Relations between urbanization and water quality and effects of runoff controls on water quality in Austin, Texas

There is much concern and speculation regarding the effects of urbanization on the water-quality of streams in the Austin area. Since about 1975, the U.S. Geological Survey (USGS), City of Austin, and other governmental agencies have been sampling the water quality of many streams in the Austin area--the sampled stream basins are within Travis county and range in size, location, environmental characteristics, and extent of development. In 1990, the USGS published a report summarizing its data and presenting findings regarding the effects of impervious cover on water quality (Veenhuis and Slade, 1990). In the same year, the City published findings from their water-quality monitoring program in a report entitled "Stormwater Pollutant Loading Characteristics for Various Land Uses in the Austin Area".

Eighteen stream sites were included in the USGS study--the impervious cover of the basins ranged from less than 1 percent to 42 percent. The sites represent most major streams in the Austin area--the basin drainage areas range from 6.3 square miles on Williamson Creek to 166 square miles on Onion Creek. Filter ponds, grass-lined swells, and other runoff controls exist in many of the basins. The number of water-quality samples for each site ranged from 9 to 147, with at least 20 samples available for 13 of the sites.

The water-quality samples for each site were aggregated into 3 flow categories for purposes of the analyses--base flow, samples from rising stages (before the peak stage), and samples from falling stages (after the peak). Furthermore, the 18 sites were aggregated into 4 development classifications: rural (less than 1% impervious cover); mostly rural (2% to 7% impervious cover); partly urban (9% to 20% impervious cover); and urban (greater than 40% impervious cover).

The report concluded that water-quality concentrations for storm samples are greatly increased with increased impervious cover. For example, the median suspended-solids concentration for rural basins is 6 mg/L (milligrams per liter) for rising-stage samples--for urban basins the median concentration is 4100 mg/L, an increase of 6700 percent. The median concentrations and percent changes in median concentrations from a rural basin to an urban basin for samples collected during rising stage for the 8 water-quality constituents investigated are presented below. The concentration units for the constituents are milligrams per liter except for the fecal constituents, which are expressed in colonies per 100 milliliters.

Water-quality constituent	Median value for rural basins	Median value for urban basins	Percent change in median concentration from rural to urban basin
dissolved solids	245	130	47 % decrease
suspended solids	6.0	410	6700 % increase
biochemical oxygen demand	0.95	6.0	530 % increase
total organic carbon	4.0	18	350 % increase
total nitrogen	0.5	2.15	330 % increase
total phosphorus	0.02	0.45	2150 % increase
fecal coliform	1,000	42,000	4100 % increase
fecal streptococci	1,200	75,000	6150 % increase

The 1990 City of Austin report provided similar findings—degradation from full urbanization for the above and other water-quality constituents represent hundreds and even thousands percent increases. In an effort to mitigate the impacts of urbanization, the City of Austin and other agencies have required best management practices (BMP) be designed and installed throughout the area--more than 1,000 BMP exist in the area and more are being built. The BMP generally represent public information programs, wetlands, wet ponds, dry ponds, filters, grass swells, and street sweeping.

In 1987, the USGS published a report presenting the data and effects of 2 different runoff controls on runoff quality in Austin (Welborn and Veenhuis, 1987). The largest sand filter pond at Barton Creek Mall was gaged for measuring flow at the inflow and outflow of the pond, and automatic water-quality samplers were installed at the pond inflow and outflow so that water samples could be analyzed. The inflow and outflow water-quality loads were determined for 22 storms at the pond. Also calculated for each storm were the reductions in water-quality loads from the inflow to the outflow--the load reductions represent those removed by the filtering pond and thus represents the efficiency of the pond in removing water-quality loads. The average (mean) removal efficiency based on all 22 storms then was calculated for each of the analyzed water-quality constituents. The mean change in water-quality load from the inflow to the outflow is presented below for the constituents.

Water-quality constituent	Mean change in water-quality load due to filtering pond
dissolved solids	13 % increase
suspended solids	78 % decrease
biochemical oxygen demand	76 % decrease
total organic carbon	60 % decrease
total nitrogen	27 % decrease
fecal coliform	81 % decrease
fecal streptococci	81 % decrease
biochemical oxygen demand	76 % decrease
chemical oxygen demand	62 % decrease
dissolved volitile solids	21 % decrease
dissolved lead	33 % decrease
dissolved iron	55 % decrease
dissolved zinc	60 % decrease

The runoff control for the other site is a grass-lined swell at Alta Vista Planned Unit Development. Water-quality samples at the inflow and outflow from this site were analyzed for several storms. The water quality at the inflow and outflow were comparable, indicating that the swell had no effect on the water quality. However, a study by the University of Texas in 1998 reported significant removal efficiencies for two grass-lined swells associated with highways in Austin. The effectiveness of such controls probably is dependent on the site characteristics (area size, type of soil and vegetation, and slope), as well as the type and extent of development in the basin.

In 1998, the City of Austin published a report evaluating the efficiency of 4 sand filters and 3 wet ponds (Glick and others, 1998). There have been many other studies of the effects of best management practices on the water quality of urban runoff. The National Urban Runoff Program sponsored by the U.S. Environmental Protection Agency and the USGS have conducted many of the studies. Based on these studies, below is a summary of the general removal efficiencies for the different types of BMP.

Type of BMP	Removal efficiencies
Public information program	5-10% for most water-quality constituents
Wetlands	up to 90%; best for nutrients, some metals increased
Wet ponds	60-80%; best for sediment-related constituents
Dry ponds	30-70%; best for sediment-related constituents
Filters	30-70%; most are horizontal; best for sediment-related constituents; efficiency dependent upon maintenance
Grassy swells	10-20%; more efficient for specific sites
Street sweeping	0-10%; some evidence that sweepers can increase water-quality loads

Some grassy swells and wet ponds are being used in the Austin area, however the filter represents the most prevalent BMP in the area. As the table indicates, the efficiency of filters is dependent upon maintenance of the filter material. Field inspections and other evidence indicate that many of the filters are not being maintained or properly maintained, thus the efficiency of such filters might be lower than indicated in the table. Also, the efficiency of filters and ponds is substantially reduced if they contain stormwater bypasses or overflows.

A relatively new BMP being encouraged for use, especially on the Edwards aquifer, involves impoundment and irrigation of urban-runoff. Information or data regarding removal efficiency for this type BMP could not be found. However, the removal effectiveness of such a BMP is highly dependent on local environmental conditions. For example, thin soils, lack of vegetation, steep slopes, or the presence of recharge features could reduce surface attenuation of containments thus allowing recharge of contaminants to the underlying aquifer. Also, irrigation practices affect contaminant-removal efficiencies—irrigation of urban runoff during or immediately after storms, when soils are wet, would likely cause runoff of contaminants from the site. Also, large storms or multiple storms creating large volumes of runoff exceeding the storage capacity of the impoundment would discharge the impoundment without filtration or be required to be irrigated during periods when soils are still saturated from rain.

A runoff-filtering system manufactured by AquaLogic Inc., in San Antonio, Texas (http://aqualogic-usa.com/frameset.html) is being used on the Edwards Aquifer recharge zone in the San Antonio area. The system contains a sediment-settling basin and standpipes containing 10-micron filtering media, designed to filter all received runoff. AquaLogic Inc. provides frequent inspection and maintenance via contract with property owners, thus assuring that the system probably retains peak or near peak performance. Maintenance includes removal of all material from the sediment pond and replacement of filter media in the standpipes. Although the effectiveness of this system has not yet been tested for most urban-related contaminants, it is likely more effective than sand filters. Also, it might be superior to other BMPs simply because it receives scheduled and mandated inspections and maintenance.

For maintained filters, data summarized in the second table and other local studies have verified national findings regarding the efficiency of such filters--they generally remove 30-70 percent of most water-quality constituents. However, as summarized in the first table, the increase in water-quality values due to urbanization for 7 of the 8 constituents range from about 300 percent to about 6700 percent in the Austin area.

The data summarized in the above tables along with other local and national studies indicate that best management practices mitigate water-quality loads but also indicate that they generally do not compensate the water-quality degradation caused by urbanization. Therefore, many ordinances and other rules have been implemented to limit the location, type, and density of urban development.

Raymond M. Slade, Jr.
Hydrologist
Prepared 8/26/03
Revised October, 14, 2004

Perspectives of the Effectiveness of Runoff Filtering Systems on the Edwards Aquifer Recharge Zone

Raymond M. Slade, Jr.
Hydrologist

BMPs ON THE RECHARGE ZONE

As part of the review process for the Barton Spring Salamander Recovery Plan, a local consulting engineering company presented a hypothetical scenario for a large, high-intensity (44% impervious cover) dwelling development using Best Management Practices (BMPs) consisting of a sediment pond and irrigated runoff. The scenario states that the development would meet SOS water-quality standards for runoff because the BMP would remove 100% of the urban-related contaminants. .

The scenario assumes that the development occurs on the recharge zone of the Edwards aquifer and also assumes runoff to the BMP to represent about 25% of rainfall from the developed area. However, the scenario does not include the water-quality impact from the portion of runoff that is lost as recharge in route to the BMP. That recharge, which represents runoff from land with 44% impervious cover, would contain substantially degraded water quality.

Runoff Lost as Recharge on the Recharge Zone

Only small volumes of rainfall directly infiltrates to the Edwards aquifer from soils. Most recharge occurs through critical environmental features (such as caves, faults, and fractures) located in streams and in areas with overland flow. The amount of runoff lost as recharge from developed areas depends upon characteristics of the land and development. Recharge would be increased for sites with many critical environmental features, especially if such features were contained in streambeds that convey large runoff volumes to such features.

Two known studies have documented relative volumes for runoff lost as recharge on the recharge zone.

Table 7 of the report "Stormwater pollutant loading characteristics for various land used in the Austin Area" (City of Austin, 1990) shows, for a 40% impervious cover area, runoff to be 15.8% of rainfall for sites on the recharge zone and 22.2% of rainfall for sites not on the recharge zone. These data are based on small basins, generally less than about 150 acres. The difference in runoff (6.4% of rainfall) represents estimated losses to recharge for the hypothetical development presented above. Therefore, for this scenario, 29% of runoff (6.4 / 22.2) would be lost as recharge.

Based on long-term gaged data for rainfall and streamflow, Woodruff (1984) made an independent analysis of runoff and recharge that included the entire recharge zone. He found that 40% of runoff is lost as recharge while 60% of runoff is not lost as recharge.

Based on recharge-runoff relations from the first study above, about 71% of runoff from the development would reach the BMP to be filtered, while about 29% of the runoff would be lost as recharge to the aquifer in route to the BMP. Based on the recharge-runoff relations documented by the second study above, 60% of runoff would reach the BMP to be filtered while 40% of runoff would recharge to the aquifer without being filtered. However, the theoretical development and most other developed areas are comparable in size to the sites studied by the City of Austin (1990), thus recharge losses probably would approximate 29% of runoff rather than 40%, unless the developed site contained many critical environmental features. Therefore, for the featured development scenario, it is likely that about 29% of runoff would recharge the aquifer without being filtered.

Water Quality of Runoff Lost as Recharge

Two substantial studies, based on local data, have been conducted to document the relation between impervious cover and water-quality characteristics. Veenhuis and Slade (1990) based their analyses on data from many large watersheds in the Austin area, while the City of Austin (1990) based their analyses on data collected from many small watersheds in Austin. Both studies found that degradation from a basin with 40% impervious cover would cause, for many water-quality constituents, increases in water-quality concentrations (levels) of many hundreds or thousands percent, as acknowledged in the documentation for the hypothetical development.

Therefore, for the theoretical development, a large percentage of water-quality loads would be removed for the runoff reaching the BMP, however, about 29% of the runoff would recharge the aquifer with water-quality levels many times greater than those for natural conditions. Based on this scenario, the overall effectiveness of the BMP in removing total water-quality loads for the development scenario is reduced by values approaching 100% to values of about 71%, thus deeming the BMP not to meet SOS water-quality standards.

Leakage From BMP Storage Ponds on the Recharge Zone

Most water-quality BMPs use large storage ponds to impound runoff prior to filtering by sand, wet ponds, or irrigation. Large volumes of water stored in such ponds can be lost as recharge. Most ponds on the recharge zone are designed to be lined with impermeable layers, often consisting of a clay material. However, such layers can be damaged by maintenance, vandalism, or large storms. For example, many years ago a thorough water-budget analysis of rainfall, inflow and outflow was performed for many storms on the largest sand-filtering basin at Barton Creek Square Mall Shopping Center. The data proved that substantial volumes of water were being lost as recharge to the Edwards aquifer from the pond. Apparently, the effectiveness of the clay liner as an impermeable layer was compromised during the process of removing and replacing the sand. Data for water-budget analyses might not exist for other BMPs on the recharge zone, thus the amounts of recharge lost from other ponds is unknown.

As demonstrated above for recharge losses from developed areas, the water quality for recharge from leaking storage ponds from developed areas would be substantially degraded from natural conditions. Also, infiltration rates to the aquifer from such ponds can be substantially greater than would occur during natural conditions, because large water depths in the ponds cause increased water pressure on faults and fractures, thus forcing more recharge than would occur naturally. Furthermore, most small streams on the recharge zone contain water while rainfall occurs and only for short periods thereafter. However, storage ponds frequently contain water, thus causing recharge to occur for longer periods than would occur naturally.

Recharge loads are calculated by multiplying recharge volumes by water-quality levels. As shown above, recharge volumes from storage ponds can be increased because of greater depths and longer durations of water availability, and the water-quality of the recharge would be substantially degraded. Therefore, water-quality loads from a leaking pond can be many times greater than would occur without such a pond.

Therefore, for a leaking storage pond on the recharge zone, the effectiveness of the BMP in reducing total water-quality loads is further reduced based on the amount of leakage.

DESIGN AND OPERATION OF BMPs

BMPs are more effective in attenuatingl water-quality loads for areas away from the recharge zone than for areas on the recharge zone. Also, BMPs on the recharge zone are probably more effective for sites on small developed areas with impervious covers approaching 100%. For such sites, only small volumes, if any, of runoff would be loss as recharge in route to the BMP because the high-level impervious cover would prohibit or substantially limit recharge volumes. However, for sites with extreme impervious-cover levels, high performance BMPs would need to be used and maintained in order to effectively lower the high water-quality levels from such developments.

The featured development scenario and others typically assume that all runoff from the development enters a single pond and further assumes that no runoff from outside the development boundaries enter the pond. Such circumstances rarely occur in the environment. Also, most ponds are designed to capture about 0.5 to about 1.5 inches of runoff and are designed to be drained in one to many days. Any rainfall depths that exceed the designed depth before the pond is drained would outflow the pond without being filtered. Many storms per year typically exceed these rainfall limits, and thus large-water-quality loads from such storms are not filtered. The removal efficiencies also assume that all filter media are operating at peak performance and equipment failures do not occur.

For example, most water-quality BMPs in the Austin area represent sand filters, many or most of which receive little if any maintenance. The effectiveness of these systems in reducing water-quality levels becomes extremely limited if maintenance is not performed because the sands become saturated with organic carbon and other urban-related contaminants

Experience in the operation of irrigation systems has identified several maintenance problems. Pumps for irrigation systems often are deemed inoperative because intakes become clogged with debris or sediment and sprinkler heads become clogged with sediment. Also, the entire system is susceptible to becoming inoperative due to vandalism. Irrigation systems require frequent inspections and maintenance to remain functional, however, not all irrigation systems receive such inspections and maintenance

.

Environmental Factors Affecting Irrigation Systems

Preliminary information indicates that irrigation of urban runoff might be effective in lowering water-quality levels. However, many factors influence the effectiveness of these systems. Soil-particle size on irrigated areas should be small enough to attenuate irrigated water—very permeable soils with large amounts of rock or sand allow contaminated water to quickly move to the underlying Edwards aquifer with minimal filtering. However, soils with large amounts of clay would not allow irrigated water to enter the soil zone. For such conditions, irrigated water could be retained on the surface as unfiltered, and then runoff or be flushed to receiving streams by rainfall.

Greater soil depths allow for greater attenuation of irrigated contaminants. Also, high density of vegetation provides greater removal of contaminants through direct absorption of irrigation and uptake and attenuation of contaminants through roots in the soils. Flat land slopes retain irrigated water on site for greater durations, which causes less runoff from the irrigated site and thus greater filtering through infiltration.

Finally, irrigation on soils wet from rainfall could cause reduced or no infiltration, thus non-filtered water could runoff from the site. Holding ponds have limited storage capacity thus irrigation has often occurred during rainfall events in order to prevent ponds from overflowing. During such conditions, it is likely that much or most irrigated waters would runoff from the site.

A Non-Conventional BMP

A runoff-filtering system manufactured by AquaLogic Inc., in San Antonio, Texas is being used on the Edwards Aquifer recharge zone in the San Antonio area. The system contains a sediment-settling basin and standpipes containing 10-micron filtering media, designed to filter all received runoff. AquaLogic Inc. provides frequent inspection and maintenance via contract with property owners, thus assuring that the system probably retains peak or near peak performance. Maintenance includes removal of all material from the sediment pond and replacement of filter media in the standpipes. Although the effectiveness of this system has not yet been tested for most urban-related contaminants, it is likely as effective or more effective than sand filters. Also, it might be superior to other BMPs simply because it receives scheduled and mandated inspections and maintenance.

<u>References</u>

City of Austin, 1990, Stormwater pollutant loading characteristics for various land used in the Austin area: Environmental and Conservation Services Department, City of Austin

Veenhuis, J.E., and Slade, R.M., Jr., 1990, Relation between urbanization and water quality of streams in the Austin area, Texas: U.S. Geological Survey Water-Resources Investigations Report 90-4107, 64 p. http://onlinepubs.er.usgs.gov/lizardtech/iserv/browse?cat=WRI&item=/wrir_90_4107.djvu&style=simple/view-html.xsl&wid=750&hei=600&props=img(Name,Description)&page=1

Woodruff, C.W., Jr., 1984, Water budget analysis for the area contributing recharge to the Edwards aquifer, Barton Springs segment: in Woodruff, C.M., Jr., and Slade, R.M., Jr., eds., Hydrogeology of the Edwards aquifer-Barton Springs segment: Austin Geological Society Guidebook no. 6, p. 36-42.