DEVELOPMENT OF A LAND USE PLAN EVALUATION AND ENHANCEMENT METHODOLOGY TO CONTROL URBAN NONPOINT SOURCE POLLUTION

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

DEVELOPMENT OF A LAND USE PLAN EVALUATION AND ENHANCEMENT METHODOLOGY TO CONTROL URBAN NONPOINT SOURCE POLLUTION

ABSTRACT

The problem of water quality degradation due to uncontrolled urban stormwater runoff is well documented. As more areas become urbanized, the negative impacts of urban runoff tend to increase. Almost all of the research efforts on nonpoint source pollution control focus on retrofitting problem areas with Best Management Practices (BMPs). As land develops or redevelops, it has been found that installing controls is less costly than later retrofitting development to include them. Unlike socio-economic factors, stormwater runoff quality has not been considered during most planning processes. The U.S. Environmental Protection Agency and other well known researchers in nonpoint source pollution control emphasize the need to initiate urban stormwater runoff control efforts at the planning stage to enhance water quality in a more economical fashion. This dissertation presents a sustainable development methodology to control urban stormwater runoff at the planning stage. It consists of guidelines to facilitate the selection of the most economically feasible and environmentally sound (with regard to water quality) alternative site plan. Further, the methodology provides ways of arming the chosen site plan with Control Options based on economic feasibility, legal requirements (water quality goals), and the characteristics/limitations of the area to minimize the concentration of critical pollutants of the area to a desired level. The application of the methodology is illustrated using a residential area near the Moisant Airport in Louisiana, which, due to noise impacts, is scheduled to be redeveloped into commercial and industrial uses.

CHAPTER 1

INTRODUCTION AND SIGNIFICANCE OF THE RESEARCH

1.1. Introduction

From the beginning of the 1960s, urban nonpoint source pollution has been a major reason for non-attainment of designated uses in the nation's waters. As will be discussed under the introduction of the problem, the costs due to nonpoint source pollution are high in most parts of the nation. For example, many states (including Louisiana) lose considerable revenue every year because some streams and lakes cannot support recreational and commercial fishing. The number of tourists who visit for water recreation and seafood dining decreases as does the yearly seafood production. Additionally, property values are also lowered by polluted rivers and lakes in urban areas.

The U.S. Environmental Protection Agency has undertaken an aggressive urban stormwater quality improvement program through the National Pollution Discharge Elimination System (NPDES) permitting program under Section 402 and 405 of the 1972 Federal Water Pollution Control Act and 1987 Clean Water Act.

The NPDES (Municipal Separate Storm Sewer System Permit) has expanded its focus from controlling only point sources (i.e., industrial facilities, wastewater treatment facilities) to controlling nonpoint sources as well. The current approach also requires a permit for stormwater discharges from cities and industrial facilities. NPDES also encourages cities and industries to mitigate the problem by long-term planning. Under NPDES permit requirements, cities need to reduce the runoff pollutant concentrations to the

Maximum Extent Practicable (MEP) based on the characteristics of the area.

The USEPA (1995) fact sheet indicates the need to include water quality at the planning and design stage of development along with all other more typical aspects of site planning designed to address safety, convenience, public service, and quality of life. Lynard et al. (1980) also have suggested that land use planning should play an important role and perhaps should be used as the first step in controlling nonpoint source pollution during development. However, as will be described in Chapter 3, there is a lack of a planning-level methodology which provides guidance at the redevelopment planning stage to enhance the quality of stormwater runoff. Furthermore, Urbonas (one of the most well-known researchers, authors, and advocates of stormwater quality enhancement) encourages planning-level controls. According to Urbonas (1994), retrofitting structural Best Management Practices (BMPs) is costlier than installing structural controls as land develops or redevelops.

Currently, water quality is not considered when evaluating land redevelopment alternatives. Instead, the focus is on socio-economic benefits. As a result, later, when the state or a local government realizes (e.g., due to a massive fishkill, lack of access to swimming, occurrence of a dead zone, or federal mandate) that uncontrolled stormwater runoff is a problem, the general practice is to build detention/retention basins targeting the critical areas. The demand to fix problems suddenly and unexpectedly after damages have been done, reacting to problems without proper planning beforehand, is not economical or environmentally sound. One of the objectives of this study is to provide evidence that retrofitting not only costs more money, but also depends on the general tax payers' money, compared to proper early planning expenses which are (eventually passed-on-to) paid only by tenants.

Although environmental costs are sometimes difficult to estimate, it should not be an excuse for not taking steps to avoid such costs. Unchecked, chronic water quality deterioration will be more harmful in the future than it is at present. The impacts and/or damages due to uncontrolled stormwater runoff should be taken seriously, similar to the noise impacts for which mitigation measures are taken for the area surrounding the Moisant Airport, LA.

A planning method is needed that takes into account water quality protection goals in addition to the usual socio-economic goals. The purpose of this dissertation is to develop a site plan evaluation and enhancement methodology that local and/or state governments can follow to minimize the undesirable and uneconomical consequences of unplanned urban stormwater runoff. This methodology describes how to achieve established stormwater runoff quality goals based on the limiting criterions (economy, space, legal requirements, available technical facilities and expertise, and characteristics) of the area of concern. Therefore, the methodology can also be used to achieve desired pollutant concentrations set forth by the municipality to satisfy NPDES requirements.

The only planning-level approach that encourages control of stormwater runoff is the watershed approach for new developments. The approach proposed in this dissertation is similar in many ways to the watershed approach, but it is more appropriate for redevelopment because it provides more specific guidelines, leads to selecting the best alternative site plan in all aspects, helps in balancing all relevant limiting criteria stated above, and is easier to implement and apply.

Both methods recommend reviewing site characteristics to assess problems and potential solutions before preparation of plans. But, the watershed approach does not specify what characteristics to look for and document. The proposed approach does that. Both methods encourage the handling of pollution due to stormwater runoff in a more comprehensive manner, and provide front-end solutions rather than retrofitting later. However, the guidelines on how to approach the problem more comprehensively are provided only in the approach proposed by this dissertation. The comprehensive approach offers significant advantages over piecemeal approaches in stormwater runoff quality controls. These advantages include, but are not limited to, more effective and efficient reduction in runoff pollutants to the receiving waters for less capital and maintenance costs (less yearly cost).

The major difference between the watershed approach and the approach proposed here is that the proposed methodology not only considers environmental factors but also all the limiting constraints when evaluating and enhancing the most suitable alternative site plan. Therefore, the proposed methodology provides one step towards sustainable development. This methodology is especially useful compared to the watershed approach for an area to be redeveloped, because in such an area runoff quantity control measures are already in place. Implementation of the proposed methodology is cost-effective and more appropriate than implementing the watershed management approach at the redevelopment stage.

Additionally, watershed planning is suitable/applicable for new developments due to the need for developing a comprehensive "master plan" at the beginning of the planning process. However, for an already developed area such as a noise impacted area, to be redeveloped to land uses that satisfy Federal Aviation Administration (FAA) requirements, the methodology described here is more suitable because the area may not fit into a single watershed. A major advantage of the proposed method over the watershed approach is that it can be applied without regard to the boundaries of the watershed.

This research is significant because the product of the research provides step by step guidance to planners and decision makers when developing or redeveloping an area to maintain/improve pre-development water quality, using local parcel boundaries instead of watershed boundaries. In the process, the increase of water pollution due to the development of the area to a higher density and various best management practices for the betterment of the runoff quality, is estimated. Most of all, the methodology tries to balance the protection of receiving water quality with consideration of economic feasibility and other factors important in planning for the area under consideration. The proposed methodology provides a decision model that consists of various water quality management elements in achieving desired water quality goals for a particular redevelopment. It is flexible enough so that the user can develop and organize the elements based on available resources (money, technical feasibility, professional expertise, land, etc.) and the characteristics and legal requirements of the area under consideration. Therefore, the proposed methodology is a useful tool for any state or local government to control additional water pollution from a development or redevelopment, to meet NPDES permit requirements, and to move toward sustainable development.

1.2. Organization of the Research

This dissertation is organized as follows. Chapter one summarizes the significance of the problem, federal efforts to mitigate the problem, the difference between the watershed approach and the proposed approach, and significance of the research. Chapter two introduces the problem, the adverse consequences of unplanned urban stormwater runoff, and the what, how, why, and where of stormwater runoff and urban nonpoint source pollution. Chapter two further explains the involvement of the federal government in nonpoint source pollution control. Chapter three discusses the findings of previous research related to stormwater runoff (especially urban versus non-urban), and some of the existing land use planning approaches and their strengths and weaknesses in improving stormwater runoff quality. Chapter four documents hydrologic models, particularly the Source Loading and Management Model (SLAMM). The description includes the SLAMM's major assumptions, the reasons for choosing it as the tool for this dissertation, and water quality control measures that can be tested using the SLAMM. Chapter five reviews water-quality-enhancing measures applicable in preparing site plans. Chapter six discusses the purpose and the procedure for the study, including goals and objectives. Chapter six contains an introduction, a summary, and the full-blown steps of the proposed methodology. Chapter seven brings out the conditions, facts, and data related to the case study of the noise impacted area of the New Orleans International Airport. It further summarizes the alternative land uses proposed for the redevelopment of the residential area into commercial and industrial uses and points out the lack of consideration of water quality as a factor at the cost evaluation stage. Then, the proposed methodology, which contains guidelines for the selection of the most environmentally and economically sound site plan(s), is applied to the alternatives to include water quality as a consideration at the planning stage. In chapter eight, the results of the analysis and conclusions are presented. The case study confirms that retrofitting costs more for local tax payers than mandating the achievement of desirable stormwater runoff quality goals at the planning stage. Chapter nine discusses the application, success of meeting the goals and objectives, and limitation of the methodology. Chapter ten summarizes the recommendations for the application of this methodology as well as future studies which could be based on the analysis. The references of the research follow chapter ten. Appendix A provides a brief description of the Clean Water Act. Appendix B provides schematic diagrams of Best Management Practices. Appendix C summarizes existing ordinances for controlling stormwater discharges in Jefferson Parish, Louisiana. Appendix D presents the City of Kenner's ordinances for controlling stormwater discharges and management of the drainage system. Appendix E provides copies of evaluations of the proposed methodology by the environmental professionals in the public and private sector in the City of Kenner and Jefferson Parish. Appendix F consists of data and output files of the Source Loading and Management Model (SLAMM).

CHAPTER 2

INTRODUCTION TO THE PROBLEM

2.1. Problem Statement

In recent years, people and animals alike have suffered due to deterioration of water quality from uncontrolled urban stormwater runoff. The cost associated with nonpoint source pollution is estimated to be in the tens of billions of dollars annually in the U.S. alone (Committee on Conservation Needs and Opportunities, 1986).

According to the USEPA's 1990 National Water Quality Report to Congress, nonpoint source pollution is the main reason for rivers and lakes failure to meet clean water standards. In total, nonpoint sources are responsible for almost two-thirds of the pollution that prevents achievement of water quality standards. Nonpoint source pollution is also responsible for the largest contribution of conventional pollutants: 79% of the nitrogen, 74% of the phosphorous, and 41% of oxygen-demanding materials (Alm, 1990).

The deteriorating quality of water resources due to land development has become an increasingly important public issue (Thum et al., 1990). Pesticides and other toxic materials are taken up in the food chain, posing a threat to both aquatic life and humans. Water quality deterioration has contributed to fish-kills and harmful effects on other aquatic life. It eventually poses a threat to human-life and the ecosystem as a whole (Alm, 1990). Fishing and food industries related to fishing are at a great disadvantage in areas where water quality has deteriorated or is in the process of deteriorating.

Another major consequence of surface water quality deterioration is that such waters pose a threat to primary water contact activities such as swimming. Additionally, the deposition of nonpoint source pollutants in drains, sewer pipes, and gutters can reduce their capacity to transport stormwater. It may lead to slow removal of stormwater and cause more frequent street flooding.

According to USEPA (1991), the adverse impacts of stormwater runoff on receiving waters and aquatic biota through increased frequency and duration of peak flow rates, erosion/sedimentation, deposition, eutrophication, or toxic impact were revealed by the results of the National Urban Runoff Program (NURP). The greater energy associated with stormwater runoff can cause sediments, fertilizers, pesticides, metals, and oil and grease to be transported into and down the streams and bottom sediments and vegetation to be scoured. This increases suspended solids concentration and turbidity in streams, which can be detrimental to aquatic life (primary producers, benthic invertebrates, and fish), since it interferes with photosynthesis, respiration, growth, and reproduction (USEPA, 1991).

If trees along the banks are lost due to bank erosion (or clearing during urbanization), shading to the stream is lost. As a result, the stream's temperatures rises. These temperatures can be too warm for some inhabitants. Additionally, water holds less oxygen as it gets warmer. The decreased amount of dissolved oxygen may also make the stream uninhabitable for stream organisms.

Increased flow and pollutant loadings into and down the stream adversely affect aquatic life in the stream as noted above. Flow itself can flush established aquatic life downstream, especially when vegetation that provides shelter from the current is uprooted. Pollutants such as oil and grease can be washed off the surface of parking lots and roads and can smother fish eggs and organisms that live at the bottom. The deposition of relatively fine-grained sediments in stream beds can dramatically reduce their value for insect production and fish spawning. The remainder of this chapter is devoted to explaining the what, why, how, and where of stormwater runoff and its associated problems.

2.2. Stormwater Runoff

2.2.1. Definition

Stormwater runoff is the portion of rainfall or snow melt which does not soak into the ground and flows across land surfaces and eventually runs into streams. In developed watersheds, the amount of runoff depends upon the amount of impervious area, the existing stormwater control measures, and other factors such as the intensity and duration of rainfall, and antecedent conditions.

2.2.2. Land Development and Stormwater Runoff

Land development occurs when land is changed from its original, natural state (e.g., forest, wetlands, open grass lands, and agriculture) to a new use such as residential, commercial, industrial and /or disposal sites. When land is in its original or natural state, it performs very important functions that protect water quality in receiving water bodies. These lands reduce the amount of runoff by intercepting a considerable amount of water in its vegetative cover, thereby increasing the amount of infiltration and reducing the pollution of water by trapping pollutants and sediments.

. Land development reduces the vegetative cover and increases the paved surfaces such as highways, parking lots, roof tops, and sidewalks. Unlike permeable grounds, paved surfaces have less retention and infiltration capacity to trap water, sediments, or pollutants in the stormwater runoff. Land development also alters the natural drainage patterns, because it disturbs the natural land cover. Ultimately, the higher amount of impervious surfaces increases the volume and accelerates the flow. According to Leopold (1968), of all land use changes affecting the hydrology of an area, urbanization is by far the most forceful.

2.2.3. Science behind Water Quality Deterioration

Raindrops dislodge soil particles and contaminants from land surfaces. This material is carried in solution or suspension and travels with the runoff. Suspended particles are deposited enroute if the velocity of stormwater decreases. Contaminants carried in solution in stormwater enter the soil through the larger pores at the soil surface and move downward and horizontally through the pore network. Water diffuses into the smaller pores by capillarity or small moisture tension. The rate of movement through the soils and surficial materials depends upon the size, shape, continuity, and arrangement of the pore network system. The most soluble constituents such as nitrates and chlorides and many organic chemicals continue to move downward through the aquifer system or to the receiving water bodies. Soils with high clay, fine sand, silt content, or with the presence of interspersed clay lenses retard the rate of movement of water and some contaminants through the soil. A portion of the constituent may be used by plants and soil bacteria. This is a very general description of a complex system.

2.2.4. Stormwater Runoff and Receiving Water Quality

Stormwater quality impacts on receiving waters are often site specific, and the extent of the problem depends on local conditions, such as rainfall quantities, point sources of pollution and their treatment, land use, infiltration capacity, and the sensitivity of the receiving water. However, under certain conditions, stormwater runoff can govern the quality of receiving waters regardless of the level of dry-weather flow treatment provided. Therefore, control of runoff pollution can be a viable alternative for maintaining receiving water quality standards.

According to the San Jose study by the USEPA (1980), if all of the total solids pollutant depositions in an urban area were added up, only about one-third would reach the outfall. Only about 10% of the nutrients and oxygen demanding materials deposited may affect the receiving water quality, but most of the heavy metals deposited in the area would affect the receiving waters.

According to Pitt (1987), it is very difficult for receiving waters to recover from frequent discharges of pollutants or flashy flows that occur several times a month due to small storms. Although heavy rainfalls which only occur once in many years also have significant effects, the receiving waters have a greater opportunity of recovering during the long inter-event period.

The short term effects of urban runoff on receiving waters occur (by definition) during and immediately after a runoff event. A comparison between the urban runoff average concentrations and the sanitary wastewater treatment plant effluent average concentrations shows that the concentrations of lead, suspended solids, chemical oxygen demand (COD), cadmium, total organic carbon (TOC), turbidity, zinc, chromium, and five day biological oxygen demand (BOD_5) are all higher in the runoff than in the sanitary wastewater effluent. Copper and Kjeldahl nitrogen, in addition to the previously listed parameters, have greater runoff peak concentrations than the wastewater average concentrations. Therefore, urban runoff may have more important short-term effects on receiving waters than the average treated sanitary wastewater effluent (USEPA, 1980).

2.3. Nonpoint Source Pollution

2.3.1. Definition

Nonpoint source pollution, which is stormwater runoff from diffuse land uses such as urban, agricultural, mining, construction sites, and forestry, eventually causes degradation of surface water and ground water. For the purpose of implementing the nonpoint source pollution provisions in the Clean Water Act (see Appendix A), nonpoint source pollution is defined by the USEPA as follows:

> "nonpoint source pollution is caused by diffused sources that are not regulated as point sources and normally is associated with agricultural, silvicultural and urban runoff, runoff from construction activities, etc. Such pollution results in the human-made or human-induced alteration of the chemical, physical, biological, and radiological integrity of water. In practical terms, nonpoint source pollution does not result from a discharge at a specific, single location (such as a single pipe) but generally results from land runoff, precipitation, atmospheric deposition, or percolation. It must be kept in mind that this definition is necessarily general; legal and regulatory decisions have sometimes resulted in certain sources being assigned to either the point or nonpoint source categories because of considerations other than their manner of discharge. For example, irrigation return flows are designated as "nonpoint sources" by section 402(1) of the Clean Water Act, even though the discharge is through a discrete conveyance" (LDEQ, 1993, p.1).

2.3.2. Sources of Nonpoint Source Pollutants

The following is a list of some of the sources of nonpoint source pollution:

- urban areas (toxics, nutrients, sediments, oxygen demand)
- construction sites (sediment, phosphorus)
- cropland (pesticides, fertilizers, nutrients, sediment, oxygen demand)
- animal feedlots (bacteria, nutrients, oxygen demand)
- septic tank failures (bacteria, nutrients, oxygen demand)
- shoreline erosion (sediment, phosphorus)
- mining (toxics, sediment)
- forestry (sediment, phosphorus, nitrogen)
- highway (deicing materials, various salts, and vehicular pollution)
- air-borne contaminants and by-products of industries (deposited by gravity, wind, or rainfall)
- improper storage and disposal of toxic and hazardous materials (e.g., dumping of chemicals such as used motor oil and antifreeze into storm sewers).
- illegal hookups of sanitary sewers to storm drains.

2.3.3. Factors Affecting Nonpoint Source Pollution

According to Weinberg et al. (1979), the factors affecting the amount of nonpoint source pollution can be categorized into five major groups: (a) rainfall; (b) vegetation; (c) soil erodibility; (d) topography; and (e) man's alteration of physical features.

(a) Rainfall: Storms are characterized by their:

- duration
- total precipitation
- intensity
- frequency
- number of antecedent dry days

When the rainfall rate exceeds the soil's capacity to absorb it, stormwater runoff occurs. Under natural conditions, during and following a rainfall, stormwater flows (within the watershed area) to lower elevations where it is either recharged to groundwater or it drains to streams, rivers, bays, and other surface waters.

(b) Vegetation: Plant cover can shield the ground surface from the full impact of falling rain and thus helps reduce erosion. When a raindrop falls on a leaf, the leaf absorbs the raindrop's energy. If the same drop falls directly on bare soil, it dislodges soil particles. Stems, leaves, and other plant litter provide surface storage and slow overland runoff. This allows more time for water to evaporate and infiltrate. Plant stems also allow more water to infiltrate into the soil by breaking the soil's crust. Plant roots improve internal soil structure, hold soil in place, and actively absorb water. Due to the gradual percolation of much of the rainfall into the soil in relatively undisturbed watersheds, both the volume of runoff and the rate of overland flow are reduced, thus maximizing aquifer replenishment in some areas and minimizing erosion.

(c) Soil erodibility: The size, shape, and arrangement of soil particles, as well as the organic matter content, determine the soil's ability to absorb water and resist erosion. Coarse-textured, sandy soils are loose and permeable, and allow large volumes of water to move through them. Percolation is generally slower in finer-textured, silty and clayey soils. Medium to fine textured soils, especially those lacking organic matter and good structure, are usually more subject to erosion.

(d) Topography: Topographic features such as drainage density, slope steepness and slope-length affect runoff and soil loss. The drainage density of a watershed refers to the number of water channels present per unit of land area. Regions with steep terrain often have high drainage densities. Actual soil loss can vary greatly depending on the land management practices employed.

(e) Alteration of physical features: Modern technology has increased the ability to alter the landscape. Earthmoving for construction, strip mining, and agriculture expose millions of acres of soil. An individual watershed may include both urban and agricultural land uses. These different land uses may destroy vegetation, remove topsoil, or transform terrain features, and may be undertaken with little consideration for their effects on water quality. Nonpoint source pollution occurs when land is disturbed without taking protective measures.

2.3.4. The Types of Nonpoint Source Pollutants

The following are the principal types of nonpoint source pollution:

- Metals- Lead, Mercury, Copper, Iron, Zinc, Nickel, Cadmium, Chromium

- Organic Chemicals
  - -Base Neutral Compounds
  - -Acid Compounds
  - -Pesticides

- Inorganic Chemicals
  - -Phosphates
  - -Nitrates
  - -Chlorides

- Bacteria and Viruses - *pseudonomoas aeruginosa*, fecal coliform, etc.

  Oxygen Demanding Substances- decaying materials

  Sediments

2.4. Urban Nonpoint Source Pollution

Urban nonpoint source pollution is the result of precipitation washing the surface of urbanized areas. In general, the more intensive the land use, the greater the amount of surface water runoff and pollution. As precipitation falls on urban areas, it picks up contaminants from: the air; littered and dirtied streets and sidewalks; petroleum residues from automobiles; exhaust products, carbon and organics from tires, metal from break linings, heavy metals and tar residuals from the roads; chemicals applied for fertilization, weed and insect control; and, sediments from construction sites.

2.4.1. Common Urban Nonpoint Source Pollutants

Sediment pollution results from excessive soil erosion. The primary source of sediment in urban areas is construction activities. The volume of sediment decreases flow capacity in drainage ways and blankets the bottom of receiving waterbodies, killing oxygen producing plants, smothering spawning grounds and juvenile aquatic organisms, and altering benthic communities. Soil in runoff may also have other pollutants attached to it such as pesticides, nutrients, or oxygen demanding substances. These pollutants may produce an impact on the receiving waters immediately, or they may settle out and slowly produce an impact on the receiving waters over a period of time.

Nutrients can enter urban runoff from a variety of sources including wash-off from excessive fertilizer application and the decomposition of fallen leaves and other organic materials. Nutrients causing the greatest concern are forms of phosphorous and nitrogen, which in high concentrations can lead to large algae blooms in still waters. As the algae die off and are oxidized, severe depletion of dissolved oxygen and subsequent fish kills can occur.

Toxic substances including heavy metals (especially copper, lead, and zinc), pesticides, herbicides, and other chemicals are often found in significant concentrations in urban runoff.

Oxygen-demanding substances include all organic materials which consume oxygen as they decompose. Excessive quantities of organic materials result in oxygen depletion of the receiving waters. This can cause a balanced aquatic population of fish and other aquatic organisms in the food chain to be adversely affected, resulting in fish kills and nuisance conditions. Animal droppings, sewage overflows, fallen leaves, and grass clippings are a few examples of oxygen demanding substances.

Petroleum products such as gasoline, oil, and grease are found in high concentrations in runoff from streets, highways, parking lots, and other vehicle traffic areas. These substances adversely affect aquatic life by adhering to them or by coating aquatic organisms thereby cutting off their oxygen supply. Petroleum products also exert an oxygen demand and decrease the aesthetic quality of receiving waters.

Pathogenic microorganisms from animal droppings (rodents, dogs, cats, and bird) and human fecal wastes (sewage overflows) are a frequent pollutant in urban runoff. This type of contamination can present a health hazard if water is used for contact activities or as a drinking water supply before natural purification or water treatment takes place.

2.4.2. The Effects of Urban Nonpoint Source Pollution on Receiving Waters

The effects of urban runoff on the quality of receiving waters are extremely complex. There are many highly variable factors involved including: the type, size, and hydrological characteristics of the receiving waters; the urban runoff quality, quantity, and flow characteristics; the designated beneficial uses of the receiving waters; and behavioral characteristics and concentration levels of the specific pollutants that affect those uses.

Pollutants (such as stated in the previous section) that are present in the atmosphere between rainfall events and those which accumulate on impervious areas are generally carried away in the first 0-1 inch of rainfall by runoff in moderate to heavy storms, possibly all the way to the receiving waters (LDEQ, 1993).

According to Pitt (1991), in-stream receiving water investigations of urban runoff effects need a multi-tiered monitoring approach, including habitat evaluations, water- and sediment quality monitoring, flow monitoring, and biological investigations over long periods of time.

2.5. Mandates of the Federal Government in Nonpoint Source Pollution Control

The U.S. Environmental Protection Agency has established Stormwater Management Programs to remedy problems from nonpoint source pollution. Historically, stormwater management has primarily focused upon the control of flooding. The 1987 amendments to the Federal Clean Water Act, however, mandated that the role of stormwater management be expanded to include the protection of water quality.

The Act established two programs to assist states and municipalities in abatement of urban runoff water quality problems, Section 319 (Nonpoint Source Control) and 402

(Stormwater Permitting). The Stormwater Permitting and Nonpoint Source Programs are complementary efforts. For example, the Section 319 Assessment Report can be used to identify water bodies for which stormwater permits are needed to address documented water quality problems.

Section 319 of the Act, which is entitled Nonpoint Source Management Programs, requires each state to assess and remediate nonpoint source pollution. It instructed the governor of each state to prepare and submit a program for control and reduction of pollution from nonpoint sources into navigable waters within the state by implementation of a four-year management plan. The State Nonpoint Source Management Programs also were to ensure that local governments have or will have adequate legal authority to implement needed urban nonpoint source and sediment control programs; to provide technical assistance; and to begin development of state/local institutional arrangements and funding mechanisms (Davenport, 1990).

The State assessments have identified several categories of potential urban stormwater pollutants: suspended solids, nutrients, bacteria, oils/grease, toxic organics, and toxic inorganics (heavy metals). Critical pollutants have been identified by: (a) frequency of occurrence within the stormwater database; and (b) high concentrations relative to the USEPA water quality criteria (USEPA, 1991).

2.6. The Evolution of Nonpoint Source Pollution Assessment

The initial federal approach to the general nonpoint source pollution problem was contained in Section 208 of the Clean Water Act (1972), which left the actual control of nonpoint source pollution to the states. Under Section 208, the governor of each state was required to identify areas with substantial water quality problems and to designate planning agencies to address the nonpoint source pollution problem.

In response to the requirements of Section 208, more basic water quality evaluations were conducted by analyzing water quality samples. However, analyzing samples from various locations in a waterbody or in a watershed is expensive, labor-intensive, and time consuming. According to Joao and Walsh (1992) the alternative approach of "onsite monitoring can be difficult since nonpoint source pollution may be discharged into streams at thousands of dispersed points". In addition, long-term, on-site monitoring of nonpoint source pollutants "is expensive, disruptive to other land uses, and requires technical expertise and long periods of time which are often not available" (Hodge, Kaden, Westervelt, and Goran, 1986).

To make water quality evaluation less tedious and expensive, the Universal Soil Loss Equation (USLE) was used in the assessment of soil loss in agricultural areas. Although the USLE fits well into a planning model, there are a number of difficulties in applying the equation in general land use planning (USEPA, 1976). Williams (1972) modified the USLE in order to improve its application for predicting storm sediment yields. But, due to the limited application of the modified equations, only the USLE was introduced into the available computer packages in the 1970s.

Most of the initial water quality research was conducted to assess agricultural nonpoint source pollution. The predominant nonpoint source pollutant found in surface water is sediment. In addition to sediment, early research efforts also focused on nonpoint source pollution due to nutrients such as nitrogen and phosphorous which mostly come from agricultural practices. Research findings revealed that there are major causes of nonpoint source pollution other than agricultural, mainly from the development of land for urban use. Therefore, the need to assess water quality in urban areas was realized.

As a result, some hydrologic models which were used to calculate runoff volume were modified to evaluate runoff quality. Because of over extension for unintended purposes and many other reasons, however, most of the models have been misused (Pitt, 1991). For example, a common error associated with the rational method is not using the time of concentration as the critical rain intensity period. The rational method also has been overly extended in attempting to predict total storm runoff volumes or to produce runoff hydrographs in many urban runoff models.

Until the computer age, researchers had to rely on simple models which used simple mathematical equations to evaluate nonpoint source pollution. In most of those models, some spatial parameters were averaged (e.g., soil properties) in order to facilitate data handling. However, Huggins, Burney, Kundu, and Monke (1973) found that “lump” parameter models are less accurate compared to distributive models which include spatial variation in the inputs, parameters, and dependent variables.

The realization of new problems and subsequent inventions of new solutions were made with the use of new technology. With the advancement of computer size (to smaller size) and speed, researchers began to introduce and use various distributive models in quantifying nonpoint source pollutants. The technology shed light on environmental interactions which helped to reveal the holistic-nature (interrelation of everything to everything else) of the environment. It led to the development of better models which simulate natural processes more accurately.

The next chapter summarizes the more recent research conducted with the use of the evolved technology to control urban nonpoint source pollution and its consequences.

CHAPTER 3

PREVIOUS RESEARCH AND PAPERS ON STORMWATER RUNOFF

A comprehensive review of the studies conducted on urban runoff water quality from the start of the stormwater studies in the 1960s is provided by Pitt (1987). He concluded that those studies are "not well enough coordinated to give a complete picture of all the processes involved in urban runoff" (p. 3). He also lists other shortcomings associated with some studies as inexperience of model developers in field research, inapplicability of the studies to other locations, and publication of research results only in research reports which are not readily available or accepted.

Pitt (1987) also has provided a critical evaluation of the two modeling components, runoff volume and particulate washoff, and a comparison of observed test results with the procedures that are mostly used in available models. He includes information related to the estimation of runoff flows and the particulate washoff from impervious surfaces during small rains. He further states that the relative importance of the different source areas is a function of the area's characteristics, pollutant washoff potential, and the rainfall characteristics.

By looking at water pollution in a broader view, Niemczynowicz (1994) emphasizes as the solution to pollution the closing of the cycle of residuals that damage the environment and recovering the lost resources emitted from all human activities. For that, he suggests the use of tools such as legislation with education on all social levels, increased public awareness, competition rules of the market economy based on long-term profits, etc. He specifies that with the use of the above tools, recycling of water, nutrients, and solid residuals should be arranged on a lowest possible level of human settlements in order to develop sustainably.

Pratt (1995) presents a review of source control of urban stormwater runoff in the United Kingdom, stating that source control measures have been studied since the 1980s. His review is mainly focused on the stormwater management techniques located at or close to where rain falls. He further specifies that sustainable developments need to include source control techniques in catchment management strategies.

Makepeace (1995) presents a literature review to identify and quantify data concerning contaminants in stormwater. Work that presents specific chemical, physical, and biological parameters, rather than the traditionally used overall water quality parameters, is the focus of the review. To assess the outcome and quantify the importance of the reported concentrations, the contaminant data are compared with pertinent guidelines, regulations, and levels that have been reported to cause possible adverse effects.

3.1. Land Use and Water Quality

Numerous researchers such as Duckson (1989), Davis et al. (1979), Pitt and Baron (1989), Newport and Davenport (1988) have studied the variation of surface water quality in relation to upstream land use (urban versus non-urban, residential, commercial, and industrial). Although the first two authors have not clearly stated their final findings, Pitt and Baron (1989) have indicated that there are wide variations of loads coming from the traditional land use categories. Reese and Noel (1990) point out that the percent imperviousness of the land use has been linked by national and regional studies to the amount of pollution generated on an annual basis. It implies that development density is a key variable to consider when analyzing pollutant loading from general land use.

According to Gelber (1996), by understanding the need of land use planning for water quality protection, New York City is attempting to improve water quality through comprehensive watershed management planning. The two major elements of the New York watershed management plan are: (1) proposed promulgation of existing watershed discharge regulations into state law; and (2) land acquisition to buffer the city's water supply system and prevent overdevelopment in sensitive areas.

During Klein's (1979) study of 27 watersheds in Maryland, stream aquatic life problems were first identified with watersheds having impervious areas accounting for at least 12% of the watershed. Severe problems were noted after the imperviousness reached 30%.

Pitt (1987) revealed that residue washoff from an impervious area is significantly affected by residue loading, rain depth, and rain intensity. He also found that some development characteristics such as grass swales and connectivity of roofs have drastic effects on runoff volume and flow rate. Grass swales are capable of reducing runoff volumes by as much as 90% (Pitt, 1987, p.445).

The Nationwide Urban Runoff Program (NURP) found that significant differences in pollutant concentration, called event mean concentrations (ECCS), could not be detected among the three major urban categories--residential, commercial, and mixed-urban. However, since NURP data were collected for large areas, these data are not representative of smaller areas where more significant differences may exist (USEPA, 1983).

Ellis et al. (1984) have reported that the analysis of the effects of urban storm runoff on the South Platte River indicated that the stream's water quality can be improved by reducing the loads of total lead and total zinc in the storm runoff. Storm runoff was the major contributor of total suspended solids, total organic carbon, and total lead.

According to a study funded by the Storm and Combined Sewer Section of the USEPA, small storms are assumed to cause pollution mostly from directly connected impervious areas such as streets and parking lots. Large storms are thought to cause pollution from soils eroding from pervious areas. For the study, storms greater than 12 mm total are considered as large storms (Pitt and Bozeman, 1982). Pitt (1987) has emphasized the requirement of a simpler model for the analysis of the effects of small storms on urban impervious areas since water quality effects due to small storms are less recoverable compared to heavy storms.

In addition to the above studies, there are numerous studies that have been conducted on the stormwater runoff problem. Some of the state-of-the art work follows. Moffa et al. (1983) summarize the research conducted during the 1980s, and Delleur (1983) provides an overview of the research conducted in relation to urban hydrology during 1980s. A broader-based review of the scientific aspects of water resources management has been prepared by the National Research Council (1982). Daub et al. (1994) investigated the chemodynamics of organic micropollutants and heavy metals in snow-melt runoff from street and roof surfaces and found that there were no distinct differences in metals' concentrations between rain and snow melt runoff except for dissolved cadmium. Oberts (1994) described the mechanics of snow melt runoff and reviewed several studies to determine that soluble pollutants are preferentially leached or purged from snowpacks in the early stages of the melt.

3.2. Urban Versus Non-Urban Water Quality

A positive relationship between imperviousness and nonpoint source pollution loadings has been demonstrated/reported by many studies/reports such as Beaulac and Reckhow (1982), Griffin et al. (1980), Randall et al. (1981), Hartigan et al. (1983), the Northern Virginia Planning District Commission Guidebook (1979), and the Metropolitan Washington Council of Governments manual (1987). Compared to undeveloped land uses such as forest-land, annual runoff pollution (lbs./acre/yr.) from urban development is as much as 10 to 20 times greater in the case of nutrients and as much as 10 to 50 times greater in the case of toxicants such as heavy metals (Orange Water and Sewer Authority, 1988).

Field (1982) has summarized the findings of the USEPA Storm and Combined Sewer Program. One of the main implications of the EPA study is that a significant amount of priority pollutants is present in urban runoff. Novotny (1991) has also stated that the monitoring of urban soils between 1969 and 1979 demonstrated that urban soils have greater pesticide residue concentrations than agricultural soils. He says that the concentrations of mercury, cadmium, and lead also have been high in urban soils.

According to Field (1982), the non-urban section of Coyote Creek in San Jose, California supported a diverse population of fish and benthic macroinvertebrates as compared to the urbanized portion which was completely dominated by pollution tolerant algae, mosquito fish, and tubificid worms. According to USEPA (1980), the pollutant yields in the Coyote Creek affecting the urbanized stations are all substantially greater than the quantities affecting the non-urban stations. As an example, the total solids discharges affecting the creek in the urban areas are more than 100 times greater than total solids discharges affecting the non-urban areas. The lead discharges affecting the urban areas were also several thousand times greater than the lead discharges affecting the non-urban areas. The Newport and Davenport (1988) study on the Rouge Basin in Southeast Michigan also shows how urban stormwater has adversely affected water quality and impaired the achievement of designated water resource uses.

The USEPA NURP field studies of stormwater pollution discharges from 61 sites throughout the U.S. found 60% of the 129 priority pollutants in urban runoff. In addition to metals such as lead, zinc, cadmium, chromium, and copper, which were found in 50% to 95% of urban runoff samples, arsenic was found in 50% of the samples, and cyanide was found in 25%. Polycyclic aromatic hydrocarbons (PAH) such as chrysene and pyrene were found in 10% to 15% of the NURP runoff samples at levels which exceed criteria for protecting human health from carcinogenic effects (Orange Water and Sewer Authority, 1988).

Field (1982) also states that many studies have indicated that urban runoff may present a public health problem. A serious threat exists in areas where urban stormwater is discharged near a water supply intake. The Nationwide Urban Runoff Program (NURP), in which samples were collected from 78 sites in 28 cities located throughout the U.S., indicated that the concentration of metals in urban runoff exceeded USEPA's water quality criteria and drinking water standards. The principal contaminants of concern are heavy metals, a limited number of the organic priority pollutants, and coliform bacteria (Heaney, 1986).

Leopold (1968) states that the increase in influx of waste material as a result of urbanization increases the dissolved-solids content and decreases the dissolved-oxygen content. In addition to that, he provides evidence indicating an increase in water temperature in urbanized areas.

According to Andoh (1994), urban runoff can have adverse environmental impacts. Therefore, an integrated cost-effective approach is needed in implementing stormwater control measures and techniques within the framework of regulators, service providers, and the general public.

The literature review revealed only a few studies conducted on water quality consequences of urban versus non-urban areas after the 1980s.

3.3. Land Use Planning for Water Quality Improvements

Ideally a land use planning/water quality management methodology should consider improvement of water quality as well as economic and any other relevant social and physical feasibility factors. The pollutants that are evaluated should be the critical pollutants for the area under consideration. Limiting criteria can be a combination of: financial resources, availability of land for the implementation of the best management practices, technical feasibility, expertise of available personnel, characteristics of the area (such as slope, high water table, soil type, permeability, pollutants of concern), social needs, and legal requirements (state or federal mandates). The margin of error of the results may vary based on the appropriateness of the assumptions of the tools that have been used to the area under study. The ideal methods are also user friendly and fairly simple.

According to Rainis (1991), before the 1960s, most land use decisions were made based only on social acceptability and economic efficiency without much regard for environmental quality. That is, the limiting criteria were restricted to economic and social needs. After the 1960s, public concern for environmental quality improved bringing forth numerous pieces of legislation by federal, state, and local government(s) to protect land and water resources. Most of the legislation demanded that environmental factors should be taken into account in all planning processes and land use decision making.

Although, the analysis and mitigation of the impacts of water pollution is sometimes not considered as a part of land use planning, various researchers have responded, in many ways, in many parts of the country, to the Clean Water Act requirements, to make water quality planning an integral part of the land use decision making process.

Rainis (1991) has conducted a study linking land capability/suitability analysis with environmental models using Geographic Information Systems to determine preliminary land use alternatives to reduce environmental impacts, especially urban nonpoint water pollution. The main objective is to allocate future land uses to sites that are not only physically suitable but also environmentally acceptable. His iterative technique simulated the impacts of urban runoff from residential, commercial, and industrial land uses on biological oxygen demand and dissolved oxygen (DO) concentrations using the Soil Conservation Service runoff model and the Streeter-Phelphs DO model. The resulting water quality was compared to a set of preset standards for DO. If the standards were not met, a new tentative land use plan is developed in the next iteration, otherwise, the resulting land use plan became the preliminary plan.

Although Rainis's study was an important study because of its efforts to improve water quality at the planning stage, it has some shortcomings. It based the quality of water solely on the DO measures rather than considering the critical pollutants for the area. It calculated DO using the Soil Conservation Service runoff model, which has some problems as described earlier. It considered primary limiting factor as environmental protection rather than balancing environmental protection with economic and other critical factors. Most of all, his method is too complicated for ordinary land use planning.

Gallimore and Xian (1991) proposed a model (a modification of the Universal Soil Loss Equation) to help assess current and future soil loss based on land use, soil type, and topographic characteristics. Thum and others (1990) integrated the SLAMM and Land Information System (LIS) and compared sediment loadings to decide on the best land development scenario. Joao and Walsh (1992) used the Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS) model to compare pollution generation based on location and condition of urban land and the significance of forested buffers around development to alleviate nonpoint source pollution levels.

Although all three of the above studies were sophisticated in the sense that they used GIS (ARC/INFO) to generate and asses different future land use scenarios, they considered/calculated only soil and/or sediment loadings for the comparison. Many other studies, such as the Myakka River Basin Project, have integrated GIS and hydrologic models to estimate the relative contribution of runoff and chemical loading. However, they only considered pollutants such as organic carbon, phosphorous, nitrogen, and suspended solids. Yet, it is extremely important to evaluate the loadings of other pollutants such as heavy metals that are important to the area, since they usually pose a greater threat to the ecosystem.

Rather than taking into account all the limiting criteria, water quality improvement has been considered as the only limiting criteria. This type of integration of GIS and water quality models has a burden of needing technical facilities and expertise. Therefore, the process might not be applicable for areas (jurisdictions) with less technical advancement and expertise.

According to Robinson and Ragan (1993), the model developed by the Northern Virginia Planning District Commission approximates the mass per unit acre loading rates of six nonpoint source pollutants as a relationship between land use and soil type. Although the system allows the user to change land uses in subareas to simulate the consequences of additional development or alternative management strategies, study only concentrates on water quality improvement rather than balancing it with socioeconomic and limiting factors of the study/study area.

Kim and Ventura (1993) and Ventura and Kim (1993) used the Source Loading And Management Model to locate critically affected areas and develop mitigation strategies. They estimated the pollution loadings of six priority pollutants due primarily to land use. They used GIS to manage land use data for nonpoint source management modeling and to aggregate pollutant loadings within various types of geographic units (sub-sewersheds). Although these studies are very costly and need technical expertise, they give only "back-end" solutions for the nonpoint source pollution problem. They neither provide a solution at the planning stage nor do they balance the environmental quality with other constrains such as economic, social, technical, physical, and geological.

Rifai et al. (1993) developed strategies for managing the water quality of Galveston Bay, Texas, based on a GIS hydrologic model developed (by coding of the SCS Curve number method to a GIS) to calculate runoff from the drainage area. They have designed a companion water quality model which calculates the total load of a given water quality constituent entering the bay. However, as discussed earlier, the use of the SCS Curve Number method for calculating runoff under a typical (small) storm introduces some errors. Additionally, this methodology neither takes into account water quality at the planning stage, nor does it posses a flexibility to include other limiting criterions other than water quality.

Most of the above studies do not endeavor to reduce pollution due to stormwater runoff at the planning stage. The studies which considered water quality at the planning stage are not flexible enough to include other limiting criteria into the methodology or they are less user-friendly due to their complex nature (e.g., linking GIS and water quality models). Application of these methods elsewhere depends on the affordability of resources (such as funding, technical advancement, professional expertise, availability of land, etc.), legal requirements, social needs/acceptance, and geophysical condition of the jurisdiction. Most of the studies do not emphasize the need to analyze the pollutants which have been a problem for the study area. Most of all, none of the above studies intends to provide a methodology to be followed by others to improve water quality; rather they focus on solving an isolated problem. Therefore, none of them provides guidelines to follow. As a result, the applicability of such methods elsewhere is questionable.

CHAPTER 4

HYDROLOGIC MODELS

4.1. Definition

A hydrologic model can be defined as a mathematical representation of the flow of water and its constituents on some part of the land surface or subsurface environment. It can take the form of a simple mathematical equation or a complex series of equations with several conditions to be met.

Watershed hydrologic models can be classified as follows:

4.2. Objectives of Hydrologic Modeling

McKinley (1991) and Huber and Dickinson (1988) have discussed the objectives of hydrologic modeling as follows: to perform complex hydrologic calculations, characterize urban runoff, locate water quality problems, perform frequency analysis on quality parameters, provide input to receiving water analysis, determine effects, size, and combination of control options, determine the magnitude of pollutants, assess the benefits of best management practices, and provide input to cost/benefit analysis.

Hydrologic models are also being used to answer questions that are difficult to address through field measurements and observations. In the case of nonpoint source pollution modeling, models can be used to simulate the long-term or short-term behavior of runoff quality and to evaluate the impacts of land use changes in a watershed on receiving waters. Pitt (1987) believes that a model should not be developed solely to be more comprehensive (and therefore possibly more complex) than available models, but to do the job better.

4.3. Advantages

In spite of errors involved in modeling complex environmental systems such as nonpoint source pollution, a model as a planning tool cannot be replaced by any "rule-of-thumb" approach which some planners unfamiliar with models might suggest. The use of models is beneficial and greatly enhances the planning process for the following reasons (Novotny and Olem, 1994):

(1) Models can provide a forecast of the impact (although only approximate) of planned action on water quality and pollution loadings.

(2) Models provide an understanding of the processes involved in pollution generation from nonpoint sources.

(3) The data base necessary to construct and calibrate the model is useful for other planning activities. Many problems will be answered and become clearer just by evaluating the data and compiling them into an appropriate input format.

(4) Critical processes and areas of concern can be delineated and detected by modeling.

(5) Regulators require proof of water quality impact during conditions for which monitoring data may not be available, especially in cases when some action is in the planning stage and has not been implemented. Such impact can only be established by modeling.

(6) Models can be updated continuously according to the state-of-the-art of the modeling technology and understanding of the modeling processes.

(7) Models can generate numerous alternatives according to the specification of the users. Various strategies can be investigated, and the impact of remedial measures can be evaluated.

(8) Although the absolute accuracy of the output from the model is limited and sometimes even small, a comparison and ranking of outputs for various alternative remedial measures often are reliable and in most cases more than adequate.

(9) Models can estimate and analyze trade-offs between planning objectives. If the environmental objective is known, the alternatives to achieve it can be measured in terms of economic efficiency by considering the willingness of those involved in the measures to pay for the consequences. If there is a financial limit, it must be treated as a constraint.

(10) Water quality loading models are a required and integral part of the permit application for discharging urban and some agricultural runoff into receiving water bodies, as specified in the United States by the Clean Water Act.

Despite the limitations listed later, McKinley (1991) has emphasized the importance of using computer models in solving the problems related to stormwater runoff.

4.4. Limitations

Although models can be used to satisfy several objectives, "Models are imperfect representations of the physical system; our knowledge is incomplete and our models can be no better" (Nix, 1991). Nix further says that mathematical models have definite limitations. First, a computer model can extract information from a database, but it cannot overcome data inadequacies. Second, no model will produce completely accurate results because every model is incomplete and biased in its representation of systems. Third, numbers produced by a computer model are no more accurate than numbers produced by hand calculations, just faster (Nix, 1991).

In the use of hydrologic models for nonpoint source pollution simulation, it is very important to keep in mind that the underlying mathematical equations in these models are only a rough estimate of the "real world" systems. Although many hydrologic models represent the best available technology for the simulation of actual processes, each and every model has its own set of assumptions and limitations. Therefore, before beginning to use a model or set of models, it is very important to examine whether the particular model's/models' capabilities satisfy the objectives of the study. For example, the STORM cannot be used to simulate runoff quality from a single storm event or to evaluate BMPs or to predict heavy metals. The Source Loading And Management Model (SLAMM) evaluates runoff quality due to small storm events rather than large storm events, but it can be used to evaluate BMPs and heavy metal loadings. Neither the STORM nor the SLAMM can be used to simulate receiving water quality; they estimate loadings of pollutants at the source areas in the watershed and at the discharge outfall.

Pitt (1987), in his discussion of urban hydrologic models, has elaborated on the problems associated with some of the available models:

(1) The use of constant (and large) runoff coefficients to estimate runoff from impervious areas results in a large over-prediction of runoff from small events rather than large storm events.

(2) Lumped models (models that combine the drainage area characteristics into a few parameters, e.g., rational formula or Soil Conservation Service curve number method) are unable to evaluate the importance of individual source area contributions or the effectiveness of source area controls.

(3) The Soil Conservation Service curve number approach has other short-comings. It uses a fixed relationship between initial abstractions and total ultimate losses and uses the assumption of zero ultimate infiltration (instead of a small, but steady ultimate infiltration rate). Although drainage design studies are not affected by these shortcomings, the use of the approach for water quality studies investigating small storms may cause problems.

Additionally, every model should go through a verification and validation process to establish its credibility. That is, model components should be examined to see if they perform as expected and should be calibrated so that the model adequately simulates field data. Therefore, modelers face the problem of uncertainty about the extent of adequacy in model calibration and verification. One is well advised to calibrate and determine hydrology first, followed by sediment, and finally pollutant transport, in determining pollutant transport.

4.5. The Source Loading and Management Model (SLAMM)

In this study, the volume of stormwater runoff and the concentration and yield of each pollutant considered under each Case will be evaluated using the Source Loading and Management Model (Version 6.3) produced by Robert E. Pitt and John Voorhees.

The reasons for choosing the Source Loading and Management Model for the analysis are as follows.

The SLAMM is a simple model developed for stormwater management planners who might lack the technical expertise or knowledge of the research information that was used in the development of the model. The SLAMM has proved to be applicable to a large variety of impervious surfaces and rain characteristics. This model was found to produce smaller errors in runoff volume prediction compared to the SCS Curve Number Method or the Horton infiltration equation for storms of interest in water quality evaluations.

Pitt (1987) discussed and listed the advantages of simplified models compared to complex models in stormwater management planning. According to his discussion, errors occur when using complex models mostly due to misunderstanding the model algorithms, processes involved, or lack of understanding of the proper application of the model. Additionally, he suggests that the use of complex models can be more costly due to the need to collect and calibrate a large number of model parameters. Not only could cost be higher, McCuen (1986) found that, the results from complex models may have larger margin accumulative error due to the need to estimate many parameters.

4.5.1. Introduction

The Source Loading and Management Model (SLAMM) is an urban rainfall runoff water quality model. It is used to calculate runoff volumes and urban pollutant loadings from individual rain events. The SLAMM was developed to assist water and land resources planners in evaluating the effects of alternative control practices and development of characteristics on urban runoff quality and quantity. The SLAMM only evaluates runoff characteristics at the source areas in the watershed and at the discharge outfall; it does not directly evaluate receiving water responses.

The SLAMM continually develops mass balances for both particulate and dissolved pollutants and runoff flow volumes for different development and rain characteristics. It is designed to give relatively simple answers (pollutant mass discharges and control measure costs for a very large variety of potential conditions). It is therefore used as a planning tool, such as to generate information needed to make planning level decisions, while not generating superfluous information unnecessary for these planning decisions.

The SLAMM predicts urban runoff discharge parameters (total storm runoff flow volume, flow-weighted pollutant concentrations, and total storm pollutant yields) for many individual storms and for the study period. It does not predict these parameters for periods within individual storms. Stormwater management decisions are most appropriately based on long-term conditions and not on rapidly varying conditions. Water quality standards (especially for heavy metals and bacteria) may be violated during most rains at outfalls, but the durations of the violations are usually short and only occur for small percentages of the year (USEPA, 1983). However, for areas where rainfall is frequent (e.g., New Orleans), violation of water quality standards is frequent, leaving the receiving waters an insufficient time to recover from the pollutant load from the last storm.

4.5.2. General Assumptions

The SLAMM model is based on the following assumptions:

(1) Land development characteristics (background landscaping, rooftops directly connected to the drainage system, streets, drainage system type, etc.) are much more important than the distribution of soil types when determining the variable source area contributing pollutants and flows.

(2) The flow contributing source areas vary, but for many areas insignificant variations occur when the rain depth exceeded about 50 mm (2 inches).

(3) Significant long-term losses are likely to occur (mostly due to infiltration) even from impervious areas after initial losses are satisfied. However, in older areas that have been repaved several times (and are in good condition, without pavement

cracks) and for roofs, the major losses occur only due to initial losses.

(4) In order to identify the "breakpoint rainfall volume" at which the different urban surfaces contribute flows, a single second order polynomial curve is fitted for the basin rainfall and runoff data. However, it is safe to assume a straight-line relationship, for highly impervious areas and for small rains (25 to 50 mm) in pervious areas.

4.5.3. Structure

There are three modules--input, parameter, and calculation/output module--made up of a series of subprograms. The input module allows the user to create, edit, or print the SLAMM data files. The parameter module allows the user to create the parameter files (rain, pollutant delivery, runoff coefficient, and particulate residue) needed to run the SLAMM. The calculation/output module calculates the runoff volumes and particulate loadings for all source areas and at the outfall. This module also evaluates the effects of any control devices in the source areas and at the outfalls.

4.5.4. Algorithm

Runoff volumes are calculated by multiplying the rain depths by varying runoff coefficients. The resulting source area runoff volumes are then multiplied by particulate residue concentrations to get particulate residue loadings for each source area.

Runoff volume = constant*(rain depth * runoff coefficient* source area) where, Runoff coefficient ~ f(rain depth, land use/source area type)

Particulate residue loading = correction factor*(runoff volume* particulate residue)

where, particulate residue ~ f(runoff depth, land use/source area)

Note: Particulate pollutants are related to the particulate residue loadings in kilograms, while filterable pollutants are related to the runoff volume in liters.

4.5.5. Control Devices (Extracted from the SLAMM User's Manual).

The control devices which are considered for this research are:

Wet detention ponds

Porous pavements

Infiltration devices

Street cleaning

Catch basin cleaning

Grass swales

The design of **wet pond** includes an outlet device description and a stage-area curve describing the incremental pond volume. The algorithm is based on the storage-indication reservoir routing subroutine in HEC-1 and in TR-20 and is summarized by McCuen (1982). A complete description of the process is in the Manual of Practice for Wet Detention Ponds (Pitt, 1987).

The **Porous Pavement** flow volume reductions are based solely on the infiltration rate through the pavement times the duration of the event. The algorithm calculates the fraction of the total rain which is infiltrated into the ground by the pavement.

Infiltration device flow volume reductions are due to infiltration from both bottom and sides of an infiltration device. The amount of infiltration is a function of the device area and the runoff volume and duration.

Street cleaning is applied by setting street cleaning frequencies and durations in the input module for each street source area. The subroutine assumes that two possible street events occur over time, street cleaning and washoff. Street dirt accumulates during the time between each event.

The **catchbasin cleaning** device right before the outfall removes particulate loadings from the runoff. The size of the basin and the cleaning dates need to be entered. The device removes solids from the given source areas until it is full. At that point no more solids are removed by the device until it is cleaned.

Grass swales reduce runoff through infiltration. The reduction is a function of the dynamic percolation rate, the duration of rain, the runoff volume entering the swale, and the area of the swale.

In the SLAMM, infiltration devices and detention basins can be located to control either source area runoff (e.g., roofs, parking lots) or at the outfalls to control runoff from all areas. Porous pavements can only be located at paved playgrounds, parking or storage areas. Street cleaning is restricted to streets and catchbasin cleaning and grass swales are restricted to the drainage system. The SLAMM also allows the use of a general "other" control category, where it is necessary to specify a constant control level for flows, filterable, and particulate pollutants (Pitt, 1991).

CHAPTER 5

POSSIBLE MEANS OF IMPROVING RUNOFF QUALITY

It has long been recognized that the best way to control urban stormwater related pollution is through the use of source controls (USEPA, 1983). There are three general classifications of urban stormwater management practice: permit, structural, and nonstructural. The permit process is generally used for large urban or concentrated rural sources of pollutants where it can be determined that water is degraded by stormwater flows from these areas. Structural management practices (such as retention ponds) involve altering hydrologic conditions by changing the flow transport system. The nonstructural classification (such as zoning ordinances) includes management measures that improve water quality without structural changes. A manual covering the basics of stormwater management such as characterization, control, and regulations was authored by Arnold et al. (1993). Current water quality best management practices design guidance (Dunn et al., 1995) covers the water quality benefits of BMPs in treating urban runoff. Schueler et al. (1992) provide an assessment of urban best management practices and techniques for reducing nonpoint source pollution in the coastal zone (See Appendix B). USEPA (1993) provides guidance on specifying management measures for sources of nonpoint pollution in coastal waters.

It is important to note that some of these practices, especially those that mitigate the problem by increased infiltration, could potentially affect groundwater in the area. This must be considered in the evaluation of stormwater control alternatives. Site-specific characteristics determine which best management practices are most suitable. The key factors that influence appropriateness include drainage area served, soil permeability, local acceptance, maintenance requirements, and other restricting factors (WCC, 1990), (Schueler, 1987), (MPCA, 1989).

5.1. Increase the Amount of Infiltration

As described in Section 2.2, in addition to producing greater per acre loadings of stormwater pollution, impervious areas are the most likely contributing areas for toxic contaminants found in urban runoff (Orange Water and Sewer Authority, 1988). Therefore, the possibility of improving stormwater runoff quality by introducing the following control measures to increase infiltration will be analyzed.

Infiltration mechanisms such as infiltration devices (subsurface infiltration trenches, surface percolation areas), porous pavements and grass swales. Though they have disadvantages, these minimize the directly connected imperviousness often present in urban areas. Grass swale drainage can be used in place of concrete curb and gutter drainage, except in strip commercial and high density areas. The infiltration structures can be designed to lower the flow rate by encouraging the settling out of pollutants in the runoff. The result is significantly lower runoff velocity and reduction of impurities.

Schueler et al. (1992) provide a complete description of Best Management Practices (BMPs) and a thorough list of references on pollutant removal capability. A description of available vegetative treatment systems for paved surface runoff, along with their value, role, and appropriate uses, is presented by Startin et al. (1994). Additionally, USEPA (1993) provides a good guide for advantages/disadvantages, removal efficiency, and cost information of BMPs.

It is often not possible to infiltrate all the runoff or pollutants into the ground using infiltration mechanisms. The rate of infiltration and the infiltration capacity depend on the level of groundwater below, the porosity of the soil, the suspended solids load in the stormwater, and the density of vegetation on the surface (Urbonas and Stahre, 1993). Soil type at the site is usually classified according to the American Association of State Highway and Transportation Officials (AASHTO) soil classification system.

In sufficient infiltration rates due to high ground water table and/or fine soil will result in standing water. For such conditions, it is necessary to install subdrains. In some cases the infiltration rates can be increased with the use of healthy vegetation. With time, infiltration capacity of the device diminishes due to the accumulation of materials. Therefore, infiltration facilities should be cleaned regularly based on their design capacity and the rate of accumulation.

Infiltration practices are not recommended in sites containing underground storage tanks, gasoline stations, chemical storage and chemically contaminated land areas (Urbonas, 1994). According to Marsalek and Sztruhar (1994), there are two major uncertainties in designing infiltration devices: determination of design infiltration parameters; and determination of operational lifetime.

5.2. Street Cleaning and Catchbasin Cleaning

Since streets are assumed to contribute most of the urban runoff flows and pollutants, acquisition area is assumed to be a potentially effective practice. Although some of the streets cleaning studies were unable to confirm the positive effect of the control measure, studies conducted in more arid locations have shown that the process is capable of reducing heavy metals (Pitt, 1991). Additionally, street cleaning can be used to improve the aesthetics and the safety of streets.

For high loadings, it may be best to first clean with a mechanical street cleaner to remove the large particles, followed by a regenerative-air street cleaner to remove the finer particles. Pitt (1991) provides information on removal efficiencies produced by various street cleaning studies.

Studies have shown that the cleaning of catchbasins twice a year would allow the catchbasins to capture particulates for most rains. The sediment accumulation in catchbasins diminishes after it is 60% full. The catchbasin cleaning operations should be scheduled and carried out before they exceed their sediment removal capacity. The sediment in the catchbasins was found to be the largest particles that were washed from the street (Pitt, 1991).

5.3. Use of Detention/Retention Facilities

Instead of abandoning wet ponds as a nuisance, they can be used to increase property values by designing them to be an attractive and aesthetically pleasing park or wildlife habitat. In this way, they will also receive the proper maintenance they need. There are two types of detention facilities: detention ponds which hold water only during a storm event and retention ponds which have a permanent pool of water. The EPA has reported that the latter type is more effective in controlling pollutants than the former (Urbonas and Stahre, 1993).

The removal of stormwater pollutants is achieved by encouraging a number of physical, chemical, and biological processes to occur in the wet pond. Particles are removed by gravity settling. Flocculation occurs when heavier particles combine with smaller particles to form heavier particles. Biological removal occurs when aquatic plants, phytoplankton, and micro-organisms uptake and metabolize the dissolved pollutants (The Urban Water Resources Research Council of ASCE and WEF, 1992).

Urbonas (1994) states that the processes taking place in the retention pond are sedimentation, flocculation, agglomeration, ion exchange, adsorption, biological uptake and remobilization, solution, and physical resuspension of particles. He further states that marsh plants around the perimeter aid in removing nutrients and trap small sediment, while in the main body of the pond pollutants are removed by settling and uptake by phytoplankton.

National Urban Runoff Program studies reveal that detention basins can be quite effective in controlling urban runoff, especially the suspended portion of the contaminants (USEPA, 1983). To assess the extent that the stormwater ponds reduce pollutant delivery to receiving waters, monitoring techniques should include analysis of water, sediment, and pollutant mass balances and identification of sources, sinks, and transport transformation processes (Watt and Marsalek, 1994)

Roesner and Aldrich (1991) state that water quality control basins employ a significantly different storage strategy than peak flow control ponds and should serve relatively large (typically over 50 acres) areas. An important distinction is that while the peak runoff rate is the key parameter for flood control, the runoff volume is significant for water quality control.

Specific design guidelines need to be followed in the design and construction of ponds to insure the expected performance and safety. The guidelines usually specify side slopes, pond depth, shape, minimum length, and vegetation (Pitt, 1991). The factors affecting optimal sizing and determination of optimal size of detention basins are described by Urbonas, et. al. (1996).

The best management practices used to control pollution due to stormwater runoff should be implemented in a comprehensive manner, i.e., as a system not separately. This increases the overall effectiveness. The selection and categorization of Water Quality Control Measures should be based on, stormwater management goals, design, construction, inspections, and maintenance requirements of stormwater management facilities, suitability of the site for application of Water Quality Control Measures, and more importantly, available funding.

CHAPTER 6

PURPOSE AND PROCEDURE

The purpose of this research is to develop a land use planning methodology to be followed by planners and/or decision makers to achieve and maintain desired stormwater runoff quality goals for large redevelopment projects.

6.1. Goals

The goals that guided the development of the methodology are as follows:

(1) Reduce additional urban nonpoint source pollution due to redevelopment.

(2) Include water quality as a factor in the planning process.

(3) Present a parallel but more practical approach than the watershed approach.

(4) Confirm that applying this methodology at the planning stage is more cost effective than retrofitting the area later.

(5) Enhance the quality of receiving waterbodies.

(6) Meet NPDES stormwater permit requirements.

6.2. Objectives

In addition, the study sought to accomplish the following specific objectives:

(1) Confirm the need to include water quality protection as a factor in the planning process.

(2) Present a systematic methodology to include water quality in redevelopment planning.

(3) Demonstrate how to select the combination of the most suitable best management

practices for the particular situation at hand to meet water quality goals.

(4) Verify the importance of minimization of directly connected impervious areas.

(5) Analyze the importance of locating runoff quality control measures at source areas.

(6) Examine the significance of drainage and outfall controls on mitigating runoff pollution.

(7) Provide an idea of the amount of local tax payer money that can be saved by employing this methodology as a planning tool.

6.3. Methodology

6.3.1. Introduction

The whole purpose of the methodology is to achieve and maintain less polluted runoff in the most economical and feasible way in large-scale redevelopment by setting up groups of Water Quality Management Measures in the form of Control Options, enforcing regulations related to nonpoint source control, and continuing "good housekeeping" practices.

To accomplish that,

(1) The desired water quality goals need to be established.

(2) The post redevelopment stormwater runoff quality of each alternative site plan, without employing any water quality controls, needs to be predicted.

(3) If and when the predicted water quality exceeds the expected water quality, then Water Quality Management Measures need to be included in the redevelopment plans to achieve the desired concentration values.

(4) The redevelopment alternative site plan with the least total annual cost after including cost of construction and maintenance of water quality Control Options is selected to be implemented in the redevelopment area.

(5) To maintain the better water quality that can be achieved after the employment of Control Options laws/regulations and ordinances for the betterment of runoff quality should be enforced and the continuation and improvement of “good housekeeping” practices should be undertaken.

(6) Inputs from the public, stakeholders, and pollution monitoring studies should be taken into account to mitigate problems and to improve collaboration.

As can be seen, the methodology can be applied with the use of a water quality model for a desired area. The model and area do not have to be the SLAMM model and the Kenner area used in this dissertation. Following is a general description of the step by step procedure of the methodology. Users should to go through the case study to get a better understanding of the whole process.

The first step is to delineate the boundaries of the area concerned. See Figure 1 and the following full-blown methodology. The desired stormwater runoff quality goals, based on the social and legal requirements, need to be established at step two of the methodology. Step three is optional. If stormwater runoff quality goals are to be set based on the predevelopment (existing) stormwater runoff quality, then water quality samples from the existing area must be collected or data needed to run the water quality model must be gathered to evaluate the existing water quality. Steps one through three can be carried out without regard to the type of redevelopment alternative(s).

In step four, the data related to redevelopment alternatives are gathered and analyzed for runoff quality with the use of a water quality model. The fifth step is to select the most suitable redevelopment alternative(s) which will be enhanced to reduce urban nonpoint source pollution. Table 1 shows the criteria for choosing alternatives to be evaluated. The runoff quality estimated under step four is used along with the comparative socio-economic redevelopment cost to select alternatives for further improvement. Alternatives that are both environmentally and economically unsound are disregarded at this stage. See Table 1.

Table 1. The process of choosing alternative(s) to be evaluated in the rest of the methodology. (A and B represent any two alternative site plan out of all the alternatives being proposed for the future development.)

Situation #	Comparative Net Socio-Economic Cost	Comparative Stormwater Runoff Quality[1]	Selected Alternative(s)
1.	A not significantly different from B	A not significantly different from B	A and B
2.	A not significantly different from B	A > B	A
3.	A not significantly different from B	B > A	B
4.	A < B	A not significantly different from B	A
5.	A > B	A not significantly different from B	B
6.	A > B	A > B	A and B
7.	A < B	A < B	A and B
8.	A > B	A < B	B
9.	A < B	A > B	A

Source: Author Net cost = Cost - Benefit

1. Water quality goals are used in Table 1. When there is a relative difference among the importance of pollutants, a hazard or pollution index could be used for assigning weights to the pollutants.

Note: The worst case scenario is considered when evaluating pollutant concentration.

If there are more than two alternatives proposed for the redevelopment, the same logic can be followed choosing two alternatives at a time and continuing until finally only one or two alternative(s) remain. For situation #1, the net socio-economic cost as well as the water quality results of the preliminary analysis of the alternatives A and B are not significantly different. Then, the proposed methodology should be applied to both alternatives to estimate the final redevelopment cost, i.e., total annual cost including the cost of achieving runoff quality goals. Similarly, for situation # 2, if the net cost of A is not significantly different from B and alternative A results in a better water quality than alternative B, then only alternative A is selected to be followed in the rest of the methodology, and so on.

It may be evident from the runoff quality of the future land use alternative plans that there is a gap between the stormwater runoff quality goals and the potential stormwater runoff quality after the redevelopment. To reduce the pollutant concentration and to achieve the desired goals, several water quality Control Options have been set up in the methodology (altogether there are six Control Options). The Control Options are organized so that the higher the number, the higher the cost. This is because the options with higher numbers require more space, technical and field experience, site evaluation, design, construction, and maintenance.

Control Option 1 : Case I or Case II
Control Option 2 : Case I + Case II
Control Option 3 : Case III
Control Option 4 : Case I + Case III
Control Option 5 : Case II + Case III
Control Option 6 : Case I + Case II + Case III

That is, each Control Option consists of **one** or **several Cases**. Similarly, each Case consists of one or more combination of Water Quality Management Measures such as street cleaning, porous pavements, wet ponds, etc. Examples of possible Cases are listed under step six of the full-blown methodology. Figure 2 displays the relationship of Control Options, Cases, and Water Quality Management Measures that can be applied to improve the water quality of each land use plan or site plan.

The Water Quality Management Measures for each Case can be selected based on the suitability to the location/site, land owner and public acceptance, type of pollutants to be controlled, the amount of pollution reduction required (removal effectiveness), availability and the extent of land requirement, operation and maintenance needs, availability and extent of technical facilities/expertise, the affordability of the measures, and the goal(s) of the study.

The sixth step of the methodology is to categorize appropriate Water Quality Management Measures under different "Cases." In the proposed methodology, some (examples) of the appropriate Water Quality Management Measures are listed. The Cases are also organized in ascending order of cost (see Table 2). That is, pollution controls listed under Case I need no additional space, no major site inspection, less design, less construction, and less maintenance burden. Therefore, the total cost is less. The pollution controls listed under Case II need moderate space, moderate site inspection, moderate design, moderate construction, moderate maintenance, and moderate expense. Case III needs more space, more site inspection, greater design, more construction, greater maintenance, and higher expense.

Table 2. Cases are organized in ascending order of total cost

Parameter Needed	Case I	Case II	Case III
Space	none or less	moderate	high
Site inspection (technical)	none or minimal	moderate	high
Design and experience	none	moderate	high
Construction and maintenance	less	moderate	high
Total cost	less	moderate	high

Source: Author

The analysis of Water Quality Management Measures and Control Options is conducted under steps seven and eight of the methodology, respectively. See Figure 3. At step seven the pollutant concentration under all the selected Water Quality Management Measures is evaluated. At step eight stormwater runoff quality under Case I of Control Option one is first compared with desired stormwater runoff quality goals. If the desired stormwater runoff quality goals are not met, Case II of Control Option one needs to be considered as the next alternative. If stormwater runoff quality goals are met, it is possible to proceed to step nine. If the results of Case II are also unsatisfactory, Control Option two is the next choice, and so on. The steps six through eight are described in more detail in Section 6.3.3.

In step nine, the total average annual costs of the Control Options which enable the reduction of pollutant concentration to the desired level are evaluated and the most suitable option is identified. If the desired runoff concentrations are not achieved even after the sixth Control Option, then other* (see Figure 3) means of achieving the unmet stormwater runoff quality goals need to be implemented. Here are some examples of other* means:

(a) Placing a greater emphasis on the pollutants of concern in implementing and enforcing water quality related regulations.

(b) Chemically treating runoff from problematic areas.

(c) Investigating possible contributing sources and taking action to avoid continuation of the contribution.

(d) Based on the type of pollutants and the already employed management measures, the possibility of removing additional amounts of pollutants can be improved; e.g., if the problem pollutant is a nutrient and one of the management measures is a wet pond, then growing of nutrient uptaking plants at the banks of the wet pond may be able to reduce an additional amount of nutrients, etc.

(e) Changing land use or other aspects of the design of the redevelopment, such as amount of impervious surface.

The appropriate land use alternative plan which incurs the least cost including the total cost of Control Options is selected at step ten. In order to make sure that the selected site plan does not cost any more than the implementation of the discarded site plans, the user should return to step five at this point before proceeding to step eleven. Steps eleven and twelve are included in the methodology in order to minimize future problems due to urban nonpoint source pollution and maintain the desired water quality using state-level water quality regulation. Step eleven outlines a possible list of pollutant-contributing sources to be regulated. Step twelve provides an example list of "encouragements" towards water quality enhancement. Especially, it is important to have a partnership between the local government and educational institutions. As part of the partnership between the local government and the schools, high school students can participate in local government programs such as, recycling, educating the public, and data gathering and revising, etc. In this way a basic understanding of the factors affecting water pollution and a sense of responsibility for the community and the environment can be conveyed. Another advantage is that the cost of data gathering, citizen complaints monitoring, and revising plans can be reduced. Steps thirteen through eighteen of the methodology deal with getting the public involved, implementation, and monitoring. After receiving inputs from the public, all the stakeholders, and from the monitoring studies (steps thirteen through eighteen), stormwater runoff quality goals can be reset appropriately at step nineteen. Step twenty deals with revising and updating the selected alternative plan by following the already explained methodology.

6.3.2. <u>Summary of the Proposed Methodology</u> (see Figures 1 and 3).

Delineate the boundaries of the study area	STEP (1)
Define the water quality goals to be achieved	STEP (2)
Evaluate the existing stormwater runoff quality	STEP (3) OPTIONAL
Inventory and evaluate the redevelopment conditions of the alternative(s)	STEP (4)
Select the redevelopment alternative(s) for use in the rest of the methodology	STEP (5)
Categorize appropriate water quality management measures for each "Case"	STEP (6)
Select management measures that are appropriate for the site	STEP (7)
Evaluate the performance of the water quality Control Options	STEP (8)
Evaluate the total annual costs and identify the optimal Control Option	STEP (9)
Select the optimal land use alternative which incur the least overall cost	STEP (10)
Formulate, improve, include, and implement policies and legislation	STEPS (11)- (15)
Pursue, monitor, and solve unanticipated problems	STEPS (16)- (18)
Reset stormwater runoff quality goals	STEP (19)
Revise and update the plan	STEP (20)

6.3.3. The Step by Step Procedure of the Methodology

See also the flow-charts (Figures 1 and 3).

(1) Delineate the boundaries of the area to be redeveloped.

(2) Define stormwater runoff quality goals to be achieved after the redevelopment. Existing stormwater runoff quality or runoff quality based on social and/or regulatory requirements and economic feasibility can be selected.

(3) OPTIONAL: required only if water quality goals are based on the existing runoff quality. Review and compile the existing characteristics as well as the field conditions of the area concerned. The factors affecting water pollution (rainfall, vegetation, soil type, topography, and man's alteration of physical features) were documented earlier in Chapter 2. Everything related to the factors affecting water pollution is compiled.

Characteristics to look for:

- Rainfall (duration, total precipitation, intensity, frequency, and number of antecedent dry days)
- Land uses (type, size, and density)
- Existing building characteristics such as roof type; roof drainage connected to impervious areas or pervious areas; setback from streets; maintenance of buildings; existence, type (pervious and impervious), texture, and sizes of parking areas and driveways.
- Size, storage, capacity, and age of existing ditches, swales, storm sewers, detention ponds, and retention areas.

- Soil type(s), depth to bed-rock and water table, slope, adjacent land uses.
- Slope of the land
- Connectedness of impervious areas
- Sediment or any other dirt loading source near-by
- Drainage type(s)

    (a) Grass swales

    (b) Undeveloped road sides

    (c) Curb and gutter, valleys or sealed swales.

- Amount of fertilizer, pesticides, and animal excretions added to the landscaped areas.
- Ways of disposing motor oil, toxic chemicals, paints, car-wash water, household cleaners, antifreeze, etc.
- Widths, texture, lengths, slope, and conditions of existing roads, highways and sidewalks
- Traffic speed and density
- Illicit discharges (characteristics, frequency, timing, and seasonality)
- citizen complaints

If information on any of the above is not available or costly to gather, proxy measures can be obtained from published literature and/or by reviewing and appropriately modifying earlier studies conducted on the area.

(4) Inventory future redevelopment conditions and evaluate the runoff quality of the land use alternative(s) selected based on socio-economic conditions.

- Land uses (type, size, and density)
- Building characteristics such as roof type; roof drainage connected to impervious areas or pervious areas; setback from streets; maintenance of buildings; and existence, type (pervious and impervious), texture, and sizes of parking areas and driveways
- Size, storage, and capacity of future ditches, swales, storm sewers, detention ponds and retention areas
- Connectedness of impervious areas
- Potential sediment or any other dirt loading source in the area
- Future drainage type(s)
- Estimate of the amount of fertilizer, pesticides, and animal excretions that will be added to the landscaped areas
- Widths, texture, lengths, slope, and conditions of future roads, highways and sidewalks
- Future traffic speed and density

(5) Select the final alternatives (one or two), based on socio-economic net cost and the

evaluated runoff quality (using a water quality model), based on Table 1. Only the alternative(s) chosen at this stage need(s) to be improved for water quality enhancement by following the rest of the methodology.

(6) Categorize the Water Quality Management Measures to be implemented in the redeveloped area to achieve the desired stormwater runoff quality goals. An example categorization is shown below.

Case I

(a) Disconnect roofs

(b) Disconnect impervious areas

(c) Street Cleaning

(d) Catchbasin cleaning

Case II

(e) Porous pavements

(f) Impose grass-swale as a drainage control

Case III

(g) Infiltration device at the outfall

(h) Wet detention pond at the outfall

(7) Select appropriate Water Quality Management Measure(s) for each Case based on the results of the preliminary analysis (removal capability) and the site investigation on soil type, depth to water table and bed rock, adjacent land uses (suitability to the site), land owner and public acceptance, type and the amount of pollutants to be removed, availability and extent of

the land required, affordability, operation, and maintenance needs of the Water Quality Management Measures, and availability/affordability of technical capability and expertise.

(8) Analyze the performance/suitability of water quality Control Options in the area to be redeveloped with the use of a model or combination of models.

(9) Identify the optimal water quality Control Option(s) which facilitate the meeting of future redevelopment runoff quality goals and evaluate the annual cost of implementation of the Control Option(s).

(10) Select the land use alternative with the least overall annual cost as the final land use redevelopment plan.

(11) Modify the selected alternative plan to regulate:

- the disposal of motor oil, toxic chemicals, paints, car-wash water, household cleaners, antifreeze, etc.
- illicit discharges based on their characteristics, frequency, timing, and seasonality
- the pollutant sources contributing to citizen complaints
- the amount of imperviousness, especially directly connected areas
- redevelopments in areas where land disturbing activities or pollutant loading from subsequent development would severely impact water quality
- sediment transport from construction and mining sites

- any other way(s) of contacting pollutant with precipitation and runoff

(12) Encourage:

- consensus and cooperation among all the parties involved
- coordination among stakeholders
- programs such as land acquisition to protect environmentally sensitive areas such as riparian areas, wetlands, and vegetative buffer
- public education on proper use and disposal of household pollutants such as paints, solvents, motor oils, pesticides, herbicides, fertilizers, antifreeze, other household chemicals, etc.
- recycling (e.g., motor oil, paint) and programs to encourage proper disposal
- site disturbance control programs
- public complaints and volunteer participation for providing information and data gathering (can get the help of high school students in educating public and gathering some simple data as part of partnership between schools and the local government)
- the use of stream side buffers, landscaped areas, etc.
- enforcement of other environmental laws and regulations, such as Clean Air Act (CAA), Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Comprehensive Environmental Response Act (CERCLA), Resource Conservation and Recovery Act (RCRA), Federal Insecticide, Fungicide, & Rodenticide Act (FIFRA), Toxic Substance Control Act (TSCA), Hazardous Material Transportation Act (HMTA), and Federal Hazardous Substances Act (FHSA).

(13) Distribute the draft plan for review and comment to the all parties concerned (for example, prospective developers, city planning commission, stormwater runoff quality division, drainage department, contractors, etc.).

(14) Hold public hearings to inform the public about the redevelopment and receive input. Conduct feasibility studies (environmental and geological) for Control Options.

(15) Revise the plan with the use of inputs from all the stakeholders and the results of the feasibility studies.

(16) Pursue the plan with diligence.

(17) Monitor the quality of receiving waters for waterbody use impairment, determining timing, frequency, and seasonality. For example, if the designated water use is recreational, determine what time, how often, and what is the pattern of impairment whichever is applicable and researchable.

(18) Regularly evaluate the effectiveness and performance of water quality control practices and the success of the plan.

(19) Reset the stormwater runoff quality goals to match with the latest technology and the results of the evaluation (inputs from the public, stakeholders, and the monitoring studies, etc.).

(20) Revise the plan to achieve the newly established or revised water quality goals by following the proposed methodology which is outlined in the Figure 1 (at this time follow only steps three through ten).

CHAPTER 7

CASE STUDY

7.1. Introduction

The case study area considered for this research is the noise-impacted area (referred to in this study as the *acquisition area*) surrounding New Orleans International (Moisant) Airport. As shown in Figure 4, the airport is located south of Lake Pontchartrain, in Jefferson Parish.

Figure 4. The location of the New Orleans International Airport, LA.

Source: g.c.r. & associates, Inc. (1995).

The airport is situated in the city of Kenner which is bounded by Lake Pontchartrain to the north, St. Charles/Jefferson Parish boundaries to the west, Mississippi River to the south, and Metairie line to the east (see Figure 5). It is located at an elevation of 1 foot above Mean Sea Level and is below the water levels of both the Mississippi River and Lake Pontchartrain.

The airport site is drained by a series of canals and major ditches that drain the airport and the southern portion of Kenner. The stormwater runoff from southern Kenner is collected by Duncan Ditch, Bellegrove Ditch, and Butler Ditch which travel north across Airline Highway into Duncan Canal, Airport Ditch, and Canal No. 17, respectively. The Airport is bounded by Duncan Canal to the east, Canal No. 17 to the west, Airport Ditch to the South, and Canal No. 14 to the north. The canals are pumped into Lake Pontchartrain by Duncan pumping station (No. 4) and a pumping station at the boarder of St. Charles Parish/Jefferson Parish.

7.2. Acquisition Area

7.2.1. Introduction and Location

Noise in the area surrounding the airport is measured in LDN (Level Day/Night) decibels, which represent the average annual noise exposure for a given location. Federal Aviation Administration (FAA) noise abatement programs involve soundproofing of homes between the LDN 65 and LDN 75 sound contours and relocating residents in a LDN 75 contour or higher (see Figure 6).

Commercial and Industrial uses are not being considered for noise abatement.

Residences that are acquired by the New Orleans Aviation Board will be demolished and the land will put into uses consistent with the Federal Aviation Administration guidelines (CUPA, 1992). Aviation Planning Associates, Inc. has prepared a development, marketing, and implementation plan for the New Orleans International Airport's *acquisition area*. The purpose of the plan is to redevelop the area to achieve long-term land use compatibility of the acquired properties, while enhancing development opportunities for local and regional economies.

The *acquisition area* is divided into seven priority areas (P1 through P7). Figure 7 also shows the land use prior to the redevelopment in the general study area. The **areas** of the redevelopment land use alternatives, Concept A and Concept B, are shown in Table 3.

Table 3. Land use types and amounts (in acres) under each concept plan.

Land Use	Concept	P 1&5	P 2&3	P 4&6	P7	Total
Existing Commercial	A B	14 6	19 19	61 44	8 10	102 79
Existing Kenner	A B	0 0	0 0	38 38	0 0	38 38
Distribution/ Warehouse	A B	46 46	0 0	40 38	16 14	102 98
Service Center	A B	40 0	0 0	25 18	0 0	65 18
Office/ Mixed Use	A B	24 17	8 8	21 18	0 0	53 43
Retail	A B	5 5	11 11	0 0	0 0	16 16
Transportation/ open space	A B	101 156	17 17	158 187	11 11	287 371
TOTAL	A/B	230	55	343	35	663

Source: Aviation Planning Associates, Inc. (1993).

For the entire *acquisition area*, a total of 56 parcels are recommended for redevelopment. The categorization of these 56 parcels by land use/development type is as follows:

Distribution/Warehousing	12 (parcels)
Service Center	17 (parcels)
Office/Mixed Use	23 (parcels)
Retail	1 (parcel)
Hotel	1 (parcel)
Transportation	1 (parcel)
City of Kenner	1 (parcel)

Total number of parcels	56

7.2.2. <u>Alternative Redevelopment Plans for the Area</u>

Three redevelopment alternatives have been considered for the redevelopment of the *acquisition area*: Do Nothing approach, Concept A, and Concept B. The Do Nothing alternative is rejected due to the following reasons (page 8-3, Aviation Planning Associates, Inc., 1993):

If Do Nothing alternative is implemented,

- the airport would be responsible for maintaining a large, non-contiguous area of vacant land.
- without businesses or residences to contribute to the local tax base the city could lose

significant tax revenue.

- non-contiguous sites of existing commercial/industrial and existing city of Kenner land uses surrounded by vast areas of vacant land could negatively impact the commercial environment of South Kenner.
- although the existing infrastructure may not need to be upgraded, sufficient revenue to cover the cost of normal maintenance to these facilities might not be readily available to the city.

According to Aviation Planning Associates, Inc. (1993), the Do Nothing alternative is not considered as the most prudent scenario nor in the best interest of the city of Kenner and its business community.

The remaining two redevelopment alternatives (Concept A and Concept B) were prepared to satisfy the following two criteria: (1) avoid penetrating the safety areas surrounding the runways; and (2) make certain redevelopment is compatible with the noise associated with the airport operations.

The principal difference between Concept A and Concept B involves the transportation scenarios. Concept A proposes the maximum reuse of the existing roadway infrastructure and street pattern. Concept B proposes the long-term, full development of the regional transportation plans to improve the highway access system. Concept A provides the basis for a 10 to 20 year plan to meet the city of Kenner's needs for revenue-producing developments. Concept B takes up where Concept A leaves off and introduces the future, long range transportation plans that further consolidate the local street pattern and combines block and parcels to permit larger scale development.

In the alternative evaluation study (Aviation Planning Associates, Inc., 1995), in addition to the redevelopment costs and revenue potential, the following elements have also been considered:

Traffic Impacts

Public Service Demands

Utility Needs

Aviation Compatibility

Environmental Impacts

Community Compatibility

7.2.3. Environmental Impacts

The Airport Environs Land Use Compatibility/ Development Study conducted by Aviation Planning Associates, Inc., (1995) did not take into account or analyze the effects of redevelopment on stormwater runoff quality. The study warns only about the potential of flooding due to the implementation of the recuse plan. Surveying the existing storm drain system for condition and re-analyzing the system's hydraulic capacity are recommended (Aviation Planning Associates, Inc., 1993).

In developing and illustrating the methodology for local stormwater runoff quality planning, this dissertation examined (in section 7.3) current planning practices in two representative local governments--Jefferson Parish (summary of ordinances in Appendix C) and the City of Kenner (summary of ordinances in Appendix D)--and evaluated the utility of the proposed methodology in terms of those governments' planning and environmental management programs.

7.3. Current Stormwater Runoff Quality Planning Practices in Jefferson Parish and the City of Kenner

7.3.1. General Plan Evaluation Process

In Jefferson Parish as well as the city of Kenner, developers are required to prepare technical plans along with site plans for redevelopments. While site plan, survey, and elevation data are reviewed by the planning department, the technical/engineering plans are reviewed by all the related departments (such as the department of inspection and code enforcement, the fire department, the public works department, the drainage department, the water and sewage department, etc.) to make sure that the redevelopment plan is in accordance with the existing standards and ordinances of the parish and the city.

Note: Although the study area is located in Jefferson Parish, Orleans Parish owns the study area, not Jefferson Parish.

7.3.2. NPDES (Municipal Separate Storm Sewer System Permit) Requirements

(a) Jefferson Parish

According to the NPDES permit part 2 of Jefferson Parish, water quality control programs focus on source control and source elimination best management practices (BMPs). In the preparation of the NPDES Permit Part 2, stormwater management plans were reviewed for other areas of the country by Jefferson Parish to determine what type of BMPs was instrumental in the successful control of stormwater runoff. Studies have shown that the successful implementation of BMPs, described previously, in other areas of the country depended upon the blending of both types of BMPs, described previously, in order to see improvement in water quality.

For Jefferson Parish, BMPs were selected to address either large-area or site-specific control strategies. The large area BMPs are designed to be implemented by the parish and co-applicants. Site-specific BMPs take the form of source control strategies which can be implemented and maintained by individual property owners, businesses, and industry (NPDES, Part 2).

According to Jefferson Parish NPDES permit Part 2, Jefferson Parish source control programs implemented to limit pollutants from entering the storm drainage system include cleaning operations, inflow and infiltration abatement programs, and monitoring programs. Currently, Jefferson Parish has several ordinances that are used to control discharges into the storm sewer system. Appendix C summarizes parish ordinances that affect the quality of stormwater runoff. The methods for measurement of the implementation and effectiveness of the management programs include monitoring actual expenditures or tracking program activity.

The goals of the first five years of the Jefferson Parish stormwater permit have been set forth based upon (a) a study of management plans from other areas, (b) the unique conditions of the area, (c) findings from available data sources, and (d) the limited financial resources available.

The major components of the stormwater management plan include (NPDES permit Part 2):

(1) A comprehensive water quality management program designed to provide comprehensive water quality data on stormwater pollutant loadings and specific identification of potential sources through limited area sampling and in-depth source identification including basin area surveys and industrial inspections.

(2) A public education and public participation program that will increase awareness of existing programs and ordinances and solicit support of the public.

(3) A management plan that will encourage the continuance of existing parish programs which have a positive impact on stormwater quality. In addition, the plan encourages the development of new programs as needed to continue the improvement of water quality.

No numeric limitations have been proposed so far. In accordance with 40 CFR 122.44(k), the USEPA has required a series of Best Management Practices in lieu of numeric limitations. However, numeric limitations may be included in the final permit if required as a condition for state certification (approval of NPDES-Municipal Separate Storm Sewer System permit Part 2). The parameters Zinc, Copper, Lead, Cadmium, and Nickel are considered toxic pollutants of concern for the Jefferson Parish municipal separate storm sewer system (USEPA, 1995).

(b) City of Kenner:

The City of Kenner Environmental Section has enforced city storm drainage regulations, State regulations, 40 CFR 403, and 40 CFR 122. The City of Kenner has its own ordinances for controlling stormwater discharges as listed in C.

As can be seen in Appendix C and Appendix D, the current approaches to water quality protection by Jefferson Parish and the City of Kenner provide only a set of good "housekeeping" practices, not front-end-solutions that can be implemented at the planning stage. In allocating future land uses for the *acquisition area*, both Jefferson Parish and the City of Kenner lack a systematic approach to mitigate pollution due to stormwater runoff from redevelopment of land. The methodology presented in Chapter Six can be used by Jefferson Parish at the planning stage of individual development projects to protect water quality. The already existing ordinances for Jefferson Parish and for the City of Kenner can be incorporated into the proposed plan at steps eleven and twelve of the proposed methodology.

7.4. Some Important Notes on the Methodology

Most of the pollutants evaluated are toxic pollutants of concern for Jefferson Parish. The rainfall data for the area were obtained from the Jefferson Parish NPDES Part 2 application. Out of the five sets of rainfall data available in the report, the rainfall period with the lowest maximum rainfall amount (i.e., 1.69 inches) was selected for the analysis. The rainfall with the lowest maximum rainfall figure was selected for the analysis to consider the worst case scenario because the small rainfalls produce the highest concentration of runoff pollutants (according to Pitt and Bozeman (1982) storms greater than 12 mm are considered as large storms). In this case, the antecedent dry days were unknown for most of the rainfall data provided. However, in actual practice of the methodology, a rainfall which produces 0.5 to 1 inch of runoff and has a considerable number of antecedent dry days (at least three to four) is recommended for the evaluation of pollutant concentrations.

In presenting pollutant concentrations, the flow-weighted average concentrations for the total area are presented to simplify the calculations and improve understanding rather than pollutant concentration ranges (for minimum and maximum rainfall and various source areas). The load reduction of various Water Quality Management Measures depends on the parameters described in Section 4.5.5.

7.5. Application of the Analytical Part of the Proposed Methodology

7.5.1. Delineate, Review, and Compile Data Related to the Existing Area [Steps (1) & (3)]

In order to simplify the calculations, a part of the acquisition areas, P1&P5 (see Figure 8), was selected to illustrate the proposed methodology. It is assumed that the areas P1&P5 are representative of all the qualities and characteristics of the total acquisition area, so that any results obtained are applicable and can be extrapolated to reach conclusions for the whole acquisition area. A limitation of this simplifying assumption, however, is that it is not possible to fully evaluate the feasibility of Control Options, such as wet ponds, that might be constructed in other parts of the site.

First, the boundaries of the area concerned were delineated as shown in Figure 8. The existing characteristics of the area were also investigated. For this case study, the existing runoff quality is considered as the water quality goals to be achieved. Therefore, the steps (1) and (3) are considered together. Table 4 provides an inventory of area and land use of parcels which will be changing from residential to commercial or industrial uses in the acquisition area P1&P5. The total area of the parcels of concern, area of the existing land uses, and the land use types after the redevelopment were obtained from Table 9.3-1, Exhibit 2.2-1, and Exhibit 9.3-1 of Aviation Planning Associates, Inc. (1993) report. The remaining characteristics of the area are tabulated in Tables 5.

Table 4: Original data related to priority area P1&P5.

Parcel Number	Total area in acres	Existing use in acres		Redevelop land use
		Residential	Vacant	
1.2	3.2	3.2		I (S.C.)
1.3	3.08	3.08		I (S.C.)
1.7	2.5	2.5		C (O)
1.8	2.08	2.08		C (O)
1.9	4.68	2.51		C (H)
1.10	1.71	1.28		I (S.C.)
1.11	2.95	2.46	0.49	I (S.C.)
1.12	2.72	0.54	2.18	C (O)
1.13	1.2	---	1.2	C (O)
1.14	7.46	6.53		I (D/W)
1.15	2.91	2.91		I (D/W)
1.16	4.04	3.67		I (D/W)
1.17	5.06	2.86		I (D/W)
1.18	5.83	4.4		I (D/W)
1.19	5.04	2.36		I (D/W)
1.20	5.77	3.09		I (D/W)
1.21	5.49	0.63		I (D/W)
1.22	1.09	1.09		C (O)
1.23	0.53	0.53		C (O)
1.25	2.26	2.26		C (O)
1.26	1.93	1.93		C (O)
1.27	1.60	1.60		C (O)

1.28	2.49	2.49		C (O)
1.29	0.90	0.90		C (O)
1.30	0.26	0.26		C (O)
1.32	8.5	1.94		I (S.C.)

Source: Computed with the use of Aviation Planning Associates, Inc. (1995).

Notes:

S.C.- Service Centers; O- Office use; H- Hotels; D/W -Distribution/Warehouses
C- categorized under commercial, I-categorized under industrial.

Table 5: Characteristics of the study area (data needed to input into P1P5befo.dat file)

Parcel #s.	Roof Area	Drive-way	Side-walk	Street Area	Street Length	Other Pervious	Unde-veloped
1.2-1.13	1.11	0.5	0.98	5.15	3.54	12.3	3.38
1.14-1.21	2.65	0.91	1.53	8.13	5.59	22.89	0.63
1.22-1.30	1.11	0.70	0.63	3.69	2.54	9.25	0
1.32	0.4	0.13	0.155	1.24	0.85	1.41	0
TOTAL	5.27	2.24	3.3	18.21	12.52	45.85	4.01

Source: Computed from aerial-photo by Jefferson Parish Engineering Department (1990).

Notes:

(1) Source areas in acres and street-length in curb-miles.
(2) Street length in curb-mile is considered as 2 times total street length; 2 time the addition of the lengths of inside roads and outside roads.
(3) Width of the roads before redevelopment assumed to be 24 feet.
(4) Lumping/isolation of several parcels are based on the location of the parcel.
(5) P1P5befo.dat is the input data file of the P1&P5 area before the redevelopment.

7.5.2. Define Water Quality Goals [Step (2)]

The critical water quality parameters, of the study area (see Section 7.3.2), Total Suspended Solids (TSS), Total Phosphorous (TP), Lead (Pb), Zinc (Zn), Chromium (Cr), and Nickel (Ni) were selected for the analysis. For the case study, all pollutants are considered as of equal concern. In order to evaluate typical stormwater runoff quality in the existing area, the Source Loading and Management Model (SLAMM) was used as a tool. Any other stormwater quality model of choice can be used instead of the SLAMM, based on its suitability and the user's preference.

The following files have been used to run the SLAMM:

(a) Resident1.RAN: containing rainfall intensity, date, and time.

(b) Runoff.RSV: containing runoff coefficient for available area types and rainfall amount.

(c) Bham.PSC: file describing the particulate residue (suspended solids) concentrations for each source area (except for roads) and land use, for several rain categories.

(d) Delivery.PRR: file to account for deposition of particulate pollutants in the storm drainage system, before the outfall, or before outfall controls.

(e) Pollutant.PPD: file to describe the particulate pollutant strengths related to particulate residue and to describe the filterable pollutant concentrations for each source area for each land use.

(f) Particle size data file (.CPZ) is prepared only for the analysis of the effects of detention ponds.

The acreage and other information of the following source areas were evaluated and tabulated for the combined P1 and P5 areas:

Roofs
Paved Parking/Storage
Driveways
Sidewalks
Street Areas/Alleys
Undeveloped Areas
Other Pervious Areas

See Table 5 for the case study values.

Other information:

Type of roof - pitched or flat

Source area Connectedness - unconnected or draining to a pervious area

Soil type -sandy (A/B) or clayey (C/D)

Pavement texture - smooth to very rough

Total street length - curb-miles

Street dirt accumulation equation coefficients

Initial street dirt loading

The roof type before redevelopment is considered as pitched. Source areas were considered directly connected to the impervious areas. Soil type was considered as sand, since the area is filled with sand for construction purposes. Pavement texture was considered as smooth. For the street dirt accumulation and initial street dirt loading, default values were assumed.

Note:

(1) Unknowns such as coefficients can be selected according to the available literature and reasonable judgement can be used in deciding other factors such as the amount of connectedness in impervious areas to save time and money where appropriate in the planning stage.
(2) Due to the extensive nature of the 46 SLAMM files (.dat, .out, .st, .sum), a hard copy of the files related to the research is not provided with the dissertation. Instead, a floppy disk is attached in Appendix F.

P1P5befo.dat input file (for the SLAMM) is prepared using the site characteristics. The existing runoff quality is obtained by running P1P5befo.dat using the SLAMM. The resulting output summary is shown in Table 6; the existing runoff quality, i.e., values under the column P1P5befo.out, is considered as water quality goals to be achieved for the redeveloped area.

Table 6. Output summary of stormwater runoff quality in the area P1P5 before and after the redevelopment (without employing any water quality control measures).

Pollutant	Concentration of pollutants in units*			
	Before Redevelopment (P1P5befo.out)	Concept A (P1P5afte.out)	Concept B (P1P5afB.out)	Nationwide Urban Runoff Program Values (NURP)
TSS	178	725	768	101-228
TP	455	755	806	380-620
Pb	197	1287	889	190-230
Zn	232	1116	970	73-102
Cr	147	392	327	144-293
Ni	106	247	303	135-254

Source: Author

Note:
1. The existing runoff quality falls in the NURP range, except for Zn.

2. The flow weighted average values of the concentrations are tabulated.
3. * The concentrations of TSS is in mg/liter and TP, Pb, Zn, Cr, Ni are in µg/liter.

7.5.3. Inventory and Evaluate the Redevelopment Conditions [Step (4)]

The land use types, source area types, and acreage of the study area, for redevelopment alternative A and B are presented in Table 7. The land use types, source area types, and amounts are almost the same for alternative B, except the first row.

Table 7: Data needed to input into the P1P5afte.dat [Concept A] and P1P5afB.dat [Concept B] files

Parcel #s.	Land Use	Roof Area	Parking Area	Side-walk	Street Area	Street Length	Other Pervious
1.2-1.13 [Concept A]	I C	1.88 3.66	0.47 4.57	0.31 0.54	1.75 3.06	1.11 1.94	3.93 2.78
1.2-1.13 [Concept B]	C	0.68	0.85	0.12	0.7	0.44	0.98
	The remaining area is kept as Open Space = 14.78 acres.						
1.14-1.21	I	8.12	2.03	1.53	8.81	5.59	16.93
1.22-1.30	C	3.87	4.84	0.63	3.99	2.54	2.35
1.32	I	0.582	0.48	0.155	1.34	0.85	0.88
TOTAL [Concept A]	I C	10.58 7.53	2.98 9.41	2.0 1.17	11.9 7.05	7.55 4.48	21.74 5.13
TOTAL [Concept B]	I C	8.7 4.55	2.57 5.69	1.69 0.75	10.15 4.69	6.44 2.97	17.81 3.33

Source: Computed using Aviation Planning Associates, Inc. (1993).

Note:
1. Table 5.5-1 and Table 6.4-3 in Aviation Planning Associates, Inc. (1993) report were used to evaluate the percentages of building coverage (roof area) and the parking area, respectively for the commercial and industrial land uses.
2. P1P5afte.dat and P1P5afB.dat are the input data files of the P1P5 area after the redevelopment for Concept A and Concept B, respectively.
3. I-industrial land use; C- commercial land use.

4. The source areas in acres and street lengths in curb-miles.

Input files P1P5afte.dat and P1P5afB.dat are prepared for the redevelopment conditions. The runoff quality after the redevelopment (without applying any Control Options) is obtained by running P1P5afte.dat and P1P5afB.dat using the SLAMM. The resulting output summary is also shown in Table 6. Dramatic difference between before and after redevelopment runoff quality is shown in Figure 9.

Since it is assumed that the area P1P5 is representative of all the qualities and characteristics of the study area, the water quality result obtained for the P1P5 is assumed to be representative of the water quality of the total acquisition area.

7.5.4. Select Land Use Alternative(s) to Proceed with the Rest of the Methodology [Step (5)]

At this stage, the runoff quality of all the redevelopment alternatives is known. By knowing the net socio-economic cost of each alternative, Table 1 can be used to select the final one/two alternative(s) to follow in the rest of the methodology. For example, if there are four alternatives all together, the logic can be applied to two at a time.

For the case study, situation # 4 (of Table 1) is applicable. In this case, the net cost of infrastructure is considered as the net socio-economic cost. The net cost of Concept A ($4, 576,072) is much less than Concept B ($8,330,677) according to Aviation Planning Associates, Inc. (1993) Table 8.7-2 and the preliminary runoff quality of Concept A is not significantly different from Concept B [Table 6]. That is , the concentrations of Total Suspended Solids (TSS), Total Phosphorous (TP), and Nickel (Ni) is lower in Concept A while the concentrations of Lead (Pb), Zinc (Zn), and Cromium (Cr) are lower under Concept B. Although water quality under the Concept B is slightly better than Concept A, the net cost of Concept B is almost twice that of Concept A. Therefore, according to the logic given in Table 1, Concept B can be eliminated. That is, Concept A is selected to follow in the rest of the methodology.

7.5.5. Categorize Water Quality Management Measures for Each Case [Step (6)]

As documented under the methodology, each "Case" can consist of several Water Quality Management Measures. The reasons for categorization of water quality management measures under different Cases were described in Section 5.3.1. They are categorized as follows:

Case I

- (a) Disconnect roofs
- (b) Disconnect impervious areas
- (c) Street cleaning
- (d) Catchbasin cleaning

Case II

- (e) Porous pavements
- (F) Impose grass-swale as a drainage control

Case III

- (g) Infiltration device at the outfall
- (h) Wet detention pond at the outfall, etc.

The users need not restrict their Water Quality Management Measures to only the ones that have been provided. Additionally, the selection of individual water quality management measure for a particular area should be based on the site conditions, the objectives, and the availability of funds.

A more complete description of the factors to be considered when selecting water quality control measures can be found in Schueler (1987) and USEPA (1993). Soil type, depth to water table, depth to bed rock, slope, and adjacent land uses are all factors in the decision making process in selecting the most appropriate water quality management practices. The selections should be based on proper site investigation and field test results. The other considerations that are usually taken into account in selecting water pollution control measures are political feasibility, recreational and environmental benefits, aesthetics, safety, and nuisance potential (Pitt, 1991).

7.5.6. Select Management Measures That Are Appropriate to the Site [Step (7)]

The first step is to choose from the selected Water Quality Management Measures for each Case the ones that are appropriate for the area based on the guidelines provided by Schueler (1987). For example, since the study area receives a high average annual rainfall (60 in./yr.), the street cleaning option [(c)] is not selected. Studies prove that street cleaning practices give satisfactory results only in arid areas (Pitt, 1991). Similarly, the use of grass swales as the drainage type [(f)] is not selected because grass swale drainage controls are recommended for residential developments. Additionally, the handling of high runoff volumes resulting from high rainfall amounts in the area may not be possible solely by a grass swale drainage system unless the swale depth is very large. Finally, infiltration device [g] is not selected due to its lower pollutant removal capability compared to wet ponds.

For the remaining Water Quality Management Measures namely impervious area disconnection, catchbasin cleaning, porous pavements in the industrial parking area, and wet pond located as an outfall device does not require additional space from the study area.

By evaluating the remaining Water Quality Management Measures, for each Case, the most appropriate ones for the particular site can be distinguished. Table 8 shows the results of the preliminary analysis conducted to evaluate the suitability of the management measures. The comparative pollutant removal capabilities of each management measure are more clearly displayed in Figure 10.

The reduction of pollutant concentration of different Water Quality Management Measures under the SLAMM depends on several factors as described under Section 4.5.5. The factor(s) affecting the reduction of pollutant concentrations for the selected measures are as follows:

(a) roof disconnection and (b) impervious area disconnection - the decrease of directly connected area (increase of infiltration).

(d) catchbasin cleaning - the size of the basin and the frequency of cleaning. For this analysis the size of the basin considered was 755 cubic feet and the frequency of cleaning was twice during the study period (of about six months).

(e) porous pavement - the infiltration rate through the pavement times the duration of the rain event, the infiltration rate was 3 inches per hour and the duration of the rain event changed from 15 to 300 minutes.

(h) wet pond - shape and size of the outlet devices and how the volume of the pond varies with the stage increments. For this case, the surface area of the pond was calculated as the sum of 3% of impervious area plus 0.5% of pervious area contained in the drainage area (Pitt, 1991). The information related to the weir angle are as follows. Weir length is 5 feet, weir height from invert 0.5 feet, and invert elevation above datum is 4.5 feet.

The stage area relationship of the pond is considered as:

Stage (ft)	0	1	2	3	4
Area(acres)	0	1.0	1.1	1.4	1.8

Table 8. Results of the preliminary analysis: concentrations of the pollutants

Pollutant	Without Management Measures		Case I			Case II	Case III
	Pre	Post	(a)	(b)	(d)	(e)	(h)
TSS	178	725	757	318	506	572	103
TP	455	755	906	325	630	650	336
Pb	197	1287	1189	566	806	913	163
Zn	232	1116	1077	619	757	853	223
Cr	147	392	283	731	278	312	57
Ni	106	247	294	132	200	220	43

Source: Author

Note:
1. Concentration of TSS in mg/l, TP, Pb, Zn, Cr, and Ni are in µg/l.
2. (a) Roof disconnected; (b) impervious area disconnected; (d) catchbasin cleaning; (e) porous pavements; (h) wet pond.

According to the results of the preliminary analysis, Water Quality Management Measures that do not contribute to a reduction of pollutant concentration are eliminated. In this case, roof disconnection can be eliminated (see Table 8). Therefore, the Cases to proceed contain the following Water Quality Management Measures:

Case I: impervious area disconnection and catchbasin cleaning

Case II: porous pavements

Case III: wet ponds at the outfall control

7.5.7. Evaluate the Performance of Control Options for the Redevelopment [Step (8)]

In general, the sequence of analysis of the Control Options is arranged so that the least costly options are evaluated first (see the zoomed-in "Green Box" (Figure 3)). According to the way the Cases are arranged for this study, the pollutant concentrations under Case I are evaluated first. Then, Case II is evaluated before proceeding to option 2 because the cost of Control Option 2 is higher than employing Case II. If the resulting pollutant concentrations are higher than the water quality goals, proceed to option 2 and evaluate the water quality under the conditions of Control Option 2 and so on. If the resulting pollutant concentrations after application of any of the Cases or Control Options are equal to or less than the expected values proceed to Step (9).

The Control Options are arranged so that the higher the option number, the higher the cost of the expected pollutant removal. Based on the limiting criteria (whether it is water quality goals and/or the availability of funding) the evaluation can be terminated when the goals are met and/or affordability is diminished. For this study, since water quality is the limiting criteria, all the Control Options are analyzed until goals are satisfied. The analysis was terminated at Control Option 3 because Control Option 2 and 3 are capable of meeting the requirements. The resulting pollutant concentrations for each Control Option are tabulated in Table 11.

The user is free to select not only Water Quality Management Measures for each Case but also to arrange different Cases under each Control Option based on the situation at hand. Based on the site specific selection of Water Quality Management Measures and their user preferred categorization, the order of Control Options may be different from the one provided here. Then, when the Control Options are organized in an ascending order, the sequence of analysis also can be different from the one depicted in Figure 3.

7.5.8. Identify the Optimal Control Option which Facilitate Meeting the Goals [Step (9)]

The pollutant loading is based on the rainfall data, and the contents of the other parameter files listed under the section 7.5.2. Ideally the model should be calibrated to the area under study. The model calibration procedure for the Source Loading and Management Model (SLAMM) is yet to be released. The calibration is basically adjusting the model parameter based on rainfall and runoff data for the area. However, the model calibration is not that critical for this case because water quality goals were obtained by analyzing the model for the existing conditions of the study area.

The pollution concentrations before and after the application of Control Options are displayed in Table 11 and Figure 11, where Control Option 1 is impervious area disconnection and catchbasin cleaning, Control Option 2 is porous pavement located in the industrial parking area, and Control Option 3 is wet pond located at the outfall location.

The relative ability of Control Options to achieve the expected water quality goal is displayed more clearly in Figure 11. As can be seen, Control Option 1 does not meet the runoff quality goals. Control Options 2 and Control Option 3, on the other hand, meet the expected goals. Therefore, either Control Option 2 or Option 3 can be used to fulfil the goals.

Before deciding on which Control Option to implement, it is very important to conduct a feasibility study to investigate the suitability of each Control Options to the site. For this study, it is important to evaluate the suitability of porous pavements for the industrial parking area and the wet pond as an outfall control:

(A) POROUS PAVEMENT

Where and when is a porous pavement feasible? According to Schueler (1992):

Soils: porous pavement is not suitable for a site with field verified infiltration rate of soil is less than 0.5 inches per hour.

Area: the usual size of porous pavement sites is less than ten acres in size.

Slope: slope of the site should be less than 5%.

Depth to Bedrock and Water Table: three feet minimum clearance from the bottom of system.

Traffic Volume: porous pavement is not recommended for roadways with heavy traffic. It is usually recommended for lightly used parking areas and access roads.

Sediment Inputs: porous pavements are not suitable for areas expected to bring high levels of off site sediment input (e.g., upland construction, sparsely vegetated upland areas and areas with high wind erosion rates).

Cold Climates: the porous pavement system is very much affected by snow removal. But a porous pavement is designed to withstand freeze and thaw conditions that normally occur in most parts of the country.

Use in Ultra-urban Areas: when suitable soils are present, porous pavements can be used during infill development.

Retrofitting Capability: the use of porous pavement is extremely limited in areas where soil is modified so that it does not have adequate infiltration rate.

Stormwater Management Capability: sites with porous pavements can meet stormwater management requirements in many situations.

The expected traffic volume for the industrial parking area and the depth to water table and to the bedrock should be investigated to decide the use of this Control Option for the area.

(B) WET PONDS

Where and when are wet ponds feasible? According to Schueler (1992):

Contributing Watershed Area: suitable for contributing watershed area of greater than ten acres and less than one square mile.

Development Situations: very useful for low and high visibility commercial and residential development applications.

Baseflow: dry-weather baseflow is required to maintain pool elevations and prevent stagnation.

Available Space: 1 to 3% of the total site area should be dedicated to the wet pond and associated buffer/setbacks.

Downstream Impacts: wet ponds are not usually recommended for cold water trout streams and may create wetland, forest and/or habitat conflicts.

Use in Ultra-urban Area: use is fairly limited due to space requirement, but can provide an attractive urban amenity if open space or park land is available.

Retrofit Capability: sometimes wet ponds are used for stormwater retrofits, within dry stormwater basins. Usually used in combination with wetlands or extended detention treatment techniques.

Stormwater Management Capability: wet ponds can provide two-year stormwater quantity control, in addition to quality control.

According to the feasibility criteria wet pond seems suitable for the site as it is. However, study area (P1&P5) is only a part of the total *acquisition area* to locate the wet pond at the outfall location (at the pumping station number 4, see Figure 5). Therefore, the methodology should be carried out for the total *acquisition area* before deciding on implementing Control Option 3.

The next factor to be considered is cost effectiveness of each option. It is important to consider both construction cost as well as operation and maintenance cost of the two management measures. Also, whether the cost is paid by the developer or by the local government should be considered. A summary of the cost of each Control Option is displayed in Table 9.

Table 9: Different costs associated with Controls Options

Control Option	Unit Cost of Construction	Unit Cost of Operation and Maintenance	Total Annual Unit Cost
Catchbasin cleaning	N/A	--------------->	\$ 0.0021/ft^2/yr
Porous pavement	\$1-\$2/ft^2	\$0.01/ft^2/yr	\$ 0.15/ft^2/yr
	\$1.0/ft^3 of storage		

Wet ponds	volume	3%-5% of capital cost	$ 0.07/ft^3/yr

Source: USEPA (1993).

Total cost of Control Option 2: (only for the area P1P5)

Annual cost of catchbasin cleaning = 80 acres*43560ft^2/acre)*$0.0021/ft^2/yr

= $7,200/yr

Annual cost of porous pavement = (2.98 acres*43560ft^2/acre)*$0.15/ft^2/yr

= $ 19,471/yr

where, 80 and 2.98 are the area served by the catchbasin and area of porous pavement, respectively. 43560 is the conversion factor to convert acres to square feet.

Neglected any costs associated with impervious area disconnection.

Total cost of Control Option 3: (only for the area P1P5)

Total Annual cost of wet pond = [(1.8 acres*43560ft^2/acre)* 4 ft]* $0.07/ft^3/yr

= $ 21,954/yr

where, 1.8 is the surface area of the wet pond and 4 is the total depth of the pond.

Note:

In actuality, there are benefits due to the employment of water quality Control Options. Unfortunately the quantification of such benefits is not possible at this stage. Therefore, the application of the Control Options at the land use planning stage is more cost effective than illustrated.

CHAPTER 8

RESULTS AND EVALUATION

8.1. Results

The results of the secondary analysis regarding the effectiveness of the considered Control Options in removing problem pollutants are displayed in the Table 10.

Table 10: The results of the secondary analysis (only for the P1P5 area)

Pollutant	Water Quality Goals	Concentration After the Redevelopment			
		Without Control	Control Option 1	Control Option 2	Control Option 3
TSS	178	725	296	90	103
TP	455	755	311	298	336
Pb	197	1287	529	154	163
Zn	232	1116	587	163	223
Cr	147	392	683	83	57
Ni	106	247	123	44	43

Source: Author

<u>Note</u>:
1. The flow weighted average concentrations of the pollutants were considered as pollutant concentration.
2. The concentration of TSS is in mg/l; the concentrations of TP, Pb, Zn, Cr, and Ni are in µg/l
3. Pollutant removal depends on the design parameters of the management device, e.g., surface area, depth, weir angle/depth, etc.

By comparing the cost of Control Options 2 and 3 for the area P1P5, it is possible to get a glimpse of the amount of money that can be saved by implementation of a state level water quality enhancement regulation. If achievement of pre-set water quality goals is mandated, the developer has to construct source controls such as porous pavement. If Control Option 2 is implemented, then the local government will have to pay only the cost of catchbasin cleaning ($7200/yr for area P1P5). Similarly, the cost of Control Option 3 provides an estimate for the cost of retrofitting ($21,954 for area P1P5) after the redevelopment. Therefore, when compared to mandating the attainment of water quality goals at the planning stage, the retrofitting costs are almost three times as much. By extending the use of the methodology to other parts of the acquisition area, the grand total of annual savings, due to the inclusion of water quality into redevelopment planning, can be calculated.

According to the assumption that areas P1 & P5 are representative of the total acquisition area, the total annual cost for the acquisition area is approximately three times as much as the total annual cost for P1 & P5 (based on area proportion). That is, the total cost that the local government has to pay for the implementation of Control Option 2 is $20,755/yr while the total cost for retrofitting the acquisition area is $63,284/yr (Control Option 3).

Although Control Option 3 is used to illustrate the potential cost of retrofitting the area, other Control Options may be suitable for the area. Selection of the appropriate Control Option should be strictly based on the site conditions and the results of the feasibility study. Due to the absence of a feasibility study on the suitability of each Control Option, this study does not recommend implementation of any of the above described Control Options for the study area at this time.

It should also be noted that before implementation of Control Option 3, the entire acquisition area should be analyzed with the use of the methodology because Control Option 3 is considered as an outfall control which receives contributions of pollutants from the other parts of the acquisition area.

8.2. Evaluation

The proposed methodology (i.e., Chapters 6 through 8) was distributed to four parties in the private and public sector of the City of Kenner and Jefferson Parish governments to be evaluated. The evaluation was requested on the user friendliness and the potential usefulness of the proposed methodology. The response was received only from two parties from the private sector of the City of Kenner and Jefferson Parish. Mr. Raymond P. Schindler and Ms. Joanne L Gaillot of the Professional Service Group, Inc. (PSG) represented the City of Kenner and Dr. Adam Fashan represented Jefferson Parish (see Appendix E). Additionally, the application of the SLAMM model for the proposed methodology was evaluated by the co-producer of the SLAMM model, Prof. Robert Pitt.

Almost all the parties who evaluated the methodology, acknowledged that currently neither Jefferson Parish nor the City of Kenner evaluates water quality effects of redevelopments or developments. Although the evaluators have some doubts about the ability of these governments to implement the proposed methodology, most of them agree that the methodology would be beneficial to the area. They believe that federal or state level regulation is required if the proposed methodology is to be used because the hidden worth of water quality takes a back seat to the very apparent power of stakeholders such as developers.

Most of the comments received from Environmental Professional Service Group, Inc. (PSG, Inc.) which is the Consultant to the City of Kenner's Environmental Section, are not relevant since it is not familiar with issues related to controlling stormwater runoff pollutants from large scale (re)developments. The major complaint of the representatives of PSG, Inc., was that the methodology was too difficult to understand without physically gathering data and running SLAMM; they are not in a position to separate the tool and the decision mechanism to get the bigger picture about the proposed methodology. Further one of them "believes that planners and engineers, in general, do not focus on stormwater pollution prevention at all" which is not true everywhere, as is evident from the literature review in Chapter 3.

The representative of the Jefferson Parish private sector, Dr. Adam Fashen of Hartman Engineering, Inc. accepts that the methodology "appears to be innovative and beneficial." The main thing that he tried to point out was the need to make a case for the necessity of the proposed methodology. That comment is relevant because although the first few chapters of the methodology make clear the case for the requirement of such a methodology, many local governments give inadequate attention to water quality. His next concern was the implementation procedure of the methodology; it is up to the local government to decide the "use of incentives or enforcement procedures for developers to cooperate with the program." His last comment was mostly related to sewage system design rather than this study. Additionally, the biological parameters were not considered for this case study because the area will be redeveloped to commercial and industrial uses as opposed to residential and diary-farm uses from where the problem that he referred originated.

The dissertation was also reviewed by Prof. Robert Pitt of University of Alabama who is the co-producer of the SLAMM water quality model and who has conducted a significant amount of research for the USEPA (some of which is cited here) related to nonpoint source pollution prevention. According to Prof. Pitt, "the performance of the

Control Options seems reasonable......the model is useful for evaluating relative (non-quantitative) changes for different control options." Despite Prof. Pitt's suggestion of comparing the results with local data, the pollutant concentration values of the Jefferson Parish MS 4 permit were not compared with the values obtained during the case study due to the questionable nature of the observed values and the lack of data for the parameters considered.

CHAPTER 9

CONCLUSIONS

This research has been able to meet all of its goals and objectives.

When an area is redeveloped for a more intense use there is an increase of pollutant concentration as evident by this research (see Figure 9). Proper planning can be used to reduce additional pollution by taking into account the quality of water (see Figure 11). This research has taken into account water quality as a factor during the analysis of land use alternatives. Goals (1), (2), and objective (1) have been met.

The only accepted planning level methodology that advocates control of urban runoff of redevelopment is the watershed approach. However, the watershed approach is not applicable for some redevelopment, especially redevelopment when there are practical problems with the watershed boundaries. Additionally, as stated previously, the watershed approach does not provide a methodology to follow or method to quantify water quality. On the other hand, the proposed methodology provides a clear description of how to include water quality as a factor in addition to socio-economic factors. Goals (3) and objective (2) have been met.

The water quality analysis of the research has shown an increase in pollutant concentrations with the increase of directly connected impervious areas. The runoff quality can be improved (Figure 10) by introducing Water Quality Management Measures such as grass swales, porous pavements, and infiltration devices, as shown (Figure 10) in this study. Objective (3) has been met. Additionally, the introduction of a runoff quality Control Option (a combination of Water Quality Management Measures) can also reduce the pollutant concentrations (see Figure 16). Objective (4) has been met. The introduction of drainage controls { e.g. catchbasin cleaning (d)} and outfall controls {e.g. wet pond (h)} can improve the runoff quality (see Figure 10). Objective (5) has been met.

The application of the proposed methodology at the planning stage can reduce the cost of meeting water quality needs (maybe for NPDES requirement) by three times as much as retrofitting the area later, for the area concerned. Goal (4) and objectives (6) and (7) have been met. The Steps (6) through the end of the proposed methodology can be applied in achieving desired runoff concentration to meet NPDES requirements. The reduction of runoff pollutant concentration due to the application of the proposed methodology enhances the water quality of receiving water bodies such as Lake Pontchartrain. Goals (5) and (6) have been met.

The execution of the methodology may vary based on the limiting criteria, e.g., cost, water quality, land available, etc. If water quality is the limiting criterion, the problem can be addressed more freely by analyzing the effect of all the pollution control types and employing them until the water quality goals are met. On the other hand, if the cost of enhancing the quality of water is the limiting factor, only the most economically feasible (and suitable) pollution control practices (such as grass swales) should be analyzed and employed. However, for this case, availability of land was limited because all the residential land considered will be converted to commercial or industrial use. There is hardly any space for Control Options such as wet ponds and infiltration devices to be located at the source areas. This complexity due to an additional limiting criterion other than water quality is simplified by selecting management measures such as porous pavements (do not require additional space to employ at the source areas) and wet ponds (located at the outfall as outfall controls).

The utility of the proposed methodology depicted in Figures 1 and 3 (flowcharts) can be evaluated by monitoring water quality after the implementation of the program and comparing it with prior water quality of the receiving waters. If and when higher concentrations are detected, samples can be collected from source areas such as roof tops, parking lots, etc., to identify the problematic source area. There are special guidelines and procedures that should be followed when collecting, preserving, and testing stormwater quality samples. The USEPA provides those specifications; however, the explanation/ documentation of such procedures is beyond the scope of this study. Additionally, the effect of infiltration devices on groundwater also needs to be monitored.

Some aspects to be considered

- In addition to implementation of the land use/site plan according to the methodology, it is also necessary to upgrade/retrofit existing drainage systems where necessary.

- Analyze the concentration of pollutants of most concern for the area.

  When there is a relative difference among the importance of pollutants, a hazard or pollution index could be used for assigning weights to the pollutants.

- The effects of additional artificial infiltration facilitated by Water Quality Management Measures need to be investigated.

There is a strong possibility of contamination of ground water due to artificial infiltration of stormwater runoff. However, the methodology was limited to the study of only the surface water contamination aspect of water pollution. Since surface water quality is greatly affected by the quality of ground water, this may be an aspect which should be taken into account in addition to surface water quality protection. Further studies are recommended on this matter.

- For problems such as higher concentrations of Total Kjeldahl Nitrogen, the growing of rooted aquatic plants or terrestrial vegetation is recommended in the wet pond.

- In the presence of an infiltration device such as porous pavement, it is recommended that a pretreatment device such as filter strips or sediment traps be constructed to avoid rapid clogging of the infiltration device and frequent maintenance.

- Design and orient the structural Water Quality Management Measures to be as unobtrusive as possible.

- Use of a manual of practice which describes the benefits as well as problems associated with pollution control programs is recommended when selecting appropriate programs for a site in addition to considering suitability to the site and pollutant removal capabilities.

- It is important to conduct a feasibility study which investigates the site specific conditions that might be problematic in implementing the considered control measures.

- Since the proposed methodology is more flexible and comprehensive in application compared to the watershed approach, further studies are recommended to improve the methodology to include control of stormwater runoff quantity for protection from flooding.

- Implement enforcement of the methodology through a state law (State Water Quality Enhancement Act) because programs implemented through a legislative mandate help to achieve cooperation and funding.

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APPENDIX A

A Summary of Clean Water Act

Clean Water Act (previously, Federal Water Pollution Control Act) a brief description of Sections deal with Nonpoint Source Pollution

The 1987 amendment to the CWA requires permit application of large and medium municipal separate storm sewer discharges. In this two part application system, part 1 of the application procedure should include source identification, existing quantitative data on volume and quality of stormwater discharges, description of existing management programs to control pollutants, etc. Part 2 of the application requires source identification indicating the location of any major outfalls, and quantitative data from five to ten representative locations in approved sampling plans for conventional pollutants and heavy metals estimates of the annual pollutant load and event mean concentration of system discharges. In addition it is required to propose management programs including structural and source control measures.

Under section 208 of the 1972 amendment to the CWA, the governors of each state were required to identify areas with substantial water quality problems and to designate planning agencies responsible for the development of "effective area-wide waste treatment management plans" needed to address the nonpoint source pollution problem. Areas not designated as having substantial water quality problems were the responsibility of the state water quality planning agency. Plans developed by the state agencies were required to be submitted to the USEPA for approval (Cox and Herson, 1987).

The USEPA issued regulations in 1979 that consolidated several of the requirements of the CWA into a single integrated procedure called the Water Quality Management (WQM) Process. Under these regulations, each state may assume responsibility for all areas within the state and submit a statewide waste treatment plan. The plans must describe "the regulatory and nonregulatory activities and best management practices (BMP) which the agency has selected as the means to control nonpoint source pollution." A basis for assessing the process of pollution abatement efforts under a state plan is provided by a biennial report on the quality of state waters required by section 305 (b) of the CWA. The state report must include "...a description of the nature and extent of nonpoint sources of pollutants, and recommendations as to the programs which must be undertaken to control each category of such sources..." The reports can be used to refine a state's nonpoint source program on an ongoing basis (Cox and Herson, 1987).

The 1987 CWA amendments (section 319) increase the potential for federal influence while continuing to recognize a primary state role in nonpoint source pollution management. Provision is made for state identification of waters that cannot attain or maintain applicable water quality standards or other CWA requirements without additional action to control nonpoint source pollution. The state assessment is also required to identify the categories of nonpoint source pollution (or particular nonpoint sources where appropriate) responsible for such pollution. The assessment is to be followed by development of a state management plan to reduce pollutant loadings from the nonpoint source categories and individual nonpoint sources identified. The plan also identifies the BMPs for achieving such pollutant reductions and the programs necessary for BMP implementation. The programs may include "...non-regulatory or regulatory programs for enforcement, technical assistance, education, training, technology transfer, and demonstration projects...". States are encouraged to conduct the prescribed assessment and prepare the necessary management plan by establishing a grant program to assist in the implementation of plans approved by the USEPA under guidelines specified in the legislation (Cox and Herson, 1987).

Alternative procedures for development and implementation of a nonpoint source management plans are provided for cases where a state does not develop and submit such a plan to the USEPA. Provision is made for the EPA to identify waters in need of additional nonpoint source pollution controls and the nonpoint source categories or individual sources in need of control . Under certain conditions, the EPA is authorized to assist local public agencies or organizations in developing and implementing nonpoint source management plans if a state fails to submit a management program or fails to obtain the EPA approval of its program. With approval of state government, the EPA may provide technical and financial assistance to such local entities (Cox and Herson, 1987).

As indicated by the 1987 amendments, the federal government employs financial assistance as a basic means of influencing nonpoint source control efforts. Technical assistance is a further form of federal involvement in nonpoint source pollution control . A primary example is the U.S. Soil Conservation Service (SCS) program encompassing land and water conservation measures (Cox and Herson, 1987).

APPENDIX B

Schematic diagrams of Best Management Practices

APPENDIX C

Ordinances for Controlling Stormwater Discharges for Jefferson Parish, LA.

APPENDIX D

Ordinances for Controlling Stormwater Discharges for the City of Kenner, LA

APPENDIX E

Evaluation of the Proposed Methodology by Environmental Professionals in the area

APPENDIX F

Input and Output Data Files of Source Loading and Management Model

See the attached disk.

VITA

The author, born in Sri Lanka, was named at the time Vishaka Vidana Pathirana. She attended elementary and high school in her country. In 1982, she worked three months as a high school science and mathematics teacher before she started her undergraduate studies. She received her Bachelor of Science degree in Civil Engineering from the University of Moratuwa, Sri Lanka in 1986. She worked as an instructor for undergraduate students in the same university for about seven months. She was employed as a demonstrator for Civil Engineering technology students at the Open University of Sri Lanka for a little less than two years. In July 1989, she came to the U.S. to be with her husband. Vishaka Wijesundera entered the University of New Orleans (UNO) in January 1990 to pursue the Master of Science in Civil and Environmental Engineering and graduated in December 1991. During this study period, she worked as a research assistant in the Urban Waste Management and Research Center under the supervision of Prof. Donald E. Barbe'. Her name was listed in the National Dean's List 1990-1991. She received a certificate of recognition for her Master Thesis and sponsored Sigma Xi membership from The Sigma Xi Club in 1992. She passed the Engineer-in-Training Examination in 1992. She enrolled in the College of Urban and Public Affairs to pursue her Ph.D. in Environmental Policy and Management. During her doctoral study at UNO, she was employed as a graduate research assistant in the Center for Revitalization of Central Cities, Louisiana Environmental Education & Resource Program, the Department of Civil and Environmental Engineering, and in the College of Urban and Public Affairs.