

EVALUATION OF STORMWATER CONTROL  
TECHNIQUES AND PROGRAMS

Prepared for:

EDWARDS UNDERGROUND WATER DISTRICT  
P. O. Box 15830  
San Antonio, Texas 78212

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## 1.0 INTRODUCTION

The Edwards Aquifer recharge zone near the City of San Antonio is experiencing continued population growth and land development. Increased urbanization may be accompanied by changes in the character of stormwater runoff. This is a particular concern in the Edwards Aquifer recharge zone because stormwater runoff eventually comprises a portion of the water that recharges the aquifer.

The Edwards Underground Water District (EUWD), in conjunction with the U. S. Geological Survey (USGS), initiated a water quality sampling program on three small watersheds overlying the recharge zone near San Antonio in the mid-1970s. The program was conceived to demonstrate the effects of urbanization upon water quality, recognizing the potential impact upon aquifer recharge. The test watersheds and streams (East Elm, West Elm and Lorence Creeks) were selected to exhibit urbanization levels ranging from undeveloped to fully developed.

In July 1986, the EUWD retained Water Resources Associates, Inc. (WRA) to compile existing data and conduct a limited statistical analysis of the three watersheds. The analysis was undertaken in order to determine if the existing data were sufficient enough to draw conclusions about the effect of urbanization on runoff water quality. Water Resources Associates did not collect any new data during the conduct of the study.

The results of WRA's analysis of the data indicated a corresponding relationship between urbanization and water quality constituent concentrations. The precise relationship, however, was not fully determined because analytical results differed depending on whether arithmetic or flow-weighted average concentrations were compared (WRA, 1986).

In order to better define the relationship between urbanization and stormwater runoff quality, it was recommended that the data collection program be continued and that the data base be updated and reanalyzed after a substantial number of additional samples had been collected. Water Resources Associates also recommended that other hydrologic and physiographic characteristics of the watersheds be studied to identify factors other than urbanization that may contribute to observed differences in constituent concentration. Finally, it was recommended that a unit loading analysis be conducted for each watershed.

After completion of the watershed study, the EUWD requested that WRA submit a proposal describing and analyzing stormwater runoff control techniques available to protect water quality. Water Resources Associates submitted its proposal on December 2, 1986, which was approved by EUWD. James Miertschin and Associates of Austin, Texas was subcontracted by WRA to help conduct the new study. Throughout this report the WRA/Miertschin team is referred to as WRA.



The objectives of the runoff control study were to provide information on stormwater runoff control techniques available to protect water quality, to provide information about existing runoff control programs in Texas and to summarize the information in order to assist the EUWD in determining the scope of further investigations.



## 2.0 WATER QUALITY CONTROL STRATEGIES

### 2.1 METHODOLOGY

Several stormwater quality control strategies, or Best Management Practices (BMPs), were surveyed through a limited research of the recent literature. Those strategies which were considered by WRA to be most applicable to the EUWD area were identified and described. The performance characteristics of each identified control strategy were summarized in qualitative terms. Similarly, a qualitative evaluation of the factors involved in the costs of each identified strategy has been prepared.

Quantitative data on removal efficiencies of control strategies reported in the various sources surveyed has been purposely omitted. The variability of the physical differences among watersheds and the variability of the storm rainfall amount, intensity and duration on which the removal efficiencies are based make comparisons difficult. In addition, the vagaries of stormwater sampling and chemical analysis may impart considerable "noise" to the data base. In fact, it is not unusual to find literature reports of negative removal efficiencies for various control strategies, indicating an increase in pollutant load in the effluent over the influent. This is a questionable outcome, contrary to theoretical principles, and is most likely explained by the intangibles involved in the sampling exercises.

Because of the difficulties in determining the impact of any BMP strategy on a watershed's assimilative capacity, stormwater quality control regulations are usually based on performance standards. A performance standard is a technology-based limitation against which a proposed water quality control strategy can be measured (Livingston, 1986). If, for example, the performance standard is the detention and filtration of the runoff of a specified volume, then control strategies which meet this performance standard are assumed to meet the applicable water quality standard. The objective of a performance standard is to achieve a level of pollution removal consistent with theoretical and historical observations.

Both non-structural and structural control strategies have been identified:

#### Non-Structural Controls

- Overland Flow
- Performance Zoning
- Sweeping Impervious Surfaces

#### Structural Controls

- Filtration Measures
- Sedimentation Basins
- Sand Filtration



These structural and non-structural strategies are usually components of a permanent stormwater management program. In addition, temporary practices to suppress erosion and prevent subsequent deposition of sediment are often part of an overall management program. A brief summary discussion of several common temporary practices, both structural and vegetative, has been included.

## 2.2 NON-STRUCTURAL CONTROLS

### 2.2.1 Overland Flow

Description. Maintaining vegetative buffer strips between urban development and creeks and streams is a non-structural approach to pollutant removal. Horner (1985) suggests that the primary pollutant removal mechanisms involved in overland flow are:

- o Suspended solids - sedimentation and filtration through the vegetative cover;
- o Metals - precipitation when associated with the suspended load, plant uptake, ion exchange and more significantly adsorption on the organic layer of the soil surface;
- o Organics - bacterial decomposition and adsorption;
- o Bacteria - precipitation when adhered to the solids portion; and
- o Nutrients - adsorption to the soil surface, nitrification, infiltration and denitrification of nitrate in the anaerobic zone of the saturated soil profile, plant uptake and precipitation.

Performance. Overland flow has received a great deal of attention as a means of treating domestic wastewater, usually involving carefully maintained, engineered systems with controlled flow rates and optimum physiography; unfortunately optimum conditions are seldom found in natural systems. The factors affecting the overall performance of vegetative buffer strips are: type and height of vegetation, buffer length, buffer slope, depth and permeability of the buffer soil profile, and the rate of runoff entering and passing through the buffer strips.

The effectiveness of the overland flow system is restricted if a uniform distribution of flow across the buffer is not achieved. Channelization of the flow can encourage erosion, eliminate vegetative contact and negate buffer efficiency.

Slope is a significant factor to efficiency if the increased flow rates and corresponding increased velocities typically associated with urban runoff



are considered. Hinricks et al. (1980) stated that slopes less than 2 percent and greater than 6 percent significantly reduce the effectiveness of the buffer strip to remove pollutants. Studies done by the Maryland Department of Natural Resources (1984) indicated that slopes less than 5 percent are most effective for efficient buffer performance.

Wong and McCuen (1981) and Karr and Schlosser (1977) have suggested that overland flow is most effective when accompanied, in series or parallel, by other BMP strategies, such as sedimentation and subsequent filtration.

Cost. The primary cost associated with overland flow is the dedication of a buffer zone, to be free of all construction activity, between impervious cover and adjacent streams. This buffer is generally related to the stream center line and may be specified as the delineated 100-year or some other flood plain with limits on width. For example, the buffer zone can be stipulated to be the selected flood plain width provided that it shall never be located greater than a specified outside limit nor less than an inside limit measured from the centerline on both sides of the waterway. Development activities adjacent to major waterways are penalized more by this control strategy than are upland developments. For example, in some water quality management programs, an additional area is required adjacent to the overland flow zone, in which limits on impervious cover are also controlled.

In some cases the regulatory entity or municipality is deeded the flood plain and additional open space (buffer zone) for park land which it must then maintain. Other costs to the regulatory entity are usually associated with the development of standards, dissemination of information and plan review.

### 2.2.2 Performance Zoning (Density and Impervious Cover Controls)

Description. Performance zoning, an alternative to conventional development planning, is an innovative approach to urban development which, in theory, is sensitive to environmental concerns. An example of performance zoning is the establishment of an open space ratio for residential development that requires a percentage of the total land area to remain undeveloped. Because performance standards, such as an open space dedication, are based on a measurable criteria (i.e., impervious cover), a developer is allowed greater flexibility than under conventional zoning regulations. The developer decides where to locate the open space and what it will look like.

Performance. Performance zoning encourages the preservation of vegetation and reduces paved areas which should result in reduced runoff volume and flow velocity. This in turn should reduce the potential for erosion. However, quantifying the relationships between land use density, impervious cover and pollutant loading is not easily accomplished.

Rimer et al. (1976) and Engineering Science (1983) have indicated a relationship between impervious cover, runoff and increased pollutant loadings.



Griffin et al. (1980) observed an abrupt increase in the normalized loadings for total phosphorus, total nitrogen, total suspended solids and chemical oxygen demand in the range of 40 to 50 percent imperviousness. They found no conclusive increase between 14 and 39 percent imperviousness, representing the low to medium land use density range.

The findings of the Nationwide Urban Runoff Program (NURP) (USEPA, 1983) established that, although there is a positive relationship between percent impervious area and runoff coefficient, land use category does not have a significant influence on pollutant concentration. When considered on a unit area basis, total pollutant mass loads were found to be significantly higher for commercial areas, attributable to increased impervious cover and runoff volume. The significance of this conclusion, however, is put into perspective when the total area of commercial development within the watershed is compared to the total watershed area.

Cost. Performance zoning and other methods of density and impervious cover controls can result in a shortened total roadway length because developers tend to cluster housing to achieve performance zoning regulations. A savings in road and utility construction costs can, therefore, be realized. However, construction cost savings can be offset by increased land costs and attendant market risks.

The savings realized to the regulatory entity or municipality are associated with street maintenance and the acquisition of park land deeded by the developer from open space areas. Additional administrative costs to the regulator would be associated with the development of standards, dissemination of information and plan review.

### 2.2.3 Sweeping Impervious Surfaces

Description. Sweeping of streets and parking lots is a non-structural source control strategy suited to developed areas where other techniques, such as sedimentation and filtration basins, are not suitable or were not implemented as control strategies at the time of development. Source controls are intended to reduce the generation and accumulation of stormwater pollutants at the source.

Two types of sweeping equipment are in use: mechanical broom sweepers and vacuum assisted sweepers. Studies have shown the vacuum assisted sweeper to be the more efficient of the two (Heaney and Nix, 1977). Sweeper efficiency is related to the proportion of material available for pick up. Best sweeper performance is achieved by use of a crimped wire or fiber broom at a slow forward speed with heavy broom pressure and fast broom rotation (Pitt, 1979). Conceptually, in an area with a high percentage of street surface, sweeping will remove a greater fraction of the total watershed pollutant load than in an area of lesser street density. By this reasoning the quality of runoff from commercial and industrial areas would benefit more from sweeping than would



residential areas. Because of heavy accumulation of sediment in commercial and industrial areas, sweeping would result in a greater amount of sediment removal and would be more efficient on a ton-per-mile basis.

Performance. Outside of the aesthetic consideration, street sweeping has limited application as a urban pollutant control strategy. Findings in the final NURP report (USEPA, 1983) stated that no significant reductions in event mean pollutant concentrations (EMCs) are realized by street sweeping. The NURP study further concluded that median concentrations "are as likely to be increased as decreased by street sweeping."

In their assessment of the results of ten years of research on street sweeping beginning in 1970, Sartor and Gaboury (1984) concluded that, in practice, if the average time between rainfall events is less than the sweeping interval, contaminants would be routinely washed away. As an average for the nation, the sweeping interval should be no more than 6 to 8 days to be effective.

Cost. The costs of a sweeping program as a pollution control strategy would be much greater than the costs of a conventional sweeping program because of the frequency necessary to achieve even marginal results. Capital expenditures are primarily associated with the purchase of sweeping equipment. Operations and maintenance costs are high in relation to other pollution control management practices because sweeping is labor intensive. Studies (Pitt, 1979) indicate that labor costs represent 73 percent of the total annual cost of a sweeping program.

## 2.3 STRUCTURAL CONTROLS

### 2.3.1 Infiltration Measures

Infiltration measures are designed to encourage recharge of stormwater to the ground water. An assortment of strategies are available including swales, infiltration trenches and porous pavement. The concept of infiltration presents somewhat of a dichotomy for the Edwards Aquifer recharge zone. Recharge of the aquifer's resources is certainly desirable from a volumetric standpoint; however, introduction of pollutants is a realistic concern. Recharge to the Edwards Aquifer occurs primarily by infiltration of surface water from streams that cross the Balcones fault zone and to a lesser extent by direct infiltration of precipitation on the outcrop (Andrews et al., 1984).

Typically, strategies which promote infiltration are historically found in geographic areas that feature relatively deep soil profiles, providing opportunity for filtration and adsorption of a variety of constituents in the infiltrating water prior to contact with subsurface water supplies. Deployment of infiltration measures in the Edwards Aquifer recharge zone should carefully consider site specific conditions. Caution must prudently be exercised to



avoid situations that would facilitate rapid infiltration of waters of unsuitable composition.

Among the strategies incorporating infiltration (porous pavement, infiltration trench and swales) as the primary mechanism for pollutant removal, the one most commonly found throughout the literature is swales. Porous paving, usually an open graded asphaltic pavement or concrete lattice blocks, encourages infiltration through the surface into a gravel sub-base. Infiltration trenches, either central or peripheral to a conventionally paved parking lot, are used to collect, store and filter runoff. Swales are discussed here in greater detail.

Description. Swales are usually broad, shallow waterways lined with vegetation. Swales, being a component of the natural drainage system, are sometimes used in the place of conventional storm sewers to collect runoff using the existing topography wherever possible. Swales are designed to mitigate the impacts accompanying urban development by reducing the volume and the velocity of runoff. The volume is reduced because the swale promotes infiltration, and the vegetated channels reduce velocity because of the resistance flow provided by the vegetation.

Performance. Pollutant removal is best achieved when the swale is constructed over permeable soils. Poorly drained or excessively compacted soils are not favorable to infiltration (North Central Texas COG, 1984).

Results reported in the NURP study (USEPA, 1983) of paired neighborhoods, one with storm sewers and one with swales indicated no significant improvement in runoff water quality associated with swales. However, the contact time in the swales was five minutes or less, an insufficient duration to allow contact with the vegetative growth and percolation into the underlying soils.

A 1982 study (Oakland, 1983) analyzed the data from 11 storm events on a grass-lined swale 100 feet long, 1 foot deep with a 10 feet top width and on a 1.5 percent slope. Contact times in the swale were usually greater than two minutes. The results indicated statistically significant reductions in chemical oxygen demand, nitrate, nitrite, as well as, cadmium, copper, lead and zinc. No significant removals were shown for biochemical oxygen demand, organic nitrogen or total phosphorus. Increases in suspended residue and fecal coliform were observed. The study concluded that water quality will be improved to the extent that infiltration is achieved in the swale. Horner (1985), in his review of the literature on highway runoff water quality, concluded that researchers are in agreement that once the contaminant is trapped in the soil profile there is virtually no migration, either horizontally or vertically.

Runoff generated from smaller, more frequent storms experience higher contaminant removal efficiencies due to lower flow volumes and velocities.



Similar to the problems encountered in overland flow, particulates settled or entrapped at the swale surface can be resuspended in subsequent runoff events.

Cost. Experience in Texas (USEPA, 1980) has shown that a natural drainage system incorporating swales can be constructed with less capital expenditure than a conventional storm sewer system. Capital expenditures for the natural system include land costs, grading and vegetating the site. Maintenance requirements include debris removal, landscape upkeep, insect control, sediment removal and fertilization.

### 2.3.2 Sedimentation Basins

Description. Sedimentation basins are ponding areas created to temporarily detain stormwater runoff for the purpose of settling suspended material. Stormwater management basins whose primary purpose is flood peak attenuation provide an opportunity for sedimentation to occur. Sedimentation efficiency in stormwater management basins is enhanced by increasing the detention time for settling purposes. Provisions for excess storage to compensate for accumulated sediment and periodic sediment removal are important considerations in the design of sedimentation basins. This type of basin is generally referred to as a "dry pond".

"Wet ponds" are stormwater management features that retain a permanent pool of water. A portion of the permanent pool is replaced by inflows from stormwater events. Wet ponds used for recreation or aesthetics can also incorporate stormwater attenuation and water quality control. Wet ponds, unlike detention/sedimentation basins (dry ponds), make use of biological processes to reduce the soluble fraction, such as nutrients, from the inflow pollutant load. The primary factors in these biological processes are algae and plant growth.

Performance. Although significant suspended solids removal can be achieved in dry ponds given sufficient detention time, research indicates that sedimentation by itself is limited as a BMP. Removal efficiencies for the soluble fraction of the runoff pollutant load have been shown to be relatively small. Results presented in the final NURP report (USEPA, 1983), based on data from more than 30 storm events, indicate that removal efficiency associated with the particulate forms (total suspended solids and total lead) of urban pollutants is "typically high" in sedimentation basins. Randall et al. (1982) supported this conclusion but also noted that, with the exception of lead, the removal of TSS did not correlate well with the removal of other pollutants. Removal of particulate material by sedimentation will affect various constituent concentrations only to the extent that they are associated with settleable matter. A large fraction of the pollutant load for a variety of constituents is carried by the smaller particles (colloids) which require longer settling times or do not settle at all.



The final NURP report (USEPA, 1983) concluded that when basins are adequately sized, significant particulate removals can be obtained in wet ponds. As with dry ponds, lower reductions are realized for the soluble fractions. High removals are encountered with those constituents (particularly lead) associated with the suspended particle load.

Cost. The initial (land and construction) costs of sedimentation basins would depend on the required storage volume. Costs can be reduced if natural topography can be used in the basin design. Construction costs can be estimated using current unit costs for construction applicable to the local area.

The type and location of the basin will greatly impact the operation and maintenance costs. Sedimentation basins will require periodic removal of accumulated material. Basins located in fully developed areas would require less frequent cleaning than basins in developing watersheds. Periodic replacement of the filter media would increase the maintenance costs associated with filtration. Access to the basins for sediment removal is necessary as is the disposal of accumulated material. Other considerations in the costs for an operations and maintenance program are: debris and litter removal, mowing and landscape upkeep, insect control, aquatic plant control, inspection and repair.

### 2.3.3 Sand Filtration

Description. In sand filtration, the first portion (typically the first one-half inch) of storm runoff is passed through granular media (sand, gravel) to an underdrain system and discharged. Stormwater is filtered through the media and particulates are retained near the surface. A portion of the soluble fraction of certain constituents may be adsorbed by soil particles within the filter profile.

The underlying assumption supporting this control strategy is based on isolating the "first flush" of runoff from the contributing watershed. The assumption is that most of the pollutant load is contained in the initial runoff volume. The first flush phenomenon may be site specific and depend upon rainfall characteristics and individual constituent behavior.

Performance. Sand filtration systems have, in general, been shown to be effective in removal of the particulate fraction of the runoff but less effective for removal of the soluble fraction. Hydrosience (1976) noted that the removal of other solids related pollutants can result from removal of the suspended solids fraction. Therefore, the performance of sand filtration systems vis-a-vis removal of specific constituents is dependent upon the constituent distribution between soluble and particulate fractions. For example, in some cases, total nutrient loads may have a large soluble component that will be largely unaffected by the filtration process. Some removal of soluble components can occur by adsorption or ion exchange. However a loss in removal effectiveness may occur as exchange capacity is exhausted.



A serious drawback to sand filtration is the problem of frequent clogging of the filter media by the trapped suspended load and biological activity. Clogging by suspended matter is considered the most serious deterrent to sand filtration. The clogging process can occur in several ways: formation of a surface layer, filling of the soil interstices near the surface, and penetration of the suspended particles and accumulation at deeper levels.

Biological clogging of the soil pore space is caused by microbial growth. It is basically a surface phenomenon which involves the formation of an organic mat. Periodic drying of the bed surface between stormwater events will bring about a return, or partial return, of the filter media to its original infiltration rate if biological activity is the primary clogging process at work.

Clogging by suspended matter is dependent upon many variables, including the size distribution of the porous media, settling velocities and the concentration of the suspended material.

Behnke (1969) showed that clogging by suspended matter is a surface sealing process. Berend et al. (1967) stated that a sediment layer will be formed on the surface if the settling velocity exceeds the infiltration velocity. A gravitational layer is formed as coarser particles settle first and the limiting layer builds upward becoming progressively finer, straining still smaller particles from the infiltrating water and therefore reducing the infiltration rate. Recovery of the infiltration rate can only be achieved by partial or total removal of the limiting layer.

Cost. The costs associated with filtration basins are discussed in Subsection 2.3.2, Sedimentation Basins.

#### 2.3.4 Temporary Erosion Control

Description. Sediment load generated during construction can be, on an annual basis, 100 times greater than the sediment loads produced from established urban areas (Daniel and Keeney, 1978). Temporary erosion control practices are used during construction to reduce sediment transport from denuded areas. Temporary erosion control practices can be classed as vegetative (non-structural) and structural. Fast growing annual and perennial grasses are used on partially completed construction sites to protect disturbed areas from erosion for short periods of time. Temporary vegetative practices consist of temporary seeding and mulching. Structural erosion control methods can be grouped as either barriers or filters.

Barriers trap sediment and reduce the velocity of runoff water, thereby reducing its sediment carrying capacity. Erosion control methods classified as barriers include:



- straw bales;
- diversion, interceptor and perimeter dikes;
- swales;
- grade stabilization structures; and
- sediment basins and traps.

Filters are erosion control devices that allow runoff water to pass through but trap sediment by filtration. Types of filters in common use are:

- rock and brush berms; and
- fabric silt fences.

Performance. The particulates associated with the sediment runoff from construction sites are generally heavier than the suspended fraction in urban runoff. This attribute facilitates the removal of sediment by settling or trapping or by filtration through a rock or brush berm or fabric filter fence.

Performance is difficult to quantify because the nature of the control strategy is preventative more than corrective. A study prepared for the Texas Water Quality Board (Bernard Johnson, Inc., 1976) gives evidence of significant sediment removal by straw bales. Rock and brush filter berms were not found to be as effective as other types of barriers. Siltation devices operate best in runoff events from storms of limited intensity.

Cost. The construction of temporary control devices requires relatively small capital expenditures. Additional costs are associated with the formulation and design of the temporary erosion control plan, the site development permit and review fees charged by the regulating entity. The costs to the regulator are associated with implementation of the program, plan review, inspection of the facilities and enforcement of the enabling ordinance.



## 3.0 TEXAS STORMWATER MANAGEMENT PROGRAM

### 3.1 METHODOLOGY

Seven Texas cities were surveyed to identify the stormwater runoff control programs which have been implemented. Telephone interviews were conducted with city departments responsible for the stormwater programs in Austin, Dallas, El Paso, Fort Worth, Houston, New Braunfels and San Marcos. Information contained in a recent statewide study, Survey of Drainage Problems of Cities in Texas (Mason and Laza, 1985), provided insight for preparation of interview questions.

In most of the cities surveyed, stormwater control programs are designed primarily for attenuation of peak runoff flows to alleviate flooding concerns. Two Texas cities, Austin and San Marcos, have established stormwater management programs which incorporate techniques specifically for water quality protection. Although the other Texas cities do not consider water quality protection as an objective of their programs, appropriate information about their programs is provided. A brief overview of the State of Texas' permitting program is provided.

### 3.2 STATE PROGRAM

The State of Texas has a program conducted by the Texas Water Commission to permit stormwater runoff discharges. This program was initiated around 1972 and runs parallel to the U.S. Environmental Protection Agency's permitting program. Program requirements differ according to the type of source. For instance, residential development is not likely to require a permit because the state does not consider runoff from such areas to be significantly contaminated. Commercial development may require a permit depending upon the proposed use, anticipated pollutant levels and other factors which are evaluated on a case-by-case basis. A permit is always required for industrial development.

When a permit is required limits are typically established for total organic carbon or chemical oxygen demand, oil and grease, and pH. The TWC establishes a monitoring program for the constituents based on the expected discharge and type of operation and requires that test results be reported. The TWC does not specify any techniques for controlling or treating stormwater; instead, the permit holder is allowed to implement appropriate measures to meet the limitations.

### 3.3 CITY PROGRAMS

#### 3.3.1 City of Austin

The City of Austin initiated its runoff control program in 1976. Deten-



tion and retention facilities were recognized as ways to control stormwater drainage and to protect water quality. In 1982, the concern for runoff water quality protection led the city to publish an erosion and sedimentation control manual. The manual offers objectives, design considerations, plan requirements and standards to assist developers and engineers in implementing the erosion and sedimentation policy. Objectives of the erosion and sedimentation control policy are to reduce sedimentation in streams, protect the quality of the water in the Austin environment, promote recharge of the Edwards Aquifer and provide restoration of construction sites.

Construction plans for current development projects in Austin must address erosion and sedimentation control and detention and retention. For erosion and sedimentation control, 15 temporary structural practices may be considered, including diversion dikes, rock berms, brush berms, hay bale dikes, silt fences and swales. Permanent structural practices which may be considered are diversions, grass-lined swales, level spreaders, stone rip-rap, gabions, subsurface drains and land grading. Other temporary and permanent structural practices will be considered on a case-by-case basis. Vegetation practices to stabilize critical areas and special practices, such as minimizing stripped areas and protecting trees during construction, are also required.

The city recommends the consideration of detention and retention facilities for drainage control, though the primary focus has been on detention facilities. Retention refers to stormwater runoff collected for a significant period of time and released or used after the runoff has ended. Retention storage usually consists of wet ponds which have recreational and/or aesthetic value. Detention consists of reducing the rate of runoff for a short period of time in order to reduce peak flows. This is accomplished by controlling the discharge through an outlet structure and thereby extending the period of runoff (City of Austin, 1983).

Maintenance of the various water quality protection facilities is the responsibility of the property owners where the facilities are located on private property or easements. Regional facilities are dedicated to the city, which is responsible for providing ongoing maintenance. Inspection and enforcement is provided by the Transportation and Public Services Department.

Currently, the City of Austin is revising the drainage standards and erosion and sedimentation control guidelines. These changes are primarily in response to the 1986 Comprehensive Watersheds Ordinance. Objectives of this ordinance include preventing loss of recharge to the Edwards Aquifer and protecting the quality of recharge to the Edwards Aquifer.

The most significant changes will occur in the drainage program, where the primary control strategy will be to capture and isolate the first one-half inch of runoff from the contributing drainage area. This first flush is defined as the water quality volume (WQV). The recommended water quality treatment



operations will be sedimentation and filtration. Guidelines will provide for the consideration of two different sedimentation-filtration system configurations to accommodate topographic limitations. Specific requirements vary according to the type of watershed, defined as either suburban, water supply suburban or water supply rural. Filtration basins located on the Edwards Aquifer recharge zone will be required to have an impermeable liner in order to prevent the possibility of unfiltered pollutants from entering the aquifer (City of Austin, 1986a and 1986b).

The City of Austin has not completed any detailed studies to evaluate the effectiveness (nor demonstrate the necessity) of its stormwater runoff control techniques. The city has, however, completed an interim study of several detention/filtration facilities. Analysis of the data indicates that the control structures are operating within the design parameters. The USGS is scheduled to publish the official results of the limited sampling effort in 1987.

### 3.3.2 City of San Marcos

Developers in San Marcos must obtain a site development permit from the engineering department before construction can begin. As part of the site development permit, the project engineer must prepare a stormwater runoff, erosion and sedimentation control plan and report. Elements of the report, as identified in the Interim Drainage and Erosion Control Ordinance (first passed in 1976), are: construction sequencing as it relates to placement, maintenance and/or removal of temporary erosion controls and restoration measures, a list of erosion controls and maintenance thereof, slope stabilization techniques to be employed and method of restoration, including vegetative types. Technical data and calculations must also be shown.

The city initially had a manual of compliance but this manual was never used. The only guidance, therefore, is the Erosion and Sediment Control Guidelines for Developing Areas in Texas prepared by the Soil Conservation Service (SCS) and the City of Austin Drainage Criteria Manual, both referenced in the ordinance. Standards for overland flow and natural drainage identified in the ordinance are as follows:

- o Natural drainage patterns shall be preserved whenever possible.
- o The loss of the pervious character of the soil shall be limited in order to prevent erosion and attenuate the harm of contaminants collected and transported by stormwater.
- o The use of streets and street right-of-ways as the central drainage network shall be avoided whenever practical.
- o Construction of enclosed storm sewers and impervious channel linings shall be permitted only when the city engineer, or his



designated representative, on the basis of competent engineering evidence, concludes that such storm sewers or impervious linings are justifiable options.

- o Necessary stormwater drainage systems and/or culverts shall be designed to mitigate the impact of erosion and stormwater runoff on water quality through the use of approved control strategies to control sediment and dissipate energy and through the use of multiple smaller outlets whenever practical, and by locating discharges to maximize overland flow.

Compliance with these standards is evaluated on a case-by-case basis by the engineering department. Inspection is provided by the environmental division.

In addition to these requirements, the city has established an impervious cover requirement to aid in water quality protection. Impervious cover is limited to 35 percent on slopes from 15 percent gradient to 25 percent gradient and to 20 percent on slopes over 25 percent gradient.

The City of San Marcos is currently preparing technical standards to be used in the preparation of stormwater runoff, erosion and sedimentation control plans. The city is also considering the preparation of a master drainage plan which would include consideration of regional detention facilities.

#### 3.4 OTHER CITIES

All of the remaining Texas cities surveyed (except New Braunfels) either allow or require the use of detention and/or retention facilities in their stormwater management programs. The purpose, however, for use of those facilities is for flood control. Any water quality protection is a secondary benefit. Several cities have also established limited erosion and sedimentation control requirements. Pertinent details of the other cities surveyed are provided.

In the City of Dallas, the public works department is responsible for the stormwater management program. The city only requires detention or retention basins in sensitive areas (escarpment area in Southwest Dallas) and in areas with overtaxed stormwater facilities. The primary purpose of these facilities is to control flood waters. The city has no formal manual but has criteria which it will review with developers and engineers. The city requires an erosion control plan for developments in the escarpment area and near floodplains. Developers typically use the SCS erosion and sediment control guidelines.

The City of El Paso initiated its stormwater management program in 1972. The city recommends and considers a variety of techniques including ponds, detention basins, retention basins, on-site ponding, desilting basins, wind



fences and swales. The specific requirements are identified in the city's grading ordinance, subdivision design standards and subdivision ordinance. Construction and maintenance of control structures is the responsibility of the developer, though the city is responsible for maintaining any structures deeded to the city. The engineering department is responsible for the stormwater management program.

The City of Fort Worth has informal recommendations for the use of detention and retention facilities and will meet with developers and engineers to discuss the recommendations. The city is considering a formal detention and retention requirement, but the requirement would be minimal. Based upon an extensive stormwater sampling program, discussions with other cities and discussions with the Environmental Protection Agency, the city feels that its stormwater quality problems are caused by illegal connections into the storm sewers. The department of environmental health services has established a storm drain entry team and is working with the building department to identify and correct illegal connections.

The City of Houston has no specific requirements for the use of detention and/or retention facilities, except where the Harris County Flood Control District has determined that the existing flood control facilities are over-taxed. In those watersheds (only 3 currently identified), the storm sewer engineering division within the public works department will require commercial developments to construct detention facilities. The Harris County Flood Control District is responsible for a district-wide detention program. The city requires that revegetation practices be used on areas disturbed by city public work projects, though this requirement does not affect private developers.

As previously mentioned, the City of New Braunfels does not have any requirements for the use of detention and/or retention facilities. The city has initiated a regional drainage study which will consider the use of detention and retention facilities as well as the use of erosion and sedimentation control measures for water quality protection.

In addition to the cities of Dallas and Fort Worth, the North Central Texas Council of Governments (NCTOG) developed a stormwater management manual in 1984 as a guideline for local governments in the Dallas-Fort Worth area. Part I of the manual suggests standardized formulas and procedures for determining different flood flow characteristics. Part II identifies different stormwater management techniques for water quality, flood control, aesthetics and recreation purposes. Specific practices discussed include stormwater management basins, on-site storage, fertilizer management, sweeping of impervious surfaces, swales and natural drainage systems, performance zoning and temporary erosion control.

The NCTCOG has worked with communities in its region to implement effective and compatible stormwater management programs. Many cities in the region



have adopted erosion and sedimentation control practices for public works projects, though NCTCOG finds that the required practices are often ignored by contractors.



## 4.0 FLORIDA STORMWATER MANAGEMENT PROGRAM

### 4.1 METHODOLOGY

As a comparison with the programs in Texas, information was collected on the stormwater management program in Florida. Sections 4.2 and 4.3 provide general information about the state program and about two local programs, respectively.

### 4.2 STATE PROGRAM

The State of Florida adopted its first stormwater management regulation in 1979. The need for regulation was identified through the Section 208 Water Quality Management Planning Process. The first regulation was based on the "significance" or "insignificance" (subjective, undefined criteria) of proposed discharges. Because the regulation was loosely defined, the state began to revise the regulation in 1980. The final rule was adopted in early 1982 as Florida Administrative Code Chapter 17-25, Regulation of Stormwater Discharge, and was revised in 1984 and 1985.

Some of the design and performance standards identified in Chapter 17-25 which are applicable to the current EUWD study are as follows:

- o Detention basins shall be designed so that the treatment volume is available again within 72 hours following a storm event.
- o Retention basins shall be designed so that the storage volume is available again within 72 hours following the storm event. The storage volume must be provided by a decrease of stored water caused only by percolation through soil, evaporation or evapotranspiration.
- o Swales shall be designed to percolate 80 percent of the runoff from a three-year, one-half hour design storm within 72 hours after a storm event, assuming average antecedent conditions.
- o Best management practices for erosion and sediment control shall be used as necessary during construction to retain sediment on-site.
- o Stormwater discharge facilities, which receive stormwater from areas which are a potential source of oil and grease contamination shall include a baffle, skimmer, grease trap or other mechanism suitable for preventing oil and grease from leaving



the stormwater discharge facility in concentrations that would cause or contribute to violations of applicable water quality standards in the receiving waters.

For the volumes mentioned in the first two items above, the state requires that the volumes be sufficient for the first one inch of rainfall or, as an option for projects with drainage areas less than 100 acres, the first one-half inch of runoff.

The Florida Department of Environmental Regulation (DER) is responsible for implementing the state's stormwater management program. The DER may issue general permits or construction permits depending upon the nature of the proposed project.

The DER may, after proper notice, delegate to either local governments or water management districts the authority to process notices, issue or deny permits, initiate enforcement actions and monitor for compliance. A water management district which has been delegated stormwater regulation may establish alternative requirements which protect the designated uses of waters of the state provided that the alternative requirements are approved by the Environmental Regulation Commission. A local government which has been delegated stormwater management regulation may also establish alternative requirements provided the DER determines such alternative requirements are compatible with, or more stringent than, those imposed by the state regulation.

Currently, four of the five water management districts in the state have received delegation of the stormwater management program. The fifth district has a constitutional limit on its authority to raise enough tax revenues to fund the management program. The DER has not yet begun delegating the stormwater management program to local governments. This, however, will be the next step in their delegation efforts.

The Florida stormwater management program is relatively new and still being changed, as evidenced by the frequent amendments to the state regulation. Major issues the state has identified (Livingston, 1985) include:

- the long-term operation and maintenance of stormwater management systems;
- achieving field efficiencies of BMPs versus the theoretical efficiencies;
- design, construction and maintenance of filtration systems;
- grandfathering of existing stormwater systems;
- promotion of a piecemeal approach which relies on individual on-site management; and



- lack of coordination between state, regional and local governments.

These concerns will be the focus of DER's administrative efforts and legislative agenda.

#### 4.3 LOCAL PROGRAMS

As previously mentioned, four water management districts in Florida have received delegation for the stormwater management program in their respective areas. These districts may establish alternative requirements. Two water management districts were surveyed in order to provide a brief summary of local programs.

##### 4.3.1 St. Johns River Water Management District

The St. Johns River Water Management District covers a 12,400 square mile area (all or part of 19 counties) in northeast and east central Florida. Most of the population is concentrated in coastal cities. Major urban centers are Jacksonville, Daytona Beach, Gainesville, and a major portion of Orlando.

The District was delegated the stormwater management program in 1983 after it adopted a district-wide rule for the management and storage of surface waters (MSSW). The MSSW rule is intended to prevent the loss of storage and recharge capabilities, lessen the risk of flooding and protect the conveyance capabilities of streams.

The District has developed an applicant's handbook (1984) which describes the program's policy and procedures, criteria for evaluation and methodologies. The handbook also provides copies of applicable state rules and application forms.

The District's program closely follows the state guidelines, requiring general or individual permits for certain development and construction activities. The District's thresholds, however, are more specific than the state guidelines. Permits are required if such activity:

- is capable of impounding a volume of water of 40 or more acre-feet;
- serves a project with a total land area equal to or exceeding 40 acres;
- provides for the placement of 12 or more acres of impervious surface which constitutes 40 or more percent of the total land area; or



- contains a surface water management system which serves an area of five or more contiguous acres of hydrologically sensitive areas.

#### 4.3.2 Suwannee River Water Management District

The Suwannee River Water Management District covers a 7,600 square mile area (all or part of 14 counties) in north central Florida. The District is predominantly rural; the greatest development pressure is on the eastern edge of the District where suburban Gainesville is expanding into the District.

The District was delegated the stormwater management program in 1986 and has prepared a draft manual (1986) which described the District's program. Three types of permits are issued by the District: general permits for small projects, individual permits for larger projects, and conceptual permits for projects phased over a long time period. General permits require only staff review and approval, whereas individual and conceptual permits require board approval and public advertisement.

The District will consider a variety of stormwater management techniques including retention with percolation and/or evapotranspiration, detention with filtration, wet detention and on-site wetlands. The District has defined four separate categories and corresponding volumes of water which must be treated:

- for areas with development containing hazardous or toxic materials -- total retention of the 100-year critical event with zero discharge;
- for areas which contribute to an active sink -- the first two inches of rainfall;
- for areas discharging to Outstanding Florida Waters -- first one and one half inches of rainfall; and
- for other areas -- first one inch of rainfall.

Under no circumstance can the volume be less than one-half inch of runoff. These specific criteria were modified from the state guidelines because of the District's concern for protecting ground-water recharge.



## 5.0 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 CONCLUSIONS

There are many practices which are used to improve the quality of stormwater runoff. These include structural controls, non-structural controls such as land use planning, and source controls which are intended to improve runoff quality by reducing the generation and accumulation of potential stormwater contaminants at the source. Source control practices include sweeping of impervious surfaces, vegetating disturbed areas associated with construction activities and maintaining the structural elements of stormwater management systems. Significant problem areas encountered in implementing a comprehensive stormwater quality management program include assurances for long term operation and maintenance of the stormwater system, enhancement of BMP efficiency to achieve theoretical contaminant removals, and retrofitting the water quality control strategies to local governments' existing master plans.

Other conclusions drawn from the literature survey relating to the performance of stormwater BMPs follow:

- o The effectiveness of overland flow as a stormwater quality control strategy is dependent on slope, vegetation and flow conditions. Steep slopes downhill from urban development may provide only minor contaminant removal due to high flow rates and velocities, insufficient vegetation or other peculiarities of the site. Continuous loadings may cause pollutant buildup and subsequent washoff.
- o The literature suggests a relationship between impervious cover, runoff and increased pollutant loadings. Performance zoning, when based on density and impervious cover, is an attempt to control the generation of contaminants. However, limiting density could result in additional land area being developed to meet the demand of population increases.
- o An individual BMP may not solve a stormwater quality problem completely. If maximum benefits are to be achieved, non-structural, source and structural controls should be combined into a comprehensive stormwater management system.
- o Sediment loads generated during construction can be, on an annual basis, 100 times the loads produced from established urban areas. A program which includes a provision for temporary erosion control consisting of both structural and vegetative



practices could be effective in preventing transport of construction-generated sediment.

The application of BMPs for urban stormwater runoff quality enhancement in Texas is limited to the cities of Austin and San Marcos. Several cities require the use of retention and detention facilities, but the primary purpose is for flood protection.

## 5.2 RECOMMENDATIONS

Previous analysis of data by WRA (1986) indicated that there is a correlation between urbanization and water quality constituent concentrations in the San Antonio area, though the precise relationship has not been fully determined. Continuation of the EUWD's data collection program on East Elm, West Elm and Lorence Creeks and the analysis of these data may provide additional insight to this relationship. An analysis of hydrologic and physiographic characteristics of the watersheds and a unit loading analysis, as previously recommended, would also provide additional information upon which to develop an appropriate stormwater runoff management program.

In the interim, however, developers who build on the Edwards Aquifer recharge zone are required to prepare a Water Pollution Abatement Plan (WPAP), that in addition to addressing the nature of the development and character of the wastewater and stormwater, must describe "the measures that will be taken to prevent pollution of stormwater runoff," and describe "the measures that will be taken to prevent pollutants from entering significant recharge areas" [31 TAC Section 313.3(b)(3)]. The intent of the WPAP is to ensure that a development uses BMPs to aid in the regulation of activities having the potential for causing pollution of the Edwards Aquifer. Guidelines, standards and criteria for implementation of the WPAP, however, are not stipulated.

In order to assist developers in accomplishing the purposes of the regulations, the Edwards Underground Water District should prepare a model WPAP. The model WPAP could include guidelines and specifications for BMP's most appropriate for the Edwards Aquifer area, and serve as a manual for developers and their engineers. Preparation of the guidelines and specifications could use information from existing Texas programs, supplemented with additional information from other areas or ongoing research.



## 6.0 REFERENCES CITED

- Andrews, Freeman L., Schertz, Terry L., Slade, Raymond M., Jr. and Rawson, Jack, "Effects of Storm-water Runoff on Water Quality of the Edwards Aquifer Near Austin, Texas," U.S. Geological Survey, Water Resources Investigation Report 84-4124, 1984.
- Behnke, Jerold J., "Clogging in Surface Spreading Operations for Artificial Groundwater Recharge," Water Resources Research, Vol. 5, No. 4, pp. 870-876, 1969.
- Berend, J.E., Rebhun, M. and Kahana, Y., "Use of Storm Runoff for Artificial Recharge," Transactions of the American Society of Agricultural Engineers, 10, pp. 678-684, 1967.
- Bernard Johnson, Inc., "Methodology for the Evaluation of Construction Related Nonpoint Sources of Pollution," prepared for the Texas Water Quality Board, November 1976.
- City of Austin, "Draft Design Guidelines for Water Quality Control Basins," Department of Environmental Protection and Department of Transportation and Public Services, 1986a.
- City of Austin, "Draft Erosion and Sedimentation Control Manual," Department of Environmental Protection, 1986b.
- City of Austin, Drainage Criteria Manual, 1983.
- City of San Marcos, "Interim Drainage and Erosion Control Ordinance," 1984.
- Daniel, T.C. and Keeney, D.R., "Nonpoint Pollution: Causes and Consequences," University of Wisconsin-Extension, G2956, September 1978.
- Engineering Science, Inc., Final Report of the Nationwide Urban Runoff Program in Austin, Texas, 1983.
- Florida Department of Environmental Regulation, "Regulation of Stormwater Discharge," Chapter 17-25, Florida Administrative Code.
- Griffin, D.M., Jr. et al., "Analysis of Non-point Pollution Export from Small Catchments," Journal of Water Pollution Control Federation 52(4): 780-790, 1980.
- Heaney, J.P. and Nix, S.J., "Stormwater Management Model: Level I - Comparative Evaluation of Storage - Treatment Management Practices," U.S. EPA, EPA-600/2-77-064, March 1977.



- Hinricks, D.J., Faisst, J.A., Pivetti, D.A. and Schroeder, E.D.,  
"Assessment of Current Information on Overland Flow Treatment of Municipal Wastewater," University of California - Davis, 1980.
- Horner, R.R., "A Review of the Literature" University of Washington,  
Taken from appendices of Washington State Highway Runoff Water Quality Research Implementation Manual, Vol. II, Report of the Washington State Department of Transportation, Report No. WA-RD72.1, 1985.
- Hydroscience, Inc., "A Statistical Method for Assessment of Urban Stormwater Loads - Impacts - Controls," U.S. EPA, EPA 440/3-79-023, May 1979.
- Karr, James R. and Schlosser, Issaac J., "Impact of Nearstream Vegetation and Stream Morphology on Water Quality and Stream Biota," University of Illinois, U.S. EPA, EPA-600/3-77-097, 1977.
- Livingston, Eric H., "Stormwater Management in Florida: An Evolving Regulatory Program," presented at American Society of Civil Engineers Urban Runoff Quality Seminar held in Henniker, New Hampshire, June 22-27, 1986.
- Maryland Department of Natural Resources, Maryland Standards & Specifications for Stormwater Management Infiltration Practices, 1984.
- Mason, John M. and Laza, Kent Michael, Survey of Drainage Problems of Cities in Texas, sponsored by Texas Public Works Association through the Public Works Resource Center, Texas Engineering Extension Service, Report No. TPWA-001, August 1985.
- North Central Texas Council of Governments, Stormwater Management Handbook, Stormwater Estimation and Management Techniques for North Central Texas, 1984.
- Oakland, P.H., "An Evaluation of Urban Storm Water Pollutant Removal Through Grassed Swale Treatment" in Proceedings of 1983 International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, 1983.
- Pitt, Robert, "Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices," U.S. EPA, EPA-600/2-79-161, 1979.
- Randall, Clifford W., Ellis, Kathy, Grizzard, Thomas J. and Knocke, William R., "Urban Runoff Pollutant Removal by Sedimentation," in Proceedings of the Conference on Stormwater Facilities, New England College, Henniker, New Hampshire, August 1982.
- Rimer, Alan E., Reynolds, David E. and Nissen, James A., "Characterization and Impact of Stormwater Runoff from Various Land Cover Types," presentation at the 49th Water Pollution Control Conference, Minneapolis, Minnesota, October 4, 1976.



- Sartor, J.D. and Gaboury, D.R., "Street Sweeping as a Water Pollution Control Measure: Lessons Learned Over the Past Ten Years," Elsevier Science Publishers, 1984.
- St. Johns River Water Management District, Management and Storage of Surface Waters, Applicant's Handbook, 1984.
- Suwannee River Water Management District, Draft Surfacewater Management Permitting Manual, 1986.
- Suwannee River Water Management District, "Surfacewater Management Rules," Chapter 40B-4, 1986.
- U.S. Department of Agriculture, Soil Conservation Service, Erosion and Sediment Control Guidelines for Developing Areas in Texas, 1976.
- U.S. Environmental Protection Agency, Final Report of the Nationwide Urban Runoff Program, prepared by Water Planning Division, U.S. EPA, Washington, D.C., December 1983.
- Water Resources Associates, Inc. and James Miertschin and Associates, Analysis of Water Quality Data for East Elm, West Elm and Lorence Creeks, prepared for the Edwards Underground Water District, September 1986.
- Wong, S.L. and McCuen, R.H., "Design of Vegetative Buffer Strips for Runoff and Sediment Control," Maryland Coastal Zone Management Program, Department of Civil Engineering, University of Maryland, College Park, 1981.



**APPENDICES**



APPENDIX A  
TECHNICAL BIBLIOGRAPHY



## APPENDIX A

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American Public Works Association, "Water Pollution Aspects of Urban Runoff," in Water Pollution Control Research Series WP-20-15, January 1969.

American Public Works Association, Urban Stormwater Management, Special Report No. 49, 1981.

Anderson, D.E., "Evaluation of Swale Design," Thesis M.S.E. Program, College of Engineering, University of Central Florida, Orlando, 1982.

Barfield, B.J., Warner, R.C. and Haan, C.T., "Applied Hydrology and Sedimentology for Disturbed Areas," Oklahoma Technical Press, Stillwater, Oklahoma, 1981.

Behnke, Jerold J., "Clogging in Surface Spreading Operations for Artificial Groundwater Recharge," Water Resources Research, Vol. 5, No. 4, pp. 870-876, 1969.

Berend, J.E., Rebhun, M. and Kahana, Y., "Use of Storm Runoff for Artificial Recharge," Transactions of the American Society of Agricultural Engineers, 10, pp. 678-684, 1967.

Bernard Johnson, Inc., "Methodology for the Evaluation of Construction Related Nonpoint Sources of Pollution," prepared for the Texas Water Quality Board, November 1976.

Black, Crow and Eidsness, Inc., "Water Quality Data for Natural and Cultural Areas and Abatement Facilities," submitted to East Central Florida Regional Planning Council, July 1977.

Brown and Caldwell, Inc., "Lake Tahoe Water Quality Management Plan, Volume II, Handbook of Best Management Practices," 1978.

Chen, Charng-Ning, "Design of Sediment Retention Basins," National Symposium on Urban Hydrology and Sediment Control, University of Kentucky, Lexington, July 1975.

City of Austin, "Draft Design Guidelines for Water Quality Control Basins," Department of Environmental Protection and Department of Transportation and Public Services, 1986.

City of Austin, "Hydrologic and Water Quality Data for Barton Creek Square Mall and Alta Vista PUD," Interim Water Quality Report, Watershed Management Division, Department of Public Works, Fall 1984.



City of Austin, "Stormwater Monitoring Program Work Plan," prepared by Watershed Management Division, Department of Public Works, November 1983.

City of Austin, "Guidelines and Procedures for Implementing Lake Austin Watershed Development Controls," Engineering Department, March 1980.

Crouse, J.M, Berg, V.H. and Mitchell, L.J., "Planning and Implementation of Regional Stormwater Management Facilities in Montgomery County," in Proceedings of Stormwater and Water Quality Model User Group Meeting, January 27-28, 1983, University of Florida, Gainesville.

Curtis, David C. and McCuen, Richard H., "Design Efficiency of Stormwater Detention Basins," Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers, Vol. 103, No. WR1, May 1977.

Dally, L.K., Lettenmaier, D.P., Burger, S.J. and Benjamin, M.M., "Operation of Detention Facilities for Urban Stream Quality Enhancement," Water Resources Series Technical Report No. 79, Washington State University, Department of Civil Engineering, Bu Rec C-00198-U(0504)(1), July 1983.

David, Ernst M., "Maximum Utilization of Water Resources in a Planned Community - Bacterial Characteristics of Stormwater in a Planned Community," U.S. EPA, EPA-600/2-79-050F, August 1979.

Driscoll, Eugene D., "Performance of Detention Basins for Control of Urban Runoff Quality," in Proceedings of 1983 International Symposium on Urban Hydrology, Hydraulics and Sediment Control, University of Kentucky, Lexington, July 1983.

East Central Florida Regional Planning Council, "Stormwater Management Practices Evaluation," compiled by M.P. Wanielista and E.E. Shanon for Orlando Metro 208 Program, 1977.

Engineering Science, Inc., Final Report of the Nationwide Urban Runoff Program in Austin, Texas, 1983.

Griffin, D.M., Jr., et al., "Analysis of Non-point Pollution Export from Small Catchments," Journal of Water Pollution Control Federation, Volume 52, No. 4, pp. 780-790, 1980.

Hardee, J., Miller, R.A. and Mattraw, H.C., "Stormwater-Runoff Data for a Multifamily Residential Area, Dade County, Florida," USGS Open File Report 79-1295, 1979.

Harper, H.H., Cassagnol, C.L. and Wanielista, M.P., "Detention/Retention Stormwater Designs," in Proceedings of the Annual Meeting of Civil Engineers, Hollywood, Florida, October 1980.



Heaney, J.P. and Nix, S.J., "Stormwater Management Model: Level I - Comparative Evaluation of Storage - Treatment Management Practices," U.S. EPA, EPA-600/2-77-064, March 1977.

Hey, D.L., "Lake Ellyn and Urban Stormwater Treatment," in Proceedings of the Conference on Stormwater Facilities, New England College, Henniker, New Hampshire, August 1982.

Hinricks, D.J., Faisst, J.A., Pivetti, D.A. and Schroeder, E.D., "Assessment of Current Information on Overland Flow Treatment of Municipal Wastewater," University of California - Davis, 1980.

Horner, R.R., "A Review of the Literature," Taken from appendices of Washington State Highway Runoff Water Quality Research Implementation Manual, Vol. II, Washington State Department of Transportation, Report No. WA-RD72.1, 1985.

Hydroscience, Inc., "A Statistical Method for Assessment of Urban Stormwater Loads - Impacts - Controls," U.S. EPA, EPA 440/3-79-023, May 1979.

Hydroscience, Inc., "Water Quality Management Planning Methodology for Urban and Industrial Stormwater Needs," prepared for the Texas Department of Water Resources, December 1976.

Jones, R.C. and Holmes, B.H., "Effects of Land Use Practices on Water Resources in Virginia," Technical Completion Report, Virginia Water Resources Research Institute, Blacksburg, April 1985.

Karr, James R. and Schlosser, Isaac J., "Impact of Nearstream Vegetation and Stream Morphology on Water Quality and Stream Biota," University of Illinois, U.S. EPA, EPA-600/3-77-097, 1977.

Kendig, Lane, et al., Performance Zoning, Planners Press. American Planning Association, Washington, D.C., 1980.

Lee, C.R. and Peters, R.E., "Overland Flow Treatment of a Municipal Lagoon Effluent for Reduction of Nitrogen, Phosphorus, Heavy Metals, and Coliforms," 1979.

Loganathan, V.G., Dallew, J.W. and Segara, R.I., "Planning Detention Storage for Stormwater Management," Journal of Water Resources Planning and Management, American Society of Civil Engineers, Vol. 111, No. WR4, pp. 382-398, October 1985.

Long Island Regional Planning Board, "NURP - The Long Island Segment - Final Report," 1982.



- Lynard, William G., et al., "Urban Stormwater Management and Technology: Case Histories," U.S. EPA, EPA-600/8-80-035, August 1980.
- Mae, R.D., Bullin, J.A., Polasek, J.C., Miculka, J.P. and Longheed, M.J., Characteristics of Highway Runoff in Texas, USDA, FHWA, Office of Research and Development, Washington, D.C., 1977.
- Maryland Department of Water Resources, "Guidelines for Erosion and Sediment Control-Planning and Implementation," U.S. EPA, EPA-R2-72-015, August 1972.
- Mason, John M., "Design of Small On-Site Detention Basins Using Multi-Staged Outlet Control," Proceedings of Southwest Regional Symposium and Workshop on Urban Stormwater Management, Texas A&M University, October 11-14, 1982.
- Mattraw, H.C., Hardee, J. and Miller, R.A., "Urban Stormwater Runoff Data for a Residential Area, Pompano Beach, Florida," USGS Open File Report 78-324, 1978.
- Miller, R.A., Mattraw, H.C. and Hardee, J., "Stormwater-Runoff Data for a Commercial Area," Broward County, Florida, USGS, Open File Report 79-982, 1979.
- Miller, R.A., Mattraw, H.C. and Hardee, J., "Stormwater-Runoff Data for a Commercial Area," Broward County, Florida, USGS Open File Report 78-612, 1978.
- North Central Texas Council of Governments, "Methodology Manual, Techniques for Assessing Rainfall, Runoff and Nonpoint Pollutant Loadings in North Central Texas," prepared by Hydrosience Inc., June 1978.
- Northern Virginia Planning District Commission, "Washington Metropolitan Area Urban Runoff Demonstration Project," prepared for Metropolitan Washington Council of Governments, April 1983.
- Northern Virginia Planning District Commission, "Guidebook for Screening Urban Nonpoint Pollution Management Strategies," prepared for Metropolitan Washington Council of Governments, November 1979.
- Northwest Colorado Council of Governments, "Point Sources - Nonpoint Sources Trading in the Lake Dillon Watershed - Final Report," 1984.
- Oakland, P.H., "An Evaluation of Urban Storm Water Pollutant Removal Through Grassed Swale Treatment," in Proceedings of 1983 International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, 1983.
- Ormsbee, L.E., "Development of a General Planning Methodology for Stormwater Management in Urban Watersheds," Water Resources Research Center, Purdue University, Technical Report No. 163, March 1984.



Poertner, Herbert G., "Practices in Detention of Urban Stormwater Runoff," Office of Water Resources Research, American Public Works Association, June 1974.

Post, Buckley, Schuh and Jernigan Engineers, Inc., "Evaluation of Two Best Management Practices," prepared for Brevard County 208 and the Brevard County Board of County Commissioners, 1982.

Pitt, Robert, "Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices," U.S. EPA, EPA-600/2-79-161, 1979.

Randall, Clifford W., "Stormwater Detention Ponds for Water Quality Control," in Proceedings of the Conference on Stormwater Facilities, New England College, Henniker, New Hampshire, August 1982.

Randall, Clifford W., Ellis, Kathy, Grizzard, Thomas J. and Knocke, William R., "Urban Runoff Pollutant Removal by Sedimentation," in Proceedings of the Conference on Stormwater Facilities, New England College, Henniker, New Hampshire, August 1982.

Rimer, Alan E., Reynolds, David E. and Nissen, James A., "Characterization and Impact of Stormwater Runoff from Various Land Cover Types," presentation at the 49th Water Pollution Control Conference, Minneapolis, Minnesota, October 4, 1976.

Sartor, J.D. and Boyd, G.B., "Water Pollution Aspects of Street Surface Contaminants," U.S. EPA, EPA-R2-72, 081, November 1972.

Sartor, J.D. and Gaboury, D.R., "Street Sweeping as a Water Pollution Control Measure: Lessons Learned Over the Past Ten Years," Elsevier Science Publishers, 1984.

Silver, R.M., "Detention Ponds: The Positive and the Negative," Public Works, Vol. 117, No. 4, pp. 40-41, 1986.

Soderlund, G., Lehtinen, H. and Frigerger, S., "Physicochemical and Microbiological Properties of Urban Stormwater Runoff," Fifth International Water Pollution Research Conference, July-August 1970.

Southeast Michigan Council of Governments, "Performance Zoning: An Innovative Approach to Water Quality Protection and Land Use Regulation," Technical Bulletin No. 7, July 1981.

Southeast Michigan Council of Governments, "Protecting Water Quality Through Cluster Development: Financial Incentives and Community Benefits," Technical Bulletin No. 7, May 1981.

Southeast Michigan Council of Governments, "Detention Basin Maintenance: Program Needs and Financing Options," Technical Bulletin No. 3, May 1981.



- Stone, S.L., "Streamside Vegetative Filters," Department of Planning and Growth Management, City of Austin, 1986.
- Urban Land Institute, American Society of Civil Engineers and National Association of Home Builders, Residential Stormwater Management: Objectives, Principles and Design Considerations, 1979.
- Urban Land Institute, American Society of Civil Engineers and National Association of Home Builders, Residential Erosion and Sediment Control, 1978.
- U.S. Department of Agriculture, Soil Conservation Service, Engineering Manual for Conservation Practices, 1978.
- U.S. Department of Agriculture, "Predicting Rainfall Erosion Losses, A Guide to Conservation Planning," Agriculture Handbook Number 537, December 1978.
- U.S. Department of Agriculture, Soil Conservation Service, Erosion Handbook, April 1, 1978.
- U.S. Department of Agriculture, Soil Conservation Service, Erosion and Sediment Control Guidelines for Developing Areas in Texas, 1976.
- U.S. Department of Agriculture, Soil Conservation Service, Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas, 1975.
- U.S. Environmental Protection Agency, Office of Water, Nonpoint Source Branch, "Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality," EPA 440/5-87-001, September 1986.
- U.S. Environmental Protection Agency, Final Report of the Nationwide Urban Runoff Program, prepared by Water Planning Division, U.S. EPA, Washington, D.C., 1983.
- U.S. Environmental Protection Agency, "Urban Stormwater Management and Technology, Case Histories," EPA-600/8-80-035, August 1980.
- U. S. Geological Survey, "Attenuation of Stormwater Contaminants from Highway Runoff Within Unsaturated Limestone, Dade County, Florida," prepared by B.G. Waller, H. Klein and L.J. Lefkoff, W.R.I. 84-4083, 1984.
- U.S. Geological Survey, "Stormwater Quality Processes for Three Land-Use Areas in Broward County, Florida," W.R.I. 81-23, 1981.
- Virginia Soil and Water Conservation Commission, Virginia Erosion and Sediment Control Handbook, Second Edition, 1980.



- Volusia Council of Governments, "Best Management Practices to Control Water Pollution in Volusia County, Florida for the Construction Industry," 1980.
- Wanielista, M.P., Gemmaro, R.N., Bell, J.H. and Johnson, J.W., "Shallow-Water Roadside Ditches for Stormwater Purification," compiled for Florida Department of Transportation, Report No. ESEI-78-11, 1978.
- Wanielista, M.P., Yousef, Y.A. and McLellon, W.M., "Non-Point Source Effects on Water Quality," Journal of Water Pollution Control Federation, Volume 49, No. 3, pp. 441-451, 1977.
- Wanielista, M.P., Yousef, Y.A., Harper, H.H. and Cassagnol, C.L., "Detention with Effluent Filtration for Stormwater Management."
- Wanielista, M.P., et al., "Stormwater Management to Improve Lake Water Quality," EPA Grant #R-8055880, Draft Report.
- Weinberg, M., Reece, D. and Allman, D., "Effects of Urban Stormwater Runoff to Surface and Groundwater Quality," South Florida Water Management District, Technical Publication No. 804, May 1980.
- Whipple, William and Hunter, Joseph V., "Settleability of Urban Runoff Pollution," Journal of Water Pollution Control Federation, Volume 53, No. 12, 1981.
- Wong, S.L. and McCuen, R.H., "Design of Vegetative Buffer Strips for Runoff and Sediment Control," Maryland Coastal Zone Management Program, Department of Civil Engineering, University of Maryland, College Park, 1981.
- Yousef, Y.A., Wanielista, M.P., Traver, R.P., Harper, H.H. and Walsh, T., "Impact of Stormwater Runoff on Lake Eola Water Quality."
- Yousef, Y.A. (Editor), "Proceedings of Stormwater Retention/Detention Basins Seminar," Florida Technological University on July 8, 1977, Report #ESEI-77-9, August 1977.
- Zimmerman, M.L., "Costs for Managing A Construction Site Runoff Control Program," Proceedings of the National Conference on Urban Erosion and Sediment Control, Institutions and Technology, October 10-12, 1979, EPA - 905/9-80-002, January 1980.



APPENDIX B

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