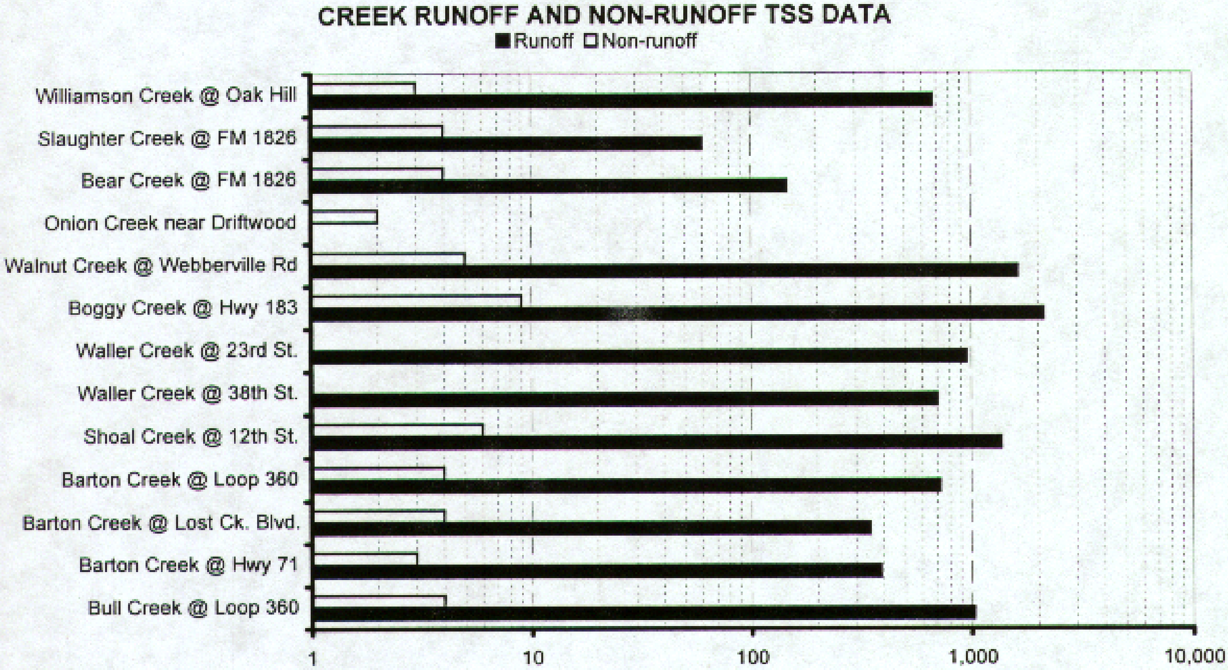
FIGURE 3-10
CREEK RUNOFF AND NON-RUNOFF FC DATA



Source: "Characterization of Stormwater Pollution for the Austin, Texas Area", City of Austin (1997)

FC (cfu/dL)

FIGURE 3-11
CREEK RUNOFF AND NON-RUNOFF TSS DATA



Source: "Characterization of Stormwater Pollution for the Austin, Texas Area", City of Austin (1997)

TSS (mg/L)

4.0 RUNOFF WATER QUALITY EFFECTS ASSESSMENT

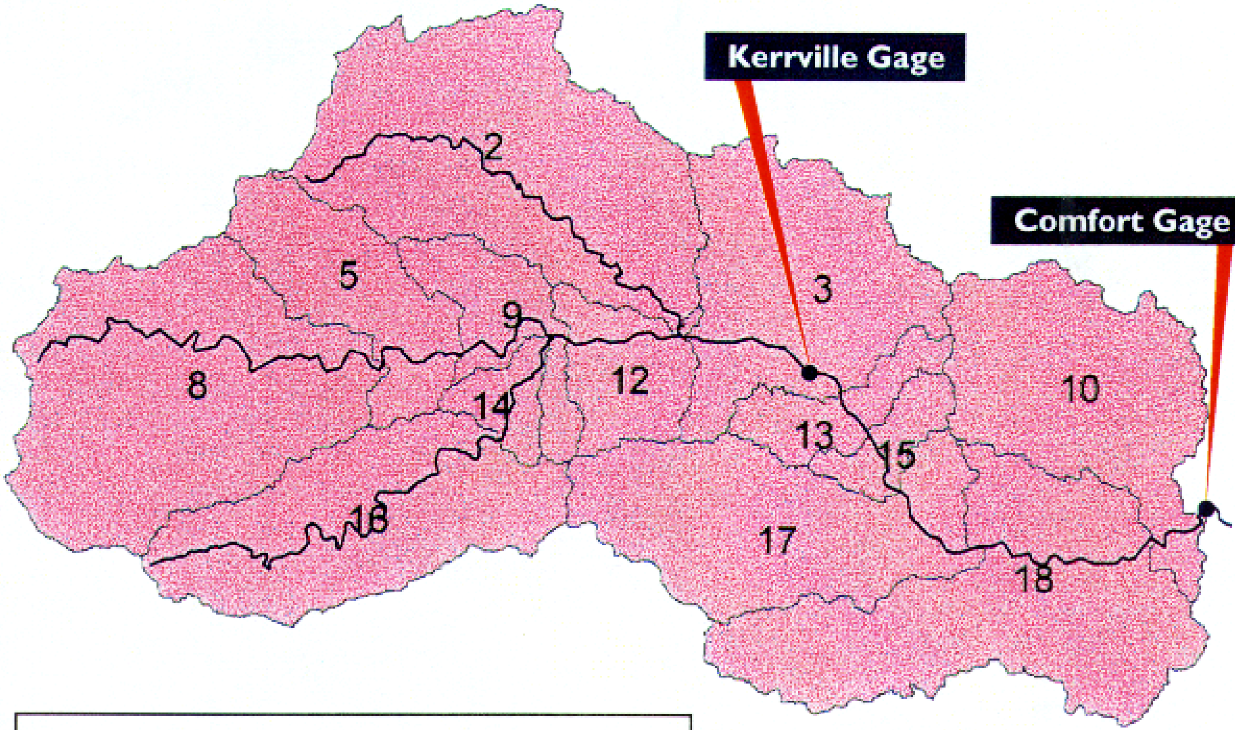
This section develops methods to estimate the changes in impervious cover that have occurred in Kerr County since 1960, and that are projected to occur with present development patterns in the future to the year 2020. Next, the information from the previous section is used to relate these impervious cover changes to water quality changes.

4.1 IMPERVIOUS COVER CHANGES

Impervious cover in urban areas ranges from near 100% in the central business district to nearly zero in areas on the suburban fringe. Data from the City of Austin has impervious cover in the more urbanized tributaries approaching 50%. These are creeks (Shoal and Waller) that terminate in Town Lake with their headwaters in suburban regions. In the absence of data on land use and impervious cover in Kerrville, a reasonable but possibly conservative estimate would be that 40% of incorporated area of the city is impervious cover. For Kerrville with a current area per capita of 0.51 acres, this converts to 0.204 acres of impervious cover per capita.

Estimating the amount of impervious cover per capita that exists in Kerr County outside of the city is somewhat more difficult. The types of development are more scattered and diverse there are no data or examples that appears to be entirely representative. In the absence of data, it will be assumed that the representative pattern is for development in the county to occur in 1-acre lots with an average of 9,750 sq ft of impervious cover per residence. This figure is based on a 2,000 sq ft roof, a 750 sq ft driveway, and a 200-ft length of access road with a width of 35 ft. These values are somewhat arbitrary but are nonetheless representative. The overall percentage impervious for the 1-acre individual residence and associated road access is 22%, which is fairly typical for suburban development. Table 4-1, taken from Schueler (1987) gives representative values for impervious cover for different types of land use.

With a further assumption of an average of 2.5 people per residence, and each residence generating 0.22 acres of impervious cover, the overall impervious cover per capita outside the city is 0.088 acres.



No.	Subwatershed	Area in Sq. Mi.
2	Johnson Creek	128
3	Goat, Town, Quinlan Creeks	82
5	Bear Creek	45
8	North Fork, Guadalupe River	126
9	Honey and Tegener Creeks	27
10	Cypress Creek	81
12	Kelley and Indian Creeks	27
13	Camp Meeting and Third Creeks	19
14	Lower South Fork	12
15	Dry Hollow and Silver Creek	13
16	South Fork, Guadalupe River	85
17	Turtle, Silver, Steel Creeks	85
18	Verde, Elm, Cherry, Bruins, Bluff & Wilson Creeks	113
		844

Stream / River
River basin sub-watersheds

N
W E
S

10 0 10 Miles

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Figure 4-1
Guadalupe River Subwatersheds

Source : TNRCC ArcInfo Files

TABLE 4-1

LAND USE AND IMPERVIOUS COVER

Land Use	Site % Imperviousness
Rural Residential	0-10
Large Lot Single Family	10-20
Medium Density Single Family	20-35
Townhouse	35-50
Garden Apartment	50-60
High Rise, Light Commercial/ Industrial	50-80
Heavy Commercial, Shopping Center	80-100

Rural Residential: 0.25-0.50 Dwelling Units (DU)/acre
Large Lot Single Family: 1.0-1.5 dus/acre
Medium Density Single Family: 2-10 dus/acre
Townhouse and Garden Apartment: 10-20 dus/acre

Source: Schueler (1987).

The USGS operates a number of stream gages in the study area:

Gage No.	Name	Area (sq. mi.)	Average '94 Flow (cfs)	Unit Flow (cfs/sq. mi.)
08165300	North Fork near Hunt	169	33.2	.196
08165500	Guadalupe River at Hunt	288	70.3	.244
08166200	Guadalupe River at Kerrville	510	102	.200
08167000	Guadalupe River at Comfort	839	166	.198

Based on the average flow in 1994, all the gages have a remarkably similar average discharge per square mile of watershed area, about 0.2 cfs.

Figure 4-1 shows subwatershed boundaries obtained from the TNRCC, along with the names that go with the numeric codes and the areas of each subwatershed. The USGS gages at Kerrville and Comfort are also shown. The Kerrville gage is located in Area 3. Between the Kerrville gage and the lower edge of Area 3 are Town and Quinlan Creeks. Camp Meeting and Third Creeks are in Area 13. The areas that drain Kerrville downstream of the Kerrville gage are taken to be 22 sq. mi. of area 3, plus 19 sq. mi. from Area 13.

The gage at Kerrville, located on the water supply ponding lake, is upstream of a substantial portion of the urbanized area. We do not have exact figures of impervious cover upstream of this point, but a reasonable estimate is that 10 to 20% of the current Kerrville City area limit is upstream of this point. In addition, the City of Ingram is entirely upstream. These urban populations are used in Table 4-2, together with suburban population in Hunt and Kerrville North to calculate impervious area. Using a total watershed area of 510 sq. mi. above the USGS gage, a percentage impervious in 1990 of 0.5% is calculated. This is a considerably lower percentage than any of the creeks in Austin. The estimated value in 1960 is approximately half that amount.

In the year 2020 the population is projected to be nearly twice the 1990 figures. Estimating the impervious cover in the same manner yields 0.81%. This value is still quite low by urban standards.

The partly urbanized drainage area surrounding Kerrville is taken as the approximately 41 sq. mi. of Town, Quinlan, Camp Meeting and Third creeks (part of area 3 and all of 13). This is not a precise determination of the urbanized area, as it does not include some of the areas to the south, but is reasonably

TABLE 4-2
IMPERVIOUS COVER ESTIMATES

Area		1960	1990	2000	2010	2020
Kerrville Ponding Dam	510 sq.mi. watershed area					
Population upstream						
Urban(1)		3,890	7,356	8,864	10,492	12,047
County(2)		800	1,325	1,591	1,871	2,123
Impervious Area (acres)(3)		864	1,617	1,948	2,305	2,644
Impervious Cover (%)(4)		0.26%	0.50%	0.60%	0.71%	0.81%
Urban Kerrville Creeks	41 sq.mi. watershed area					
Population						
Urban(5)		8,011	15,646	19,072	23,022	27,383
County(6)		2,800	4,897	5,879	6,916	7,848
Impervious Area (acres)(3)		1,881	3,623	4,408	5,305	6,277
Impervious Cover (%)(4)		7.17%	13.81%	16.80%	20.22%	23.92%
Guadalupe River at Comfort	839 sq.mi. watershed area					
Population						
Urban(7)		12,000	23,002	27,936	33,514	39,429
County(8)		4,800	13,302	15,886	18,611	21,064
Impervious Area (acres)(3)		2,870	5,863	7,097	8,475	9,897
Impervious Cover (%)(4)		0.53%	1.09%	1.32%	1.58%	1.84%

(1) Sum of Ingram and 10% of Kerrville

(2) Sum of Hunt and Kerrville North

(3) Calculated from .2 ac/cap in urban and 0.088 ac/cap in suburban areas

(4) Impervious area/watershed area

(5) 90% of Kerrville

(6) Sum of Kerrville South and Other

(7) Sum of Ingram and Kerrville

(8) Remainder of County

close. The population and associated impervious cover within these watersheds are also listed in Table 4-2. With these areas the percentage impervious cover is relatively high.

Finally, the overall county-wide impervious cover picture is calculated for the USGS gage at Comfort, slightly downstream of the Kerr-Kendall county border. While the values are substantially higher than at the upstream Kerrville gage, they are still representative of a largely undeveloped watershed.

4.2 RUNOFF QUALITY CHANGES

After developing estimates of the changes in the percentage of impervious cover, 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 3 of the report.

Table 4-3 presents the long-term average stormwater runoff concentrations for TSS, TN, TP and FC, along with the runoff coefficient, all calculated from the impervious cover percentage. At the Kerrville gage location the changes between 1960 and 1990 are small for all values except TP. In most cases, these changes would be far too small to be detected with routine water quality monitoring. However, the TP change, from 0.006 mg/L to 0.011 mg/L, might be large enough to detect, if there were sufficient observations of TP during runoff events. However, as storm runoff events are not everyday occurrences, it is doubtful that even a specially designed stormwater sampling program could detect a change of that magnitude.

The situation is markedly different for the urban creek location. In this case, the impervious cover percentage almost doubled between 1960 and 1990, and the concentrations of most parameters increased by a similar amount. If there were a program of stormwater monitoring in the urban creeks, it is entirely possible that a change of this magnitude calculated from Austin data would have been detected experimentally. It is also noteworthy that in the absence of change, growth in the area can be expected to produce another near doubling of runoff concentrations in the next 30 years.

The final location at Comfort is somewhat similar to the Kerrville gage location in that the changes are fairly modest. However, they are not insignificant changes. For example, the calculated TP concentration has doubled since 1960 and is expected to almost double again by 2020, in the absence of changes in land use practice.

The dramatic aspect of the changes can be more easily perceived in terms of percentage changes in the load of the parameters. The stormwater load in this case is defined as the product of the runoff coefficient and the average runoff concentrations. In Table 4-4, the percentage change in this load

TABLE 4-3
KERR COUNTY RUNOFF QUALITY CALCULATIONS

Location	Period	Impervious Cover (%)	Runoff Coefficient (%)	Average Runoff Concentration[1] TSS (mg/L)	TN (mg/L)	TP (mg/L)	FC (cfu/dL)
Kerrville Ponding Dam	1960	0.26%	0.79%	259	1.09	0.006	10,866
(510 sq. mi. watershed)	1990	0.50%	0.93%	261	1.11	0.011	10,999
	2000	0.60%	0.99%	262	1.11	0.014	11,058
	2010	0.71%	1.06%	263	1.12	0.016	11,122
	2020	0.81%	1.13%	264	1.13	0.019	11,183
Urban Kerrville Creeks	1960	7.17%	5.15%	329	1.48	0.166	15,636
(41 sq. mi. watersheds)	1990	13.81%	9.59%	413	1.86	0.319	22,190
	2000	16.80%	11.68%	457	2.03	0.388	25,983
	2010	20.22%	14.13%	514	2.22	0.467	31,116
	2020	23.92%	16.85%	584	2.43	0.553	37,824
Guadalupe River at Comfort	1960	0.53%	0.96%	262	1.11	0.012	11,022
(838 sq.mi. watershed)	1990	1.09%	1.30%	267	1.14	0.025	11,350
	2000	1.32%	1.44%	269	1.15	0.031	11,489
	2010	1.58%	1.60%	271	1.17	0.036	11,645
	2020	1.84%	1.76%	274	1.18	0.043	11,809

[1] Values calculated from impervious cover and regressions developed in Section 3.

TABLE 4-4
KERR COUNTY RUNOFF LOAD CHANGES

Location	Period	Impervious Cover (%)	Runoff Coefficient (%)	Runoff Loads as Percentage of 1960 Level			
				TSS	TN	TP	FC
Kerrville Ponding Dam	1960	0.26%	0.79%	100%	100%	100%	100%
(510 sq. mi. watershed)	1990	0.50%	0.93%	119%	119%	221%	119%
	2000	0.60%	0.99%	127%	128%	283%	128%
	2010	0.71%	1.06%	136%	137%	358%	137%
	2020	0.81%	1.13%	145%	146%	435%	146%
Urban Kerrville Creeks	1960	7.17%	5.15%	100%	100%	100%	100%
(41 sq. mi. watersheds)	1990	13.81%	9.59%	234%	233%	359%	265%
	2000	16.80%	11.68%	316%	310%	532%	377%
	2010	20.22%	14.13%	430%	411%	774%	546%
	2020	23.92%	16.85%	582%	536%	1093%	792%
Guadalupe River at Comfort	1960	0.53%	0.96%	100%	100%	100%	100%
(838 sq.mi. watershed)	1990	1.09%	1.30%	138%	140%	277%	140%
	2000	1.32%	1.44%	155%	157%	372%	157%
	2010	1.58%	1.60%	173%	176%	494%	177%
	2020	1.84%	1.76%	193%	197%	635%	197%

is calculated relative to the value that would have existed in 1960. At the Kerrville gage, the TSS load in 1990 is 119% of the load in 1960, or only a 19% difference during the 30-year period. TP is calculated to have more than doubled to 221% of the 1960 load.

The dramatic percentage load changes are in the developing urban creeks. Between 1960 and 1990 the loads have increased from by a factor of 2.5 to 3.5, and between 1990 and 2020 there will be another major increase. By 2020, the calculations indicate that TP and FC runoff loads will be approximately ten times their 1960 values.

The percentage changes at the Comfort gage appear to be approximately a 100% increase from 1960 levels, except for TP where the increase would appear to be a factor of five.

4.3 DISCUSSION

Using estimates of the changes in impervious cover based on population data, and stormwater monitoring experience from the City of Austin, estimates of past and future changes in stormwater runoff concentrations and loads have been developed. In some cases the estimates indicate rather dramatic increases over time, particularly in Total Phosphorus and Fecal Coliform bacteria. Several points are worth noting in interpreting these results.

First, the estimates provided deal with stormwater runoff only, not to the entire flow of the Guadalupe River. No determination has been made as to the percentage of the total flow represented by stormwater runoff on the Guadalupe, but in the Austin area the USGS estimated that in the undeveloped watersheds about a third of the total flow was contributed by stormwater (Table 3-1). This probably is a little high but in the correct order for the Guadalupe River in Kerr County. This means that the changes calculated previously for the river gages only apply to less than a third of the flows. The changes in impervious cover county-wide do not appear to be large enough to change this situation significantly. However, in the urban creek areas runoff makes up the bulk of the flow, and as impervious cover increases, the percentage of the total flow contributed by runoff increases. Accordingly, the changes calculated for the urban creeks do apply to essentially all of the flows.

A second point is that the changes calculated are predominantly increases in particulate matter scoured from the streambeds and not necessarily inputs from watershed polluters. This is not to say that residential landowners will not occasionally over-fertilize their grass or construction site runoff will not add extra TSS. These processes undoubtedly occur and make a contribution to runoff loads. However, the real changes seen in Austin data are in the urban creeks where the concentrations are considerably higher than in the developments contributing the urban runoff. It is difficult to see how changes in the concentrations that are already low relative to the creeks, will have a major effect on the creek concentrations.

The changes in particulate matter calculated for the Kerr County area are potentially important from a water quality perspective. First, the series of run-of-river impoundments have been shown to be sensitive (EH&A, 1990) to the concentration of phosphorus as one control on the amount of aquatic plant growth. An increase in sediment load that contains some phosphorus may act as a stimulant to aquatic plant growth in the urban lakes. This is a potential concern that should be evaluated with local data, as Austin sediments and the biological availability of particulate phosphorus may well be different. Second, sediment itself can be a pollutant blanketing aquatic habitat and reducing some forms of biological activity. To the extent that this sediment accumulated in reservoirs, it would reduce capacity for their established uses. This should not be a concern in Kerr County as the reservoirs tend to be scoured during very large flow events, but it is a potential concern downriver at Canyon Lake where the material accumulates. Third, additional stormwater flow that scours urban creeks has the effect of damaging the aquatic habitat in these creeks. Since providing for aquatic life is a use designated for nearly all of the waters of the state, damaging aquatic habitat is a water quality impact. Fourth, higher FC bacteria levels during runoff events have the effect of raising overall average levels, which could potentially have regulatory implications. For all of the above and possibly other reasons, residents of Kerr County should be sensitive to the effect of urbanization and take appropriate actions to avoid or at least minimize the effects.

5.0 POTENTIAL ACTIONS TO MANAGE STORMWATER EFFECTS

The previous sections present analyses that suggest that urbanization in Kerr County has had effects on area waters and that these effects are likely to become larger with the projected future growth. Kerr County and metropolitan Kerrville are likely to be subject to emerging Phase II Stormwater regulations proposed by the US EPA in 1998. How this program will ultimately be structured is difficult to predict at this writing (spring, 1999), but it is safe to assume that some form of administrative responsibility for stormwater will be placed on the area. The challenge to be faced will be to structure an effort that is appropriate and effective for the area.

Whatever regulatory requirements evolve in the coming years, the Austin data and experience suggests that a major objective should be to avoid or at least minimize increases in the amount of total site runoff as development occurs. This is an ambitious goal; one that has not been widely pursued, but one that is gaining a degree of acceptance in the northeast. 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 a document "Low-Impact Development Design Manual" (PGC, 1997) that details many of the methods required to maintain predevelopment stormwater runoff volume, peak runoff flow rates and frequencies. These methods include a combination of site planning to minimize impervious cover, and landscape and drainage features to retain and infiltrate runoff. One specific example is collecting rainfall from roof gutters and using it for lawn irrigation in the days following the rain. 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 at public expense, and have a limited degree of effectiveness (PCG, 1997). If such measures could be implemented in Kerr County for new projects, some of the water quality impacts predicted in the previous section could be avoided.

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