Effects of Impervious Cover Limits to Improve Water Quality

Submitted to:
City of Sunset Valley

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1. Introduction

Municipal and private wells within the City of Sunset Valley, Texas rely upon the Barton Springs Edwards Aquifer for water. The quantity and quality of water within the Aquifer is therefore critical to sustaining the beneficial use of these wells. Furthermore, the City of Sunset Valley benefits from the economic prosperity and cultural vitality of the Central Texas region. The flow of clean water from Barton Springs and in our creeks, rivers, and lakes is a key indicator of the quality of life, the health of the environment, and of our commitment to protecting values that make the Texas Hill Country attractive and vibrant.

This report describes impervious cover and its effect on streams and the Barton Springs Aquifer. It describes the effects of different levels of impervious cover on the quantity and quality of storm and baseflow runoff from undeveloped and developed sites. It contains estimates of pollutant loads from development with different impervious levels. These estimates were made using available technical information based on field investigations in the Central Texas/Barton Springs region. Results here are consistent with those of nationwide research on impervious cover effects on water quantity and quality.

2. Impervious Cover

Impervious cover is any surface that disrupts the relationship between rainfall and runoff and the natural soil and vegetation. It includes paved roads, parking lots, sidewalks, driveways, roofs, and other impermeable surfaces in the built environment. Impervious cover prevents water infiltration and significantly alters the natural hydrologic cycle. Without impervious cover, precipitation falls on land and is intercepted, used, and returned to the atmosphere by plants and solar heat. Rainfall also moves through the soil beyond the root zone and re-emerges in streams and waterways as baseflow, or moves more deeply to recharge aquifers. Only a small fraction of the rainfall runs off the surface as stormwater.

On developed land, however, impervious cover increases the volume of runoff dramatically, causing flooding, erosion, and water quality degradation. With higher impervious cover levels, more water reaches waterways faster and with proportionately greater erosive force. The resulting scour widens and deepens channels, abrades aquatic and streamside vegetation, and creates shifting sediment bars. Sediments and adsorbed pollutants introduced by this runoff suffocate and contaminate riverine ecosystems, and eliminate the natural pool and riffle sequences critical to fish and wildlife.

Soil and vegetation that once detained water and removed or trapped pollutants are bypassed entirely. Impervious surfaces also collect and contribute additional pollutants (trash, oil and toxics from vehicles, leaf litter, atmospheric depositions of nutrients, bacteria, etc.) to the runoff. Stream temperatures increase and oxygen is depleted. A narrower range of biological species can tolerate these conditions and biodiversity is reduced. Both the biological and physical stream systems are less resilient and become more susceptible to damage from future runoff.

The correlation between impervious cover and increased pollutant loads has been well-documented. National stormwater expert Thomas Schueler (1995) writes: “Monitoring and modeling studies have consistently indicated that urban pollutant loads are directly related to watershed imperviousness. Indeed, imperviousness is the key predictive variable in most simulation and empirical models used to estimate urban pollutant loads.” Schueler’s organization, the Center for Watershed Protection, has examined over 225 studies which directly or indirectly examined the relationship between impervious cover and 26 environmental stream indicators, such as increased runoff volume and peak discharge, stream channel enlargement, decline in stream habitat quality, and decline in fish diversity. The authors conclude: “A negative relationship between watershed development and nearly all of the 26 stream quality indicators has been established over many regions and scientific disciplines…. In some cases, the IC [impervious cover] and indicator relationship is considered so strongly established by historical research that it has been directly incorporated into accepted engineering models. This has been particularly true for hydrological and water quality indicators” (Center for Watershed Protection, 2002). Table 1 shows the 16 indicators which were directly correlated with impervious cover.

Studies of Central Texas data support these conclusions. Michael Barrett, Ann Quenzer, and David Maidment (1998) examined the relationship between impervious cover and twelve pollutants in Austin, Texas.[1] The data indicated that the pollutant load increases with increased impervious cover for every constituent measured.

Because increases in stormwater runoff, erosion, and pollution are directly attributable to impervious cover, it has become a primary focus of watershed protection regulations across the United States. Regulations to limit impervious cover serve to protect channel stability, sustain baseflow quantity, and reduce sedimentation, pollutant levels, and property loss from erosion.

The City of Sunset Valley currently limits allowable impervious surface in the development process depending on zoning. Section 4.301(f) of the Land Development Code allows commercial property a maximum impervious cover of 40%, except that impervious cover may be 50% with transfers of development intensity or 50% if the property is located along Highway 290 and storm runoff can be treated using one water quality control. Section 4.301(e) of the Land Development Code allows residential lots a maximum impervious cover of 18%. This report examines the benefits of reduced storm flows, erosion and pollutant loads that would accrue to the City from stricter impervious limits.

[1] The twelve pollutants examined are: Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Dissolved Phosphorus (DP), Total Phosphorus (TP), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN), Nitrate-Nitrogen (NO_3), Copper (Cu), Lead (Pb), and Zinc (Zn).

Table 1. Review of the Current Research Indicating a Decline in Stream Quality Indicators with Increased Impervious Cover[2]

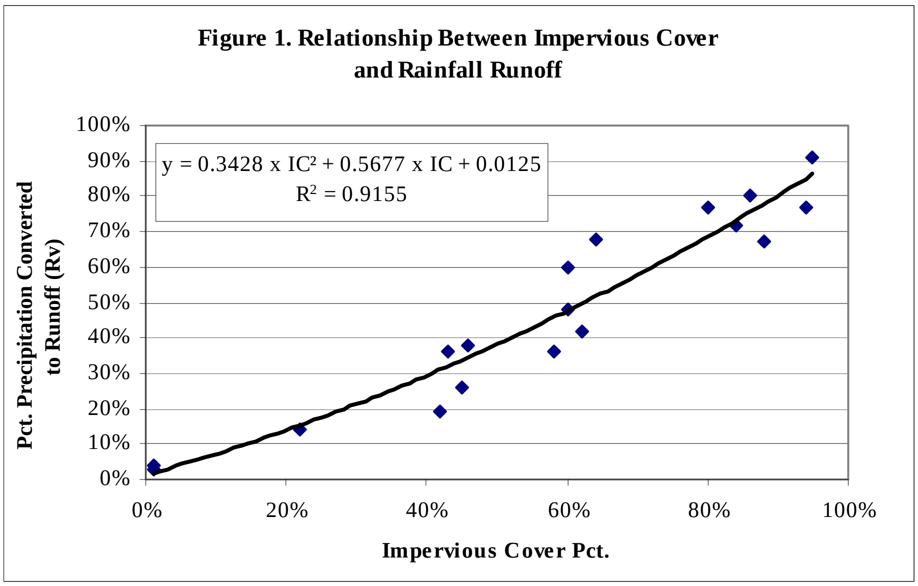
Increased Runoff Volume
Increased Peak Discharge
Stream Channel Enlargement
Increased Channel Modification
Loss of Riparian Continuity
Reduced Large Woody Debris
Decline in Stream Habitat Quality
Changes in Pool Riffle/Structure
Decline in Streambed Quality
Increased Stream Temperature
Violations of Bacteria Standards
Decline in Aquatic Insect Diversity
Decline in Fish Diversity
Loss of Coldwater Fish Species
Reduced Fish Spawning
Decline in Amphibian Community

[2] *Source: Center for Watershed Protection, 2002.*

3. Effect of Impervious Cover on Storm Runoff Volumes

Increased Runoff. On undeveloped land, plants and soils absorb most rainfall. Water is temporarily stored, filtered and slowly released into waterways as baseflow. Impervious cover prevents infiltration and storage; rainfall is converted to surface runoff and channeled rapidly into waterways, while subsurface baseflow drops off and creeks run dry soon after storms end.

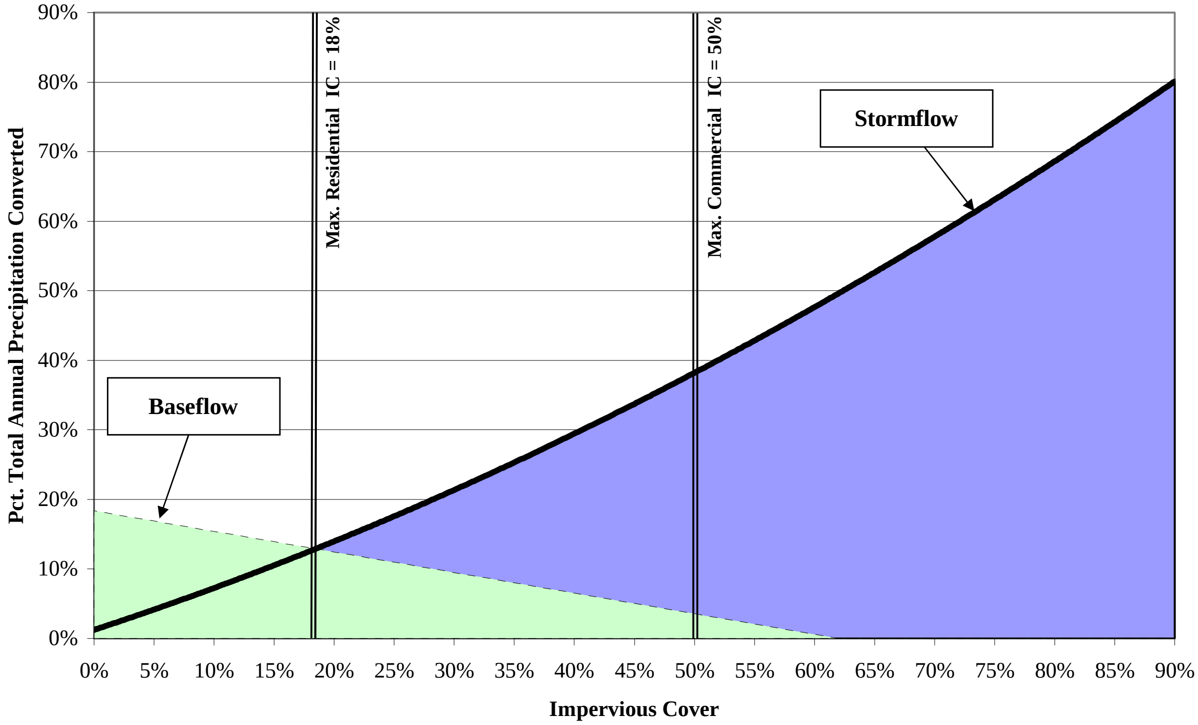
Barrett, Quenzer, and Maidment (1998) studied data from the City of Austin, Texas to determine the relationship between impervious cover and the portion of total precipitation converted to storm runoff. They found a statistically significant relationship between these two factors as shown on Figure 1.



Some of the additional runoff shown in the above figure will be routed through a water quality control before proceeding into waterways. The City of Sunset Valley requires all new developments to provide sedimentation-sand filters to remove pollutants from stormwater. These systems temporarily detain a portion of the total runoff and slow its release back to waterways. This delay helps dampen the impacts of increased stormwater flow caused by impervious cover.

Water quality controls cannot, however, completely mitigate the increased erosion and baseflow depletion from the increased storm runoff volume. Furthermore, some of the runoff from larger storms is not contained in these controls and is bypassed as direct stormwater flow. Figure 2 illustrates how the percentage of total precipitation converted to stormwater flow increases as impervious cover increases.

Figure 2. Impervious Cover (IC) vs.
Pct. of Precipitation Converted to Stormflow and Baseflow



The following 6 scenarios are examined in Table 2, Figure 3, and in subsequent analyses presented later in this report:

1. *5% Impervious Cover.* Rural impervious levels range between 0% and 5% imperviousness, with widely scattered pavement and roofs. Five percent impervious cover is used here as a benchmark for undeveloped land.
2. *15% Impervious Cover.* Maximum allowed by the City of Austin, City of San Antonio and U. S. Fish and Wildlife Service for properties developed in the Edwards Aquifer recharge zone.
3. *18% Impervious Cover.* City of Sunset Valley maximum for residential property.
4. *25% Impervious Cover.* Arbitrary mid-point between 18% and 40%.
5. *40% Impervious Cover.* City of Sunset Valley maximum for commercial property with no transfers or along Highway 290.
6. *50% Impervious Cover.* City of Sunset Valley maximum for commercial property with transfers of development intensity or located along Highway 290 and developed with one water quality control.

Table 2 and Figure 3 show the runoff volumes from a 1-acre tract under these six scenarios.

Table 2. Stormflow (ac-ft/yr) for 1-acre of Land

	5% IC (Undeveloped)	15% IC	18% IC (Current Max. Residential)	25% IC	40% (Current Max. Commercial No Transfers)	50% (Current Max. Commercial with Transfers)
By-Passed Flow	0.11	0.01	0.02	0.03	0.07	0.10
Flow through Control	0.00	0.27	0.32	0.45	0.73	0.93
Total Flow*	0.11	0.29	0.34	0.48	0.80	1.03
Pct. Increase over Undeveloped Land	0%	152%	201%	321%	605%	815%
* Totals may not add due to rounding.						

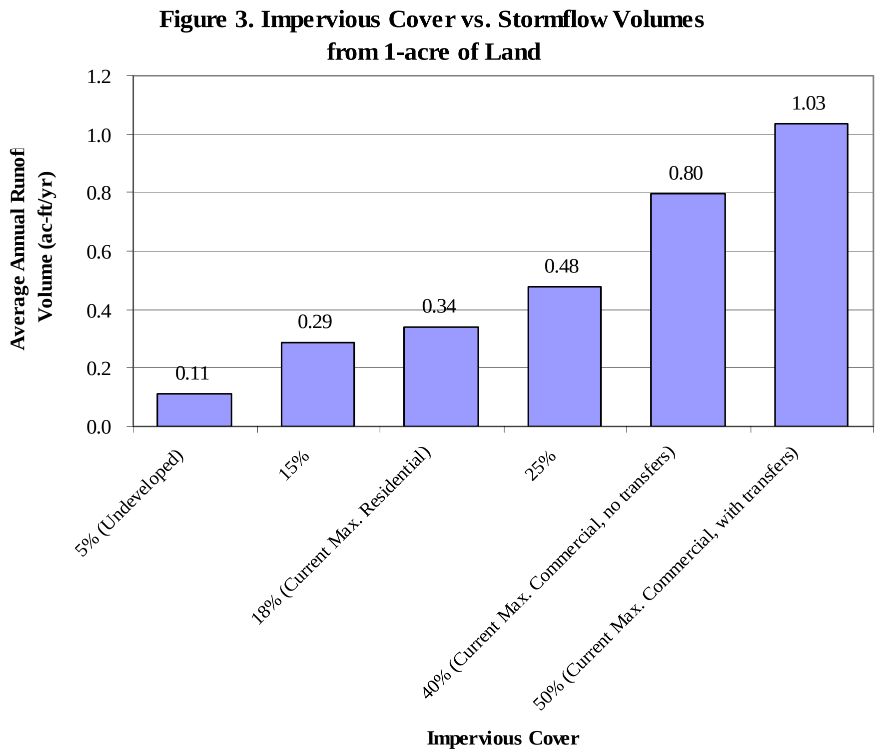


Figure 3. Impervious Cover vs. Stormflow Volumes
from 1-acre of Land
Average Annual Runof
Volume (ac-ft/yr)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.11
0.29
0.34
0.48
0.80
1.03
5% (Undeveloped)
15%
18% (Current Max. Residential)
25%
40% (Current Max. Commercial, no transfers)
50% (Current Max. Commercial, with transfers)
Impervious Cover

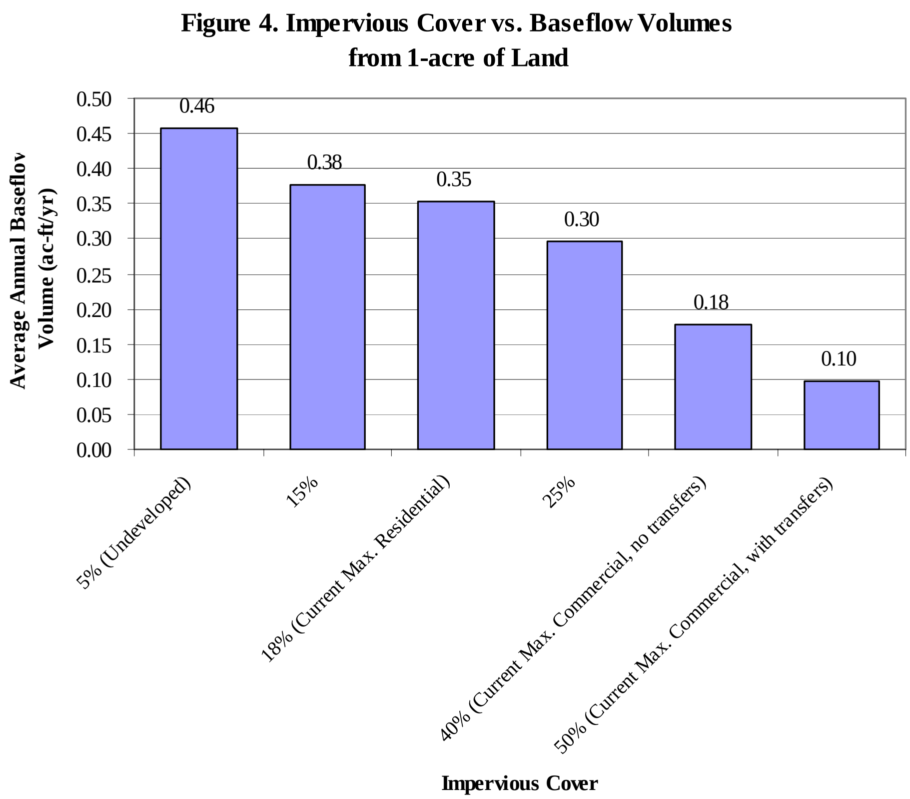


Figure 4. Impervious Cover vs. Baseflow Volumes
from 1-acre of Land
Average Annual Baseflov
Volume (ac-ft/yr)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.46
0.38
0.35
0.30
0.18
0.10
5% (Undeveloped)
15%
18% (Current Max. Residential)
25%
40% (Current Max. Commercial, no transfers)
50% (Current Max. Commercial, with transfers)
Impervious Cover

In the undeveloped scenario, there are no water quality controls and all water bypasses into the receiving waters at a rate of 0.11 acre-feet (4,900 cubic feet) per acre per year. In the 15% impervious cover scenario, total flow from the site has risen to 0.29 acre-feet per acre per year. While most of the increased volume will be routed through a water quality control, little or none of the flow is converted to baseflow, aquifer recharge or used by plants. Flow volumes increase as impervious cover increases, and thus at the 40% and 50% impervious levels, total flow volumes are about 600% and 800% of the volumes from undeveloped land.

Increased Flooding. Development that increases impervious cover changes flow velocity and the timing of peak flows, as well as flow volume. Changes in flow velocity, timing, and flow peak may combine to increase flooding and risk to human life and property. The effect of impervious cover is more significant for more frequent flood events, such as 2-year or 10-year floods, because these events are more sensitive to the storage capacity of the land to absorb and delay much of the flood waters.[3]

These changes may cause flooding in areas with no previous flooding problems. Existing development along creeks can be flooded more frequently because new development upstream causes the same amount of rainfall to be converted into a larger flood event. For example, a 1-acre undeveloped property (2% impervious cover) in Travis County will produce about 640 cubic feet of runoff during a 2-year storm (2.639 inches of rain in a 3-hour period) whereas the same 1-acre property would produce about 8,500 cubic feet of runoff if developed at 80% impervious cover. Detention ponds are designed to mitigate these impacts by capturing and releasing water from a site at the pre-developed flow rate. They will not, however, mitigate the flooding effect of a longer storm flow duration. Also, their design typically does not examine the problem of flow peak coincident with the arrival of peak flows from other areas of the watershed.

Decreased Baseflow Volume. Baseflow is the water flowing in creeks after storm flows have peaked and subsided. Baseflow is largely composed of rainfall that infiltrates into the soil, slowly migrates beneath the surface, and discharges through springs and seeps into creeks. Adequate and clean baseflow is critical to healthy aquatic ecosystems, creek aesthetics, natural character, and channel stability (by sustaining riparian vegetation), all of which are dependent upon steady water flow. Baseflow is also the principal source of recharge into the Edwards Aquifer.

Impervious cover prevents the infiltration of water into the soil, which in turn decreases creek baseflow. Barrett, Quenzer, and Maidment (1998) studied data from the City of Austin and examined the relationship between impervious cover and the percentage of the annual rainfall volume discharged as baseflow. They found a strong, statistically

[3] Larger storms, such as 25- or 100-year floods, are not as exacerbated by impervious cover since the sheer intensity and/or volume of precipitation saturates the soil and overwhelms the storage capacity of the land. Under these conditions infiltration rates are low and soils contribute runoff at a rate approaching that of impervious surfaces. However, reduced impervious cover will still provide benefits in larger storms as flood flow velocities will still be reduced from what they otherwise would be.

significant relationship ($R^2 = 0.9315$) between the two. As shown in Figure 2 (page 5), baseflow drops with rising impervious cover.

Table 3 (below) and Figure 4 (page 7) show the baseflow volumes from a 1-acre tract under these six scenarios.

Table 3. Baseflow (ac-ft/yr) for 1-acre of Land

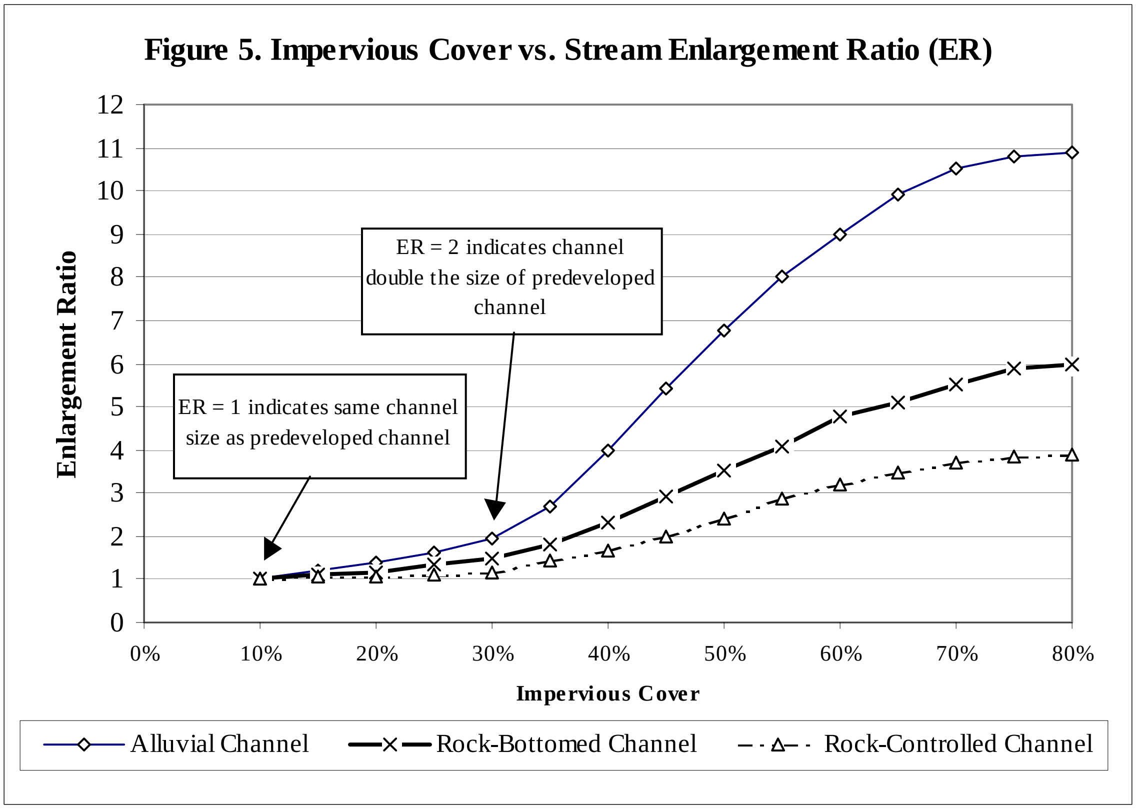
	5% IC (Undeveloped)	15% IC	18% IC (Current Max. Residential)	25% IC	40% (Current Max. Commercial No Transfers)	50% (Current Max. Commercial with Transfers)
Total Flow	0.46	0.38	0.35	0.30	0.18	0.10
Pct. Increase over Undeveloped Land	0%	-18%	-23%	-35%	-61%	-79%

In the undeveloped scenario, a typical acre of land generates baseflow at a rate of 0.46 acre-feet (20,038 cubic feet) per acre per year—over four times higher than the amount of stormwater flow for this same impervious cover level. With 15% impervious cover, total baseflow from the site has dropped to 0.38 acre-feet. Baseflow volumes decrease as impervious cover increases; at the 40% and 50% impervious levels most of the baseflow volume that would be generated from undeveloped land is lost. A second method of measuring baseflow used by the City of Austin shows even more precipitous declines in baseflow with increased impervious cover (about 98% of the undeveloped baseflow levels is lost by 50% impervious cover), but only the more conservative method used by Barrett, Quenzer, and Maidment (1998) is presented in the table and figures.

4. Effect of Impervious Cover on Stream Bank Erosion

Increased Erosion. Stream channel geometry is largely shaped by smaller, more frequent "bank full" floods (1- to 2-year events) rather than by large, infrequent floods.[4] As noted above, a 2-year rainfall event over an undeveloped watershed will produce much less runoff than from a more impervious watershed. This additional storm runoff will flow through the stream channel, even if delayed for a short time (usually less than 12 hours) by a flood detention pond. Stream channels accommodate these increased flows by widening channel banks and downcutting the streambed. Raymond Chan & Associates (1997) quantified the relationship between impervious cover and the enlargement of creek channel cross-sections in the Austin area. The results of their field investigations are shown in Figure 5.

[4] During large floods, so much water is introduced into waterways that the normal channel cannot accommodate all of the flows, forcing much of it out of the stream banks and into the flood plain. While this causes flooding problems, it serves to spare the channel itself from greater force and damage.



Only where the impervious cover was very low (less than 10%) did channels retain their original, unaltered geometry. Depending upon the soil and geology of the channel bottom and banks, a doubling of channel size could be expected with between 30% and 45% impervious cover. This erosion and channel instability contributes to adjacent private property loss, loss of riparian habitat and trees, downstream sedimentation, loss of capacity in lakes and reservoirs, and loss of parklands.

The cost to fix these channel erosion problems is high. Raymond Chan & Associates and Aquafor Beech (1999) documented that erosion from unplanned growth in Little Walnut Creek (13.1 square mile drainage area) in Austin, Texas, for example, has required a $15 million dollar CIP program to shore up the damage. The team evaluated the ability of sand filters—required in all new developments and sized using the same Half-Inch-Plus criteria used by Sunset Valley—to control erosion in the adjacent Walnut Creek watershed. The study predicted that, while sand filters could reduce the anticipated channel enlargement in Walnut Creek by 43 to 59%, they alone were still incapable of meeting the City of Austin's criteria that the system have the stability and low maintenance of a channel with 10% impervious cover. Additional means—such as the use of impervious cover limits—must therefore accompany the use of structural controls to prevent stream erosion and degradation and their associated costs.

5. Effect of Impervious Cover on Pollutant Loads

This report estimates pollutant loads from varying levels of imperviousness for three pollutant parameters: Total nitrogen, chemical oxygen demand, and total suspended solids. Total nitrogen measures a group of nitrogen species important in influencing the level of algal and vegetative growth in water with depleted oxygen levels. Chemical oxygen demand measures a variety of petrochemical type pollutants. Total suspended solids measures the sediment load.

The estimates presented here have been calculated assuming that storm runoff from a site has been treated using a water quality control meeting the City of Sunset Valley criteria. Detailed information regarding the supporting calculations is presented in the appendix.

Total Nitrogen. Table 4 and Figure 6 show the total nitrogen loads from a 1-acre tract under 6 scenarios.

Table 4. Total Nitrogen Load (lbs/yr) for 1-acre of Land

	5% IC (Unde-veloped)	15% IC	18% IC (Current Max. Residential)	25% IC	40% (Current Max. Commercial No Transfers)	50% (Current Max. Commercial with Transfers)
Total Load	0.34	0.94	1.15	1.71	3.22	4.49
Pct. Increase over Undeveloped Land	0%	177%	239%	403%	848%	1223%

In the undeveloped scenario, an acre of land generates an average of 0.34 pounds of nitrogen per year. In the 15% impervious cover scenario, total nitrogen loads more than double to 0.94 pounds. At the 40% and 50% impervious levels annual nitrogen loads are eight to twelve times those generated from undeveloped land.

Chemical Oxygen Demand (COD). Table 5 and Figure 7 show the chemical oxygen demand loads from a 1-acre tract under 6 scenarios.

Table 5. Chemical Oxygen Demand Load (lbs/yr) for 1-acre of Land

	5% IC (Unde-veloped)	15% IC	18% IC (Current Max. Residential)	25% IC	40% (Current Max. Commercial No Transfers)	50% (Current Max. Commercial with Transfers)
Total Load	2.5	9.2	12.1	20.6	48.2	75.1
Pct. Increase over Undeveloped Land	0%	270%	385%	723%	1828%	2906%

In the undeveloped scenario, an acre of land generates an average of 2.5 pounds chemical oxygen demand per year. In the 15% impervious cover scenario, chemical oxygen demand loads more than triple to 9.2 pounds. At the 40% and 50% impervious levels, pollutant loads from development add almost twenty to thirty times respectively that initially generated from undeveloped land.

Figure 6. Impervious Cover vs. Total Nitrogen Loads from 1-acre of Land

(assumes use of Sand Filter controls)

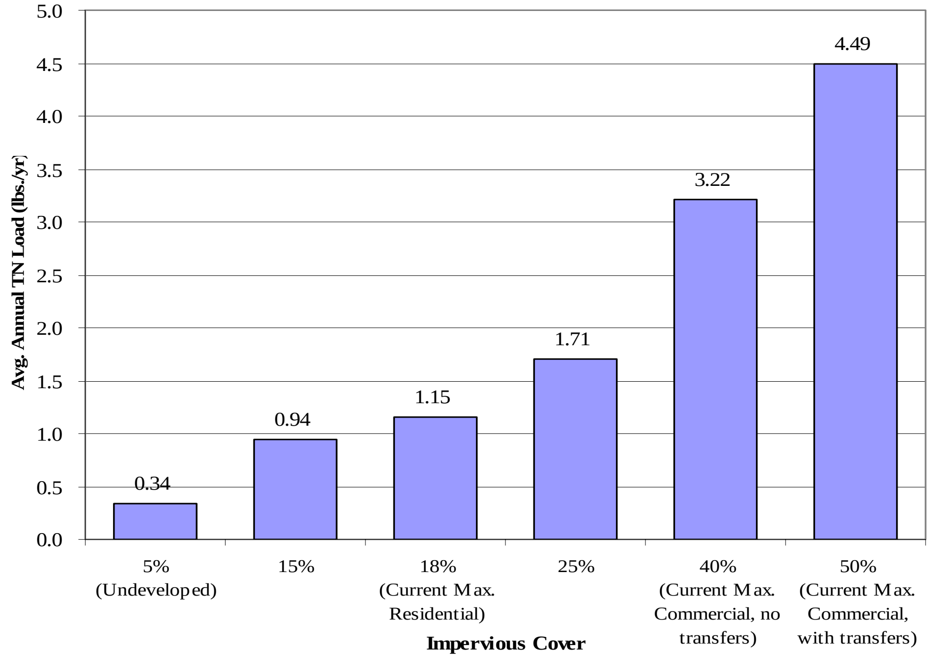
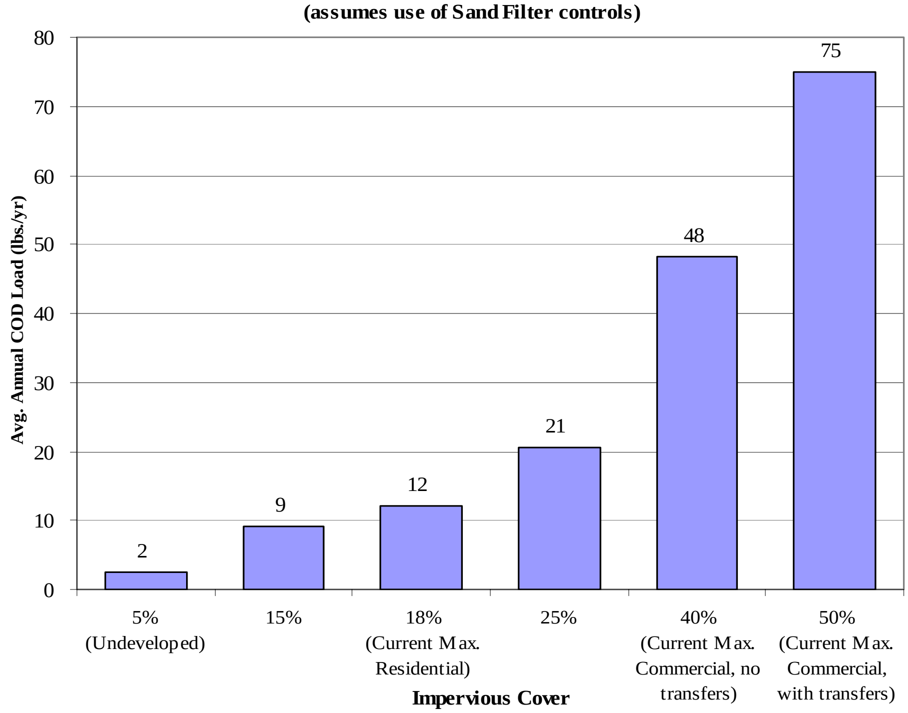


Figure 7. Impervious Cover vs. Chemical Oxygen Demand Loads from 1-acre of Land

(assumes use of Sand Filter controls)



Total Suspended Solids. Table 6 and Figure 8 show the Total Suspended Solids loads from a 1-acre tract under these six scenarios.

Table 6. Total Suspended Solids Load (lbs/yr) for 1-acre of Land

	5% IC (Unde-veloped)	15% IC	18% IC (Current Max. Residential)	25% IC	40% (Current Max. Commercial No Transfers)	50% (Current Max. Commercial with Transfers)
Total Load	9.2	25.2	30. 8	45.3	84.2	116.4
Pct. Increase over Undeveloped Land	0%	174%	235%	393%	815%	1166%

In the undeveloped scenario, an acre of land generates an average of 9 pounds total suspended solids per year. In the 15% impervious cover scenario, total suspended solids loads more than double to 25 pounds. Totals suspended solids loads increase as impervious cover increases, and thus at the 40% and 50% impervious levels, pollutant loads add about eight to twelve times respectively that initially generated from undeveloped land.

Increased impervious cover changes the water quality and hydrology of a watershed—greater pollutant loads, decreased baseflow, and altered channel forms. Impervious cover levels on the order of 10 to 15% must be maintained to protect the optimal functioning and habitat of sensitive Texas Hill Country streams. Structural controls alone are not capable of maintaining pre-developed pollutant loading rates. Schueler (1995) summarizes: "Reviewed here is the scientific evidence that relates impervious cover to specific changes in the hydrology, habitat structure, water quality and biodiversity of aquatic systems. This research, conducted in many geographic areas, concentrating on many different variables, and employing widely different methods, has yielded a surprisingly similar conclusion—stream degradation occurs at relatively low levels of imperviousness (10-20%)."

In conclusion, impervious cover causes fundamental changes in watershed hydrology which are known to increase flooding, erosion, and water quality problems. Schueler (1995) outlines a three-tiered system of watersheds: sensitive, degrading, and non-supporting. Table 7 (page 14) presents this system. This system acknowledges two facts based upon the scientific evidence. First, if development is allowed to increase impervious cover above 10%, the sensitive characteristics of high-quality streams will not be maintained. Second, if development exceeds 25% impervious cover, significant stream degradation will occur. As cited in Section 2, a follow-up study tracked 26 different urban stream indicators in over 225 research studies and concluded that this three-tiered system was still useful: "In particular, the chance that a stream quality indicator will attain a high quality score is sharply diminished at higher IC [impervious cover] levels. This trend becomes pronounced within the 10 to 25% IC range and almost inevitable when watershed IC exceeds 25%" (Center for Watershed Protection, 2002).

Figure 8. Impervious Cover vs. Total Suspended Solids Loads from 1-acre of Land
(assumes use of Sand Filter controls)

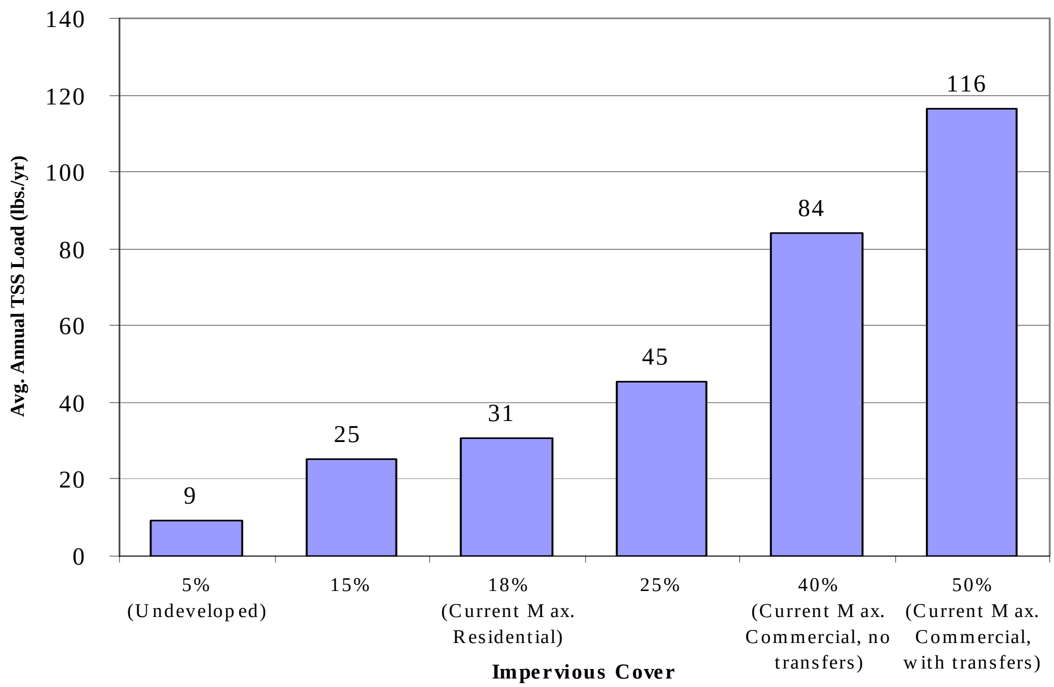


Table 7. A Model for Classifying Urban Streams Based on Impervious Cover

Urban Stream Classification*	**Sensitive 0-10% Impervious**	**Degrading 11-25% Impervious**	**Non-Supporting 26-100% Impervious**
Channel Stability	Stable	Unstable	Highly unstable
Water Quality	Good-Excellent	Fair-Good	Fair-Poor
Stream Biodiversity	Good-Excellent	Fair-Good	Poor
* Note: range of impervious cover used to classify urban streams may shift among ecoregions. *Source: Schueler, 1995.*			

6. Relationship between Impervious Cover and the Quality and Quantity of Flow in the Barton Springs Aquifer

Municipal and private wells within the City of Sunset Valley rely upon the Barton Springs Edwards Aquifer for water. The Barton Springs Aquifer is recharged in two ways. A portion of the recharge enters the aquifer from soil and dispersed recharge features like faults, cave openings, sinks, and solution cavities. An estimated 85%[5] of the recharge enters the aquifer as flow losses through the streambed and banks. Impervious cover affects both the quantity and quality of flow from both of the recharging water sources.

The University of Texas Center for Research in Water Resources has developed a simple empirical model to estimate changes in the Barton Springs Aquifer from different levels of development (Barrett, et. al, 1996). This model evaluates the effect of development on the proportion of recharge from stormwater runoff, from baseflow, and on the average nitrogen concentrations for these two flow regimes. Table 8 below summarizes the study results relevant to the effects of development at different impervious cover levels:

Table 8. Estimated Changes Resulting from Development at Different Levels of Impervious Cover[6]

Area of Concern	20% Impervious Cover	45% Impervious Cover
Average Nitrogen in Storm Runoff	2.79 mg/L	3.72 mg/L
Average Nitrogen in Baseflow	0.88 mg/L	1.21 mg/L
Diffuse Recharge	decreases by 20%	decreases by 40%
Barton Springs Average Discharge	decreases by 11%	decreases by 34%
Average Aquifer Water Level in Williamson Creek Area	450 ft mean sea level	444 ft mean sea level
Average Nitrogen Concentration in Barton Springs[7]	1.8 mg/L	3.5 mg/L

This model has some limitations. One limitation is that it uses data from the Williamson Creek watershed where there are few water quality or flood control structures. Other sections of this report, however, have documented the limited ability of water quality and flood control structures to mitigate the effects of impervious development.

Since almost all pollutants occur in higher concentrations in stormwater flow compared to baseflow, development can be expected to degrade water quality in the aquifer.

[5] Slade, et. al, 1996.

[6] Based on Barrett et. al, 1996.

[7] Higher nitrogen concentration attributable to more septic systems, higher concentrations in stream losses and reduction in creek recharge. Nitrate concentration increases in Sunset Valley area may be higher than those of the entire aquifer. Nitrate increases may produce concentrations exceeding the drinking water standard of 10 mg/L as nitrogen.

Furthermore, increased sediment loads in the creek will increase sediment concentrations in the aquifer. The ability of water quality controls to mitigate this change is limited.

7. Impervious Cover Regulations in Other Jurisdictions

The City of Sunset Valley is one of several municipal and federal jurisdictions that regulate impervious cover to protect water quality and the Edwards Aquifer. Table 9 compares City of Sunset Valley impervious cover limits with those of similarly situated communities. This table demonstrates that most communities with impervious cover regulations in the Edwards Aquifer recharge zone have established a level of 15%.

Table 9. Central Texas Area Government: Limits on Impervious Cover

Regulation	Impervious Cover (IC) Limits
City of Sunset Valley (§ 4.301 of Land Development Code)	18% max. IC for Residential 40% max. IC for Commercial 50% max. IC for Commercial w/ transfers or along Hwy. 290 Calculated using Net Site Area Basis
City of Austin: Barton Springs Zone (§ 25-8-514 of Land Development Code)	15% max. IC in Recharge Zone 20% max. IC in Barton Creek Contributing Zone 25% max. IC in Remaining Contributing Zone Calculated using Net Site Area Basis
US Fish and Wildlife (Rules for Salamander Protection)	15% max. IC in Recharge Zone 20% max. IC in Contributing Zone Calculated using Net Site Area Basis. Net site area does not include golf courses.
City of San Antonio (§ 34.935 of City Code)	*Properties within ETJ, within Recharge Zone, & not grandfathered* 15% max. IC for Single-Family Residential 15% max. IC for Multi-Family Residential 15% max. IC for Commercial Calculated using Gross Site Area
City of San Marcos (§ 94.524 of City Code)	40% max. IC for site size ≤ 3 acres 30% max. IC for site size 3-5 acres 20% max. IC for site size ≥ 5 acres Calculated using Gross Site Area

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Appendix: Water Quality Control Pollutant Removal Calculations

This section describes calculations underlying pollutant loads presented in Section 5. The pollutant load removed by a structural control depends on the size of the control and on the efficiency of the control to remove pollutants. The size of the control determines what portion of the average annual runoff is treated versus what portion is bypassed. The pollutant removal efficiency of the control depends both upon the type of treatment provided and the pollutant of interest.

The City of Sunset Valley requires sedimentation-sand filtration water quality controls. These controls are sized according to the imperviousness of the site. Filters must provide treatment for 0.50 inches of capture over the contributing area plus an additional 0.1 inches for each 10% of imperviousness above 20% imperviousness (Half-Inch-Plus criteria).

The City of Austin developed the following regression formula to describe the percentage of the average annual stormwater flow captured by the controls sized according to Half-Inch-Plus criteria:

Pct. Capture = 0.9762 - 0.154 x IC

For developments with 20% impervious cover (requiring 0.5 inches of capture), almost 95% of all stormwater flow is captured by the structural control. As impervious cover increases to 100% the required capture depth increases to 1.3 inches. The percentage of stormwater flow captured by the structural control drops, however, to below 85%. Even with increased capture volumes, controls for areas with greater impervious cover capture a lower percentage of the total runoff than do controls for lower levels of impervious cover. More water bypasses these controls and flows untreated to the channel.

Pollutant Removal Efficiency. For the stormwater captured and treated in controls, only a portion of the pollutant load is removed by the sedimentation/sand filter. Table 10 below shows sand filter removal efficiencies for total nitrogen, chemical oxygen demand, and total suspended solids.

Table 10. Sand Filter Removal Efficiencies for Selected Pollutants

Pollutant	Sand Filter Removal Rate[8]
Total Nitrogen	31%
Chemical Oxygen Demand	67%
Total Suspended Solids	87%

Sedimentation-sand filtration is relatively efficient at removing sediments and relatively inefficient at removing dissolved constituents, such as nitrogen.