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16. Abstract

Because bridges usually span bodies of water, quantifying and controlling non-point pollutant flux from them will take on added significance as federal regulations begin to address non-point contamination of the environment. The objectives of this study were to examine the quality and quantity of the non-point contamination coming from the Cross Lake Bridge and to examine the effectiveness of a detention pond (holding pond) in removing contaminants from the runoff.

These objectives were accomplished by installing sampler/flow meters at the basin inlet and outlet to quantify the volume of runoff and mass of conventional contaminants (COD, TSS, nutrients, hydrocarbons) entering and leaving the basin. The runoff flow rate into and out of the basin was logged at periodic intervals and discrete samples were collected across flow hydrographs entering and leaving the basin. Using this data, the basin efficiency in removing pollutants from runoff could be estimated.

Study results show that runoff from the bridge contains pollutant concentrations similar to those found in domestic wastewater. However, the Cross Lake holding pond removed 100 percent of total petroleum hydrocarbons, 82 percent of oil and grease, and 85 percent of the total suspended solids entering the pond. Removal percentages for other contaminants were smaller and exhibited greater variation.

Analysis of pond sediments and the overlying water column showed that the majority of the metals in the runoff were concentrated in (sorbed onto) the sediments. Partitioning coefficients on the order of several thousand were measured.

Holding ponds are relatively simple, low-maintenance systems that could be employed as a best management practice (BMP) at a number of DOTD facilities and be a major factor in reducing non-point contamination at existing DOTD facilities such as district offices and maintenance yards.

Holding ponds appear to be a simple and relatively inexpensive way of complying with upcoming federal and state mandates regarding export of non-point contamination from DOTD facilities; however, such facilities must be cleaned on a regular basis to remain functional.

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Determination and Treatment of Substances in Runoff in a Controlled Highway System (Cross Lake)

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ABSTRACT

Because bridges usually span bodies of water, quantifying and controlling non-point pollutant flux will take on added significance as federal regulations begin to address non-point contamination of the environment. The objectives of this study were to examine the quality and quantity of the non-point contamination coming from the Cross Lake Bridge and to examine the effectiveness of a detention pond (holding pond) in removing contaminants from the runoff.

These objectives were accomplished by installing sampler/flow meters at the basin inlet and outlet to quantify the volume of runoff and mass of conventional contaminants (COD, TSS, nutrients, hydrocarbons) entering and leaving the basin. The runoff flow rate into and out of the basin was logged at periodic intervals and discrete samples were collected across flow hydrographs entering and leaving the basin. Using this data, the basin efficiency in removing pollutants from runoff could be estimated.

Study results show that runoff from the bridge contains pollutant concentrations similar to those found in domestic wastewater. However, the Cross Lake holding pond removed 100 percent of total petroleum hydrocarbons, 82 percent of oil and grease, and 85 percent of the total suspended solids entering the pond. Removal percentages for other contaminants were smaller and exhibited greater variation.

Analysis of pond sediments and the overlying water column showed that the majority of the metals in the runoff were concentrated in the sediments. As a result, several thousand partitioning coefficients were measured.

Holding ponds are relatively simple, low-maintenance systems that could be employed as a best management practice (BMP) at a number of DOTD facilities and be a major factor in reducing non-point contamination at existing DOTD facilities such as district offices and maintenance yards. They appear to be a simple and relatively inexpensive way of complying with upcoming federal and state mandates regarding export of non-point contamination from DOTD facilities; however, such facilities must be cleaned on a regular basis to remain functional.

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IMPLEMENTATION STATEMENT

Holding ponds such as the one at Cross Lake can be operated and maintained in such a way as to reliably remove sediment (mean removal efficiency 85 percent) as well as pollutants commonly associated with sediment from runoff such as COD (71 percent), total phosphorous (55 percent), and heavy metals (partitioning coefficients >1000). The ability to store and release runoff as desired (fill and draw operations) makes the pond an ideal settling basin. Installation of these type facilities at DOTD district offices and other outlying facilities would serve as a best management practice (BMP) for the control of non-point contamination. This is significant since recent court decisions have made it necessary for EPA to mandate discharge requirements for non-point discharges.

In order for the pond to be effective in the long term, a regular program for removing accumulated material from the basin must be implemented. If this is not done, that material will ultimately be scoured and discharged as the pond is emptied. The performance of this facility could be substantially improved in two ways:

1. by constructing a berm or baffle structure in front of the outlet to prevent sediment accumulation very near the pond exit, thus minimizing scour of settled material and

2. by operating pond discharge valve(s) in such a way as to control scouring. For example, partially opening the valve (draining the pond slowly) will limit high exit velocities and reduce sediment scour. At present the valve is fully opened to drain the pond as rapidly as possible.

TABLE OF CONTENTS

ABSTRACT..iii

ACKNOWLEDGMENTS..v

IMPLEMENTATION STATEMENT..vi

TABLE OF CONTENTS……………………………………………………….....ix

LIST OF TABLES...xi

LIST OF FIGURES..xiii

INTRODUCTION...1

OBJECTIVES...21

SCOPE 23

METHODOLOGY…………………………………………………………… 25

ANALYSIS OF DATA...33

SUMMARY 43

DISCUSSION...55

CONCLUSIONS...59

RECOMMENDATIONS...61

REFERENCES..63

LIST OF TABLES

Table 1: Potential Highway Pollutants and Their Sources 4

Table 2: BOD, TSS and COD Loadings - Initial Data...33

Table 3: Pollutant Monitoring Results...36

Table 4: Percent Pollutant Mass Loads corresponding to 25, 50, and 75 percent of Runoff Volume Sampled 39

Table 5: Hydrologic Characteristics of Rainfall and Runoff from Cross Lake Bridge 40

Table 6: Comparison of Bridge Surface Pollutant Runoff Concentrations (mg/L) at Three Different Sites with Pollutant Concentrations Associated with Cross Lake Bridge 44

Table 7: Removal Efficiency of Cross Lake Holding Pond 47

Table 8: Basin Performance for TSS Removals - 32 drainage events................48

Table 9: Mean Pollutant Loadings at Cross Lake Holding Pond 51

Table 10: Metal Concentrations in Liquid and on Sediment - Selected Events...53

LIST OF FIGURES

Figure 1: Cross Lake Holding Pond Showing Sampler Locations 27

Figure 2: Runoff Hydrograph showing sample collection and Rainfall Amount..... 29

Figure 3: Traffic Counts on Cross Lake Bridge 34

Figure 4: First Flush Analysis for Runoff Event Occurring April 27, 1997 38

Figure 5: Histogram of Observed Runoff Coefficients - Cross Lake Bridge 41

Figure 6: Event Mean Concentrations at the Inlet and Outlet for TSS (1999-2000) 50

INTRODUCTION

The impetus for this project has its origins in section 303(d) of the Clean Water Act (CWA) of 1972. As described by Houck *[1],* the CWA, which was originally predicated on state programs to achieve water quality standards, was overhauled in 1972. The revised CWA required national technology standards for point source dischargers. These technology provisions of the act have been successful. Industrial pollution plummeted; rates of wetland loss slowed and in some regions even reversed; and municipal waste loadings, the subject of 128 billion dollars in public funding for treatment works, dropped by nearly 50 percent while the populations served were doubling. However, according to Houck, the country's waters are not now significantly cleaner. The problem is that those sources of pollution not initially regulated by the CWA have increased to the point where they have negated the gains realized from point source reduction. These remaining sources of contamination are commonly referred to as diffuse or non-point sources of pollution. A good example of the effects of non-point contamination is the 8000 square mile "dead zone" at the mouth of the Mississippi River Here, the marine environment has become too anaerobic for most higher life forms to exist. The cause of this dead zone is commonly believed to be runoff from agricultural land, most of which comes from above the confluence of the Mississippi River with the Ohio River, more than 975 miles away. Houck points out that just about every state has similar problems caused by agriculture, logging, or some other industry that creates non-point pollution. Section 303(d) of the original CWA was retained when it was revised in 1972. This section provided a structure for water quality based regulation for waters that remained contaminated after the implementation of the technology-based provisions of the CWA. States would identify those waters that remained contaminated and develop total maximum daily loads (TMDLs) that, if enforced, could be expected to bring these remaining waters into compliance. These TMDLs would then be allocated to discharge sources via permits and state water quality plans. Neither the states nor the EPA did so until a series of court cases in the late 1980s and early 1990s caught EPA and the states by surprise. Eclipsed by more imperative provisions of the new CWA this provision had lain dormant for 20 years. A wave of litigation followed, compelling states to prepare listings of impaired waters and develop schedules for TMDLs. Ironically, the reason 303(d) was retained from the original CWA was precisely because both the states and those industries responsible for both point and non-point pollution wanted it. They wanted it because of its water quality based provisions and its primary reliance on the states and localities for implementation.

As part of its attempt to meet the requirements of 303(d), EPA is now requiring states to develop BMPs for use in mitigating non-point contamination. This project examines the use of holding ponds as a best management practice for reducing pollutant flux from roadways.

The Cross Lake site

The Cross Lake Bridge is a part of I-220 that spans Cross Lake in Shreveport, Louisiana. Cross Lake serves as the potable water supply for the city of Shreveport, a city of approximately 200,000 persons. I-220 is the bypass around

Shreveport for I-20, the longest Interstate highway in the country. As a result, I-20 is heavily traveled. During construction of the bridge, concern was expressed over the possibility of an accident on the bridge contaminating the city's water supply. As a result of this concern, the LADOTD agreed to modify the bridge to include a "closed" drainage system and to construct a concrete lined holding pond on the east bank of Cross Lake to hold the runoff. Thus, the Cross Lake Bridge is, in effect, a closed catchment and all the runoff drains to a holding pond. This is a rather unique situation and offers the opportunity to examine the usefulness of such holding ponds in reducing pollutant flux from roadways.

Runoff held in the pond is periodically released into wetlands that drain into a 12-mile bayou. The average detention time in the pond is highly variable but is estimated to be between five and 10 days. Over the last 10 to 15 years, Cross Lake has been the subject of numerous news articles relating to both water quality as well as its hydrologic characteristics. In addition, the lake and the dam at the outlet have been involved in at least one lawsuit related primarily to flooding of surrounding property. Aside from this research, no scientific articles were found in refereed publications specifically addressing non-point contamination effects on Cross Lake. However, research dealing with roadway pollution and the use of holding basins as a BMP is referenced.

Review of Pertinent Literature

In 1985, a nationwide survey by the Association of State and Interstate Water Pollution Control Administrators reported that 75 percent of the rivers, 56 percent of the lakes, and 76 percent of the estuaries in Louisiana had water-quality problems related to non-point source contamination. Corbitt *[2]* found that non-point sources contribute 80 percent of the total nitrogen and 50 percent of the total phosphorous to the nations receiving waters. Contaminants specific to roadways have been listed by several authors and are summarized in Table 1 below.

Table 1 - Potential Highway Pollutants and Their Sources *[3],[4],[5],[6]*

Classification	Contaminant	Source
Heavy Metals	Copper,Iron,Lead,Zinc	Auto fuels(exhaust), brake wear, Tire wear, Moving engine parts
Inorganic Salts	Sodium, Calcium, Chloride	De-icing salts.
Nutrients	Nitrogen, Phosphorous	Fertilizers, industry emissions, vehicle exhaust.
Organic Compounds	Oxygen Demanding Substances	Domestics, commercial, and industrial wastes; natural decay of organic materials.
Particulates	Dust and dirt “airborne” particles	Atmosphere, highway maintenance, pavement wear, vehicle activity.
Pathogenic Bacteria	Coliform bacteria	Animal transport or grazing in adjacent areas, roadkill.
Petroleum	Road characteristics, vehicle operation	Asphalt surface, oil and other vehicle leaks, spills.
PCB, Pesticides		Atmospheric deposition, synthetic tires, spraying of right-of-ways.
Other	Rubber, Asbestos	Tire wear, clutch and brake wear.

The literature on highway (not bridge deck) runoff is substantial and space does not permit a complete review here. However, six research projects dealing with highway runoff are listed along with a brief statement as to their findings and significance. The reader is referred to the accompanying reference, *[7],* for additional information.

1. FHWA Project - Phase I-Constituents of Highway Runoff, *[8]* - Investigators sampled 159 events at six sites; three in Milwaukee, one in Denver, one in Nashville, and one in Harrisburg, Pa. Sampling was carried out in 1976-77. Loadings from highways were found to be correlated to design features such as shoulder type and type of drainage (curb and gutter vs. grassy swale). Dissolved lead and zinc concentrations in runoff were low (< .05 to.1 mg/L) even when total zinc concentrations were as high as 160 mg/L.

2. FHWA Phase II - Sources and Migration of Highway Runoff Pollution, *[9]* - Researchers identified and quantified background pollutant loadings such as atmospheric deposition for the highway system. Their findings suggested that atmospheric deposition of metals on the right of way to be significant during dry periods and to be significantly greater in urban areas as compared to rural areas. Highway design features, traffic volumes, and location (rural vs. urban) strongly influenced constituent loading.

3. FHWA Phase III Effects of Highway Runoff on Receiving Waters, *[10]* - Investigators carried out extensive physical, chemical, and biological sampling of receiving waters at three sites: two in Wisconsin and one in North Carolina. All three sites were classed as rural/suburban. A key finding here was that runoff from highways with less than 30,000 vehicles per day would not adversely affect aquatic biota. The study found no violations of existing state water quality standards or EPA acute toxicity criteria in receiving waters attributable to highway runoff.

4. FHWA Phase IV Maintenance Impacts and Management Practices, *[11], [12], [13]* - This project evaluated the effects of highway maintenance on water quality. Results indicate that highway maintenance practices have a low potential for water quality impacts. Four management measures were considered effective for highway runoff pollutant removal: vegetative controls, wet detention basins, infiltration, and wetlands.

5. Pollutant Loadings and Impacts from Highway Storm water Runoff, *[14]* - The investigators updated an existing database to include 933 storm events at 31 sites in 11 states. Data used to develop probabilistic methods to allow estimation of the frequency and magnitude of criteria pollutant excursions.

6. <u>Evaluation and Management of Highway Runoff Water Quality</u> *[15]* – This study compiled past documentation and research on highway runoff quality, impact assessment and mitigation. Extensive information is provided on best management practices (BMPs).

Studies Specifically Addressing Bridge Deck Water Runoff Impacts

Relatively few studies have been carried out dealing specifically with bridge deck runoff. Most of these have been summarized by the National Cooperative Highway Research Program *[7]*. Two of the most informative are described here:

1. I-94/Lower Nemahbin Lake Site, southeastern Wisconsin, west of Milwaukee, ***[10]-*** This was one of the sites in FWHA's Phase III research program. The site represents the single most comprehensive field study of bridge deck runoff effects found in the literature. The site contained an elevated 1,400 foot-long, one-acre, curbed bridge deck for the eastbound lane of the bridge,and regularly spaced scupper drains that discharge directly to the lake. The ADT during the study was 15,000 vehicles per day.

Significant findings were that wetland vegetation was effective at retaining metals with background concentrations achieved within 20 meters of scupper inputs. Elevated levels of metals were observed in sediments near scuppers. Quantitative sampling showed that invertebrate density was not significantly different at runoff influenced stations when compared to controls.

2. Lake Ivanhoe and Lake Lucien, Florida – This study evaluated the effects of elevated bridge runoff on Lake Ivanhoe, a small lake just north of downtown Orlando, and Lake Lucien, a small lake north of the city**, [16]**, **[17].** The ADT on I-4 at Lake Ivanhoe was 110,000 while that of Lake Lucien was 42,000. The lakes receive bridge drainage directly from scuppers as well as drainage that has passed through grassy flood plains or detention ponds. Researchers concluded that plant species exhibited higher metal concentrations when exposed to direct scupper discharge compared to locations where runoff first passed through flood plains or ponds.

Summary of Bridge Deck Studies

Several studies summarized by NCHRP have shown that direct scupper drainage to some types of receiving waters can result in localized increases in the concentrations of some pollutants such as metals and in some cases aquatic biota. Most studies did not consider whether such increases adversely affected the biota or other receiving water uses.

The most comprehensive study, I-94/Lower Nemahbin Lake, described above concluded no adverse impacts on biota near scupper discharges. However, because the ADT was low this result may not be representative.

Detention Basin Performance

"Detention basins are online storage devices which can take advantage of solids-settling processes as well as other mechanisms to reduce non-point pollution loading in urban runoff", *[18], [19]*. Detention is a highly effective management measure for pollution abatement if sufficient detention time is provided. Numerous research efforts have been conducted to examine the performance of detention ponds in removing highway pollutants. Studies have found that the removal efficiency of highway runoff pollutants in detention ponds varies from very poor to excellent. Settling of suspended materials is the primary action in removing pollutants in a wet detention pond, although biological reactions within a permanent pool of water also contributes to the removal of nutrients, *[20]*. Further, the general assumption has been that highway pollutants, like nutrients and metals, are absorbed into sediments and settle with sediments in the pond. The performance of detention ponds in this review is grouped into four categories: (a) theoretical performance (using settling column) (b) performance of wet detention pond, (c) performance of dual-purpose detention basin, and (d) performance of detention basin and wetland systems.

Theoretical Performance of Detention Basins

Whipple and Hunter studied the removal of different types of pollutants in urban runoff by sedimentation *[21]*. Samples from five urban watersheds were analyzed using a settling column six feet deep (chosen as the representative depth of many detention basins in use) in the laboratory. Data indicated that 70 percent of the original TSS concentration settled within 32 hours. With the same detention time, removal of lead and phosphate ranged from 60 to 85 percent and 30 to 60 percent respectively. For other pollutants (5-day BOD, copper, nickel), total removals varied from 20 to 50 percent. Whipple and Hunter concluded that the removal efficiency of specific pollutants by sedimentation varied widely from one site to another.

Randall et al. studied the effectiveness of sedimentation for the removal of pollutants from urban storm water runoff using a settling column with a 5-inch diameter and a four-foot water column depth *[23]*. Samples were collected from culverts draining three different shopping-mall parking lots in Virginia and were analyzed for the removal of TSS, COD, BOD, total organic carbon, phosphorus, nitrogen, and heavy metals. Seven experiments were run using a settling period of 48 hours. The results showed that the best reductions were obtained for TSS, lead, and BOD with average removals of 90, 86 and 64 percent, respectively, whereas removals of 45.5, 56, and 33 percent were obtained for COD, total phosphorus, and total nitrogen, respectively.

Stanley conducted laboratory settling-column experiments to measure the times required for maximum settling of runoff pollutants *[24]*. The settling column was 56 inches tall with a 12-inch diameter. The results show that the average percentage removals for TSS, total phosphorus, and total nitrogen after 72 hours were 93, 46, and 50 percent respectively, while the removals for metals ranged from

33 to 77 percent. Most settling had taken place after the first 12 hours. The removal percentage of TSS and the metals after 12 hours were found to be almost as high as they would be after 72 hours.

Dorman studied the settling characteristics of highway runoff via settling-column studies *[25]*. The depth of the settling column was five feet, which was representative of the depth of the prototype pool. Thirteen storms sampled at six highway sites in northern Virginia were analyzed for specific constituents at settling times of 2, 6, 12, 24, and 48 hours. The mean pollutant removal efficiencies measured at settling times of six and 48 hours ranged from 70 to 78 percent and from 87 to 92 percent respectively, whereas the removal efficiency of total phosphorus ranged from 33 to 39 percent and from 43 to 45 percent at settling times of six and 48 hours, respectively.

Wet Detention Basins

McCuen examined the removal efficiency of a detention basin located in south-central Montgomery County, Maryland, for 11 water quality parameters (BOD, nutrients, metals) *[26]*. Data collected on this site showed a reduction of at least 60 percent for all parameters depending upon storms characteristics. The maximum trap efficiency was 98 percent for zinc.

Striegl investigated the suspended sediments and metals-removal efficiency of a small lake in the Chicago metropolitan area *[27]*. He reported that the efficiency of the small lake was from 91 to 95 percent in removing suspended sediments and 76 to 94 percent in removing copper, iron, lead, and zinc from urban runoff. The study showed that concentrations of copper, lead, and zinc were closely associated with suspended sediment concentrations and with accumulations of fine-grained sediments.

Kathuria et al. examined the effectiveness of nine selected surface-mine sedimentation ponds in three eastern coal-mining states of Pennsylvania, West Virginia, and Kentucky *[28]*. All selected ponds were sampled to determine pond behavior under two different operating conditions, a base line (non-storm) and a rainfall event. The sedimentation ponds,when properly used and maintained, had higher efficiencies of suspended-solids removal than ponds that were not properly utilized and maintained. The removal efficiencies of seven out of nine ponds were measured to be approximately 90 percent or greater during baseline (non-storm) conditions. The efficiencies during the storm events were generally much lower than during the baseline conditions. Timely removal and disposal of the accumulated sediments, cleaning of clogged outflow pipes, and repair of emergency spillways and embankments are recommended for the proper functioning of the whole sedimentation pond system.

Stanley evaluated pollutant removal by a demonstration urban stormwater detention pond in Greenville, NC, in 1992 *[29]*. The effectiveness of the pond in removing urban runoff pollutants was assessed by eight monitored storms. He found that pond treatment efficiencies for particle-bound pollutants were normally positive. Median pond treatment efficiencies were 71 percent for TSS, about 45 percent for particulate organic carbon and particulate nitrogen, 33 percent for particulate phosphorus, and 26 to 55 percent for metals.

House et al. investigated the effect of a wet detention pond on the water quality of storm runoff *[30].* A wet detention pond was constructed to protect the water quality and ecology of Lake Wingra in Madison, Wisconsin, from the effects of storm-sewer inflow to the lake. Samples were collected for 64 runoff events. Inflow and outflow EMC and constituents' loads were compared in order to estimate the trap efficiency of the pond. In general, they found a decrease in the EMC of sampled constituents at the outlet as compared to the inlet. The decrease in EMC for suspended solids was 88 percent, 60 percent for total chemical oxygen demand (COD), 43 percent for total phosphorus, 38 percent for total Kjeldahl nitrogen, 65 percent for total nitrite plus nitrate, and 71 percent for total lead. The decrease is attributed to the deposition of suspended solids in the pond. For chloride, the EMC was generally found to be higher in outflow than the inflow. This increase in chloride concentration is attributed to the possibility of an influx of chloride to the pond during unmonitored periods in the winter.

Dorman et al*.* investigated the effectiveness of the wet detention ponds in Florida, Connecticut, and Minnesota in reducing the pollutant loads from highway storm water runoff *[31]*. The Florida basin was the most effective in removing the nutrients and metal. Over 90 percent of the nitrate, 40 to 60 percent of Total Kjeldahl Nitrogen (TKN) 60 to 70 percent of total phosphorus, 20 to 30 percent of suspended solids, 60 to 90 percent of the copper, and 65 to 75 percent of the zinc were removed in the Florida site. In contrast, the Minnesota basin was removing 20 to 30 percent of TKN, 60 to 80 percent of the nitrite/nitrate, and less than 25 percent of the total phosphorus. However, the Minnesota basin also exhibited the removal of

35 to 65 percent of copper, 65 to 70 percent of zinc, and 60 to 70 percent of total suspended solids. The Connecticut basin by comparison, removed 15 to 60 percent of TSS, less than 35 percent of TOC, and less than 35 percent of TKN and nitrite/nitrate. The results presented for the Minnesota and Florida detention ponds are based on storm data after screening to eliminate storms with unusual data (e.g. outflow concentrations substantially larger than inflow concentrations). The Minnesota results are based on eight storms (five storms excluded), and the Florida results are based on six storms (four storms excluded). The results presented for the Connecticut basin are based on the total database of seven storms.

The United States E.P.A. established the Nationwide Urban Runoff Program (NURP) in 1978 to study the quality characteristics of urban runoff as well as the performance characteristics and the overall effectiveness of management practices for the control of pollutant load from urban runoff *[32]*. NURP investigated performance characteristics of detention devices such as the dry detention basin, wet detention basin, and dual-purpose basins. They found that the performance of individual basins ranged from poor to excellent. In addition to the removal of pollutants by sedimentation, some basins exhibited substantial reduction in nutrients (phosphorus and nitrate/nitrite nitrogen). This reduction can be attributed to biological processes, developed in the permanent pool of water of the detention pond.

Wu monitored three urban wet detention ponds (Lakeside, Waterford and Runaway Bay) in the Piedmont region of North Carolina to investigate long-term pollutants removal efficiency of the ponds *[33]*. The removal efficiencies were determined on the basis of event mean concentrations. The Lakeside pond attained the average removal efficiencies of 93 percent for TSS, 80 percent for zinc, and 87 percent for iron. Efficiencies for total Phosphorus and TKN were 45 percent and 32 percent, respectively. The Runaway Bay pond exhibited the average removal efficiencies of 62 percent for TSS, 32 percent for zinc, and 52 percent for iron. Total phosphorus and TKN removal efficiencies were 32 percent and 21 percent respectively. The average TSS removal efficiency for Waterford was 41 percent. Other parameters were not measured for the Waterford pond. Although these detention ponds were not originally designed as water-quality control devices, they were effective in reducing urban runoff pollution.

Multi-purpose Detention Ponds

Kantrowitz and Woodham studied a multipurpose wet storm water detention pond in Pinellas Park, Florida, to estimate the efficiency of the detention pond in reducing the load of urban runoff contaminants commonly found in urban stream flow *[34]*. Loads for 19 constituents (four major ions and 15 urban runoff contaminants) in storm water were computed for six storms at the inflow and outflow sites on Saint Joe creek. The detention pond was effective in reducing storm water loads of such urban runoff contaminants as metals, nutrients, suspended solid, BOD, and COD. Estimated median pond efficiencies for reducing contaminant loads ranged from 25 to 60 percent for metals, 2 to 52 percent for nutrients, 7 to 11 percent for suspended solids, and 16 to 49 percent for the oxygen-consuming substances.

The United States E.P.A. reported on the performance of a dual-purpose detention basin at Stedwick, Washington, D.C., as examined by the (NURP) project *[32]*. This pond was converted from a conventional dry pond by replacing the outlet pipe. It was designed to detain storm water runoff for up to 24 hours instead of the one to two hours observed in conventional dry ponds. This dual-purpose detention device exhibited a 64 percent reduction in mean EMC for TSS, 30 percent for COD, 84 percent for lead, and 57 percent for zinc. The removal of soluble pollutants (e.g., soluble P and nitrite/nitrate) was less than 10 percent, which is not effective when compared to the performance of a wet detention pond. The fact that this pond was less effective can be attributed to the absence of a permanent pool within which biological processes take place in addition to sedimentation in the pond.

Detention Pond/Wetland Systems

Martin and Smoot monitored the quality of urban storm water runoff entering and leaving a detention pond and wetland system in Orlando, Florida *[35]*. The reduction efficiency of a detention pond and wetland system for 22 constituents, including the dissolved, suspended, and total phase of many of the constituents, was investigated. It was concluded that settling of suspended solids is the primary process controlling the reduction. The detention pond generally reduced the loads of suspended solids. The pond had a removal efficiency of 65 percent in reducing suspended solids, 41 percent for suspended zinc, 17 percent for suspended nitrogen, and 21 percent for phosphorus, while the system (the pond and wetland combined) achieved 55 percent for total solids, 83 percent for total lead, 70 percent for total zinc, 36 percent for total nitrogen, and 43 percent for total phosphorus.

Gain evaluated the treatment efficiency of the Orlando detention pond and wetland system following the installation of a flow barrier, which approximately doubled the flow path and increased detention time *[36]*. He reported that changes in the geometry of the storm water treatment system can significantly affect the pollutant retention efficiency of the pond and wetland system. However, he also indicated that the changes in efficiency are caused not only by changes in residence time but also by changes in storm water mixing and pond flushing during storms. Increased flushing of the pond after modification caused decreased retention efficiencies for pollutants that settle in the pond between storms and increased retention efficiencies for pollutants that settle out of ponds and wetland storage systems between storms. The detention pond was most effective in increasing retention efficiency from 19 percent to 73 percent after modification. The overall effect of modification on the system (pond and wetland combined) was a reduction in retention efficiency for all but two constituents (total zinc load and total ammonia nitrogen).

Holler, [*37]*, conducted water quality studies at the Springhill subdivision in suburban Lake Worth, Florida, to examine the nutrient removal efficiency of a combination grassed swale/wet detention storm management system *[37]*. They found treatment efficiencies of 64 percent for total phosphorus, 98 percent for orthophosphorus and nitrite + nitrate nitrogen, and 77 percent for TKN.

The Cross Lake Project

Initial funding for this project resulted from a grant by the Louisiana Department of Natural Resources (DNR) Interagency Agreement 25104-96-01. Funding came about as a result of concerns expressed by the Cross Lake Advisory Committee relating to elevated levels of toxic compounds entering the lake. Stated objectives in the DNR proposal were:

1. To determine a correlation between traffic flow and water runoff quality for this bridge and similar settings,
2. To determine the relationship between water runoff quality from the bridge and effluent quality from the detention pond thus allowing development of a predictive relationship for similar settings, and
3. To develop recommendations for further investigation.

The initial sampling period was to be February 1, 1996 through December 31, 1996. Traffic counters were installed under both lanes of I-220 in early November 1996. In reality, sampling occurred during November and December of 1996, and eight events were monitored. The initial monitoring program was to consist of the following activities:

1. Collecting rainfall data for the bridge area (accomplished),
2. Collecting data on the nature of the runoff from the bridge (accomplished),
3. Collecting atmospheric data such as air quality, dust fall, temperature, and

humidity, as available. (some data was collected, some data such as temperature and humidity was not considered useful to the study and thus was not collected.),

4. Monitoring one-way traffic flows on the bridge for targeted traffic periods, including low, average and peak periods. (not accomplished because data was unavailable), and
5. Installing equipment to measure runoff flow into the pond and collect composite samples to monitor average runoff quality from the bridge. (accomplished, equipment to monitor pond discharge also installed).

In June of 1996, LTRC increased funding for this project and increased the sampling time to 24 months; however, funds only allowed the sampling to continue until the project ended on June 30 1999. Concurrent to this work, Louisiana Tech entered into a proposal as a subcontractor to Washington State University for an NCHRP project (NCHRP Project 25-12 Wet Detention Pond Design for Highway Runoff Pollution Control). The site to be monitored in this proposal was also the Cross Lake holding pond. This project resulted in additional funds that were used to purchase additional sampling equipment and to allow collection of samples when the pond was drained. Thus, it became possible to determine the actual efficiency of the pond in removing pollutants from runoff.

Work Performed

Between November of 1996 and December of 1997, 81 individual runoff events into the holding basin were monitored, sampled, and analyzed for flow and pollutant concentrations and loads. Not every event was analyzed for every contaminant. Events that were monitored as part of the original DNR work order were among those not analyzed here. Of these, 64 were considered reliable for use. Between June of 1997 and March of 1999, 33 “drainage events” were monitored. A drainage event is defined as the time interval between the sequential drainings of the holding pond. Thus, a drainage event may include from one to five runoff events entering the pond. Results include summary statistics for contaminant concentrations, an investigation of the degree of flushing occurring during runoff events, the performance of the pond in removing conventional contaminants from runoff, and a small amount of data analysis relating to metal concentrations and metal partitioning.

OBJECTIVES

Because of the several funding sources as well as experiences and difficulties that occurred as the project progressed, some of the initial objectives in the original DNR agreement (INTERAGENCY AGREEMENT NO. 25104-96-01) could either not be met, were met in modified form, or were superceded by objectives considered more important, in a practical sense, to LTRC and DOTD. The initial objectives were:

1. To determine a correlation between traffic flow and water runoff quality for this bridge and similar settings,
2. To determine the relationship between water runoff quality from the bridge and effluent quality from the detention pond, and by this relationship, develop a predictive relationship for similar settings,
3. To quantify pollutant loads entering and leaving the Cross Lake Holding Pond,
4. To assess the efficiency of the Cross Lake Holding Pond in removing contaminants from bridge runoff, and
5. To develop recommendations for further investigation.

SCOPE

The scope of this report consisted of monitoring and analyzing as many runoff events as possible from the Cross Lake Bridge between November of 1996 and June of 1999. In addition, discharge of stored runoff from the Cross Lake holding pond was monitored between August 1997 and June 1999. Rainfall amounts were measured for all runoff events. This was accomplished using American Sigma programmable sampler/flow meters and data logging rain gauges. Discrete samples were collected and analyzed for several conventional pollutants. Flow rate and rainfall data were logged and periodically downloaded to laptop computers for additional analysis.

METHODOLOGY

Because of the several different sources of funds as well as experience gained and difficulties encountered during the course of the project, the scope and methodology changed as the project progressed. The initial scope of work was developed jointly by personnel from DNR and LTRC and concentrated on sampling the quantity and quality of flow entering the basin. The initial sampling period was to be from February 1, 1996 to December 31, 1996. Unfortunately, the American Sigma flowmeter/sampler was not delivered to the Cross Lake site until November of 1996. However, eight runoff events were sampled and analyzed from November 1 to December 31, 1996. In addition, the scope of work called for traffic data to be obtained from traffic counters installed in both lanes of the bridge. However, once the counters were installed in November of 1996, neither the principal investigator nor LTRC personnel were able to obtain traffic data from DOTD. A final report by Griffin et al. based on these nine events was prepared, submitted to DNR, and accepted *[41]* . LTRC funds in FY 96/97 increased the budget of this project, and the sampling period lasted until early 1999. In addition, funds were received from an NCHRP (NCHRP Project 25-12) project. With these additional funds, these research efforts coincided for a time. A second sampler was installed at the pond outlet that allowed mass balance calculations to be carried out on the liquid volume and pollutant mass entering and leaving the pond. This allowed the efficiency of the pond to be quantified. Concurrently, analyses of runoff events entering the pond also continued. Analyses of runoff entering the pond centered on several factors:

1. The nature of the contaminants, their forms, and concentrations,
2. Relationships, if any, which existed between contaminants entering the pond and characteristics of the rainfall events that produced them, and
3. The extent to which the “first flush” phenomenon occurred at this site.

The project proceeded in this fashion until January 1998.

From January 1998 until its end in June of 1999, the project concentrated on measuring the efficiency of the pond in removing conventional water pollution constituents such as BOD, COD, TSS, and nutrients. However, during this time, Louisiana Tech purchased a computer-controlled atomic absorption spectrophotometer that is used to measure the concentration of metals. Because of the minimal additional cost to the project, some samples of pond contents, both liquid and deposited sediment, were collected and analyzed for a suite of heavy metals.

The Cross Lake Bridge is 10,000 feet long. It may be considered completely impervious with a surface area of approximately 880,000 square feet. The bridge presumably has a closed drainage system and all runoff is conveyed to a concrete-lined holding pond located at the east end of the bridge. An American Sigma series 950 flowmeter/sampler measured and logged the runoff flow rate entering the pond. In addition, it could be programmed to collect samples across the runoff hydrograph. A recording rain gauge, mounted on top of the sampler enclosure, recorded rainfall amounts over time in increments of .01 inch. The pond itself has an average surface area of 40,000 square feet with a maximum depth of six to 8 feet depending on location. The pond bottom slopes toward the outlet. A schematic of the site is provided in figure 1 below.

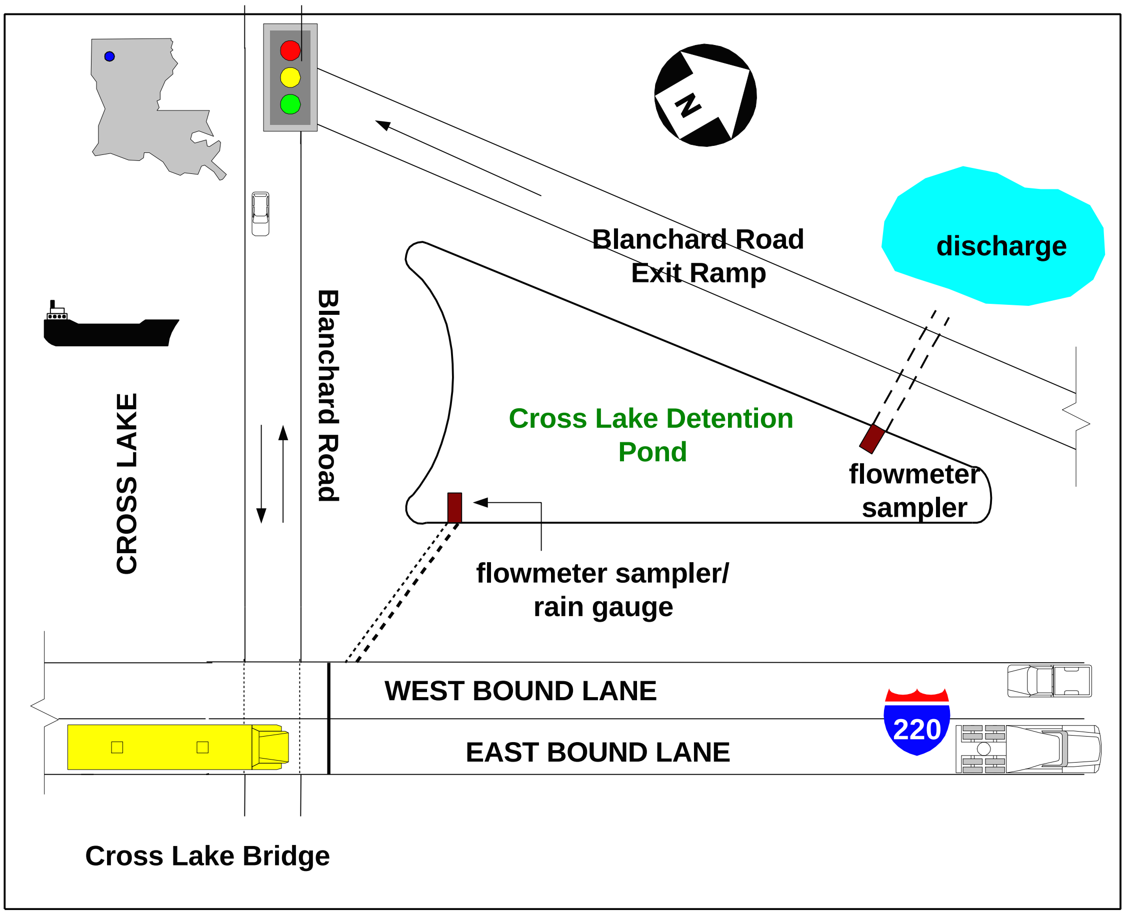


Figure 1 - Cross Lake Holding Pond Showing Sampler Locations

A second sampler/flow meter is located at the pond outlet. The operation of the pond may be considered as a “batch” or “fill and draw” process. Once the pond has been emptied, the valve at the outlet is closed. Runoff from one or, more likely, several rainfall events, is stored in the pond until local DOTD personnel determine it should be emptied. Louisiana Tech personnel then empty the pond, measuring flow and collecting samples across the outflow hydrograph.

Data logged by the flow meters and rain gauge is downloaded to laptop computers for further analysis. Samples are returned to the Folk Lab at Louisiana Tech University for analysis. Ultimately, flow and sample are manipulated and calculations performed using Excel and Mathcad. Excel is a spreadsheet software application, and Mathcad is an application, for performing mathematical calculations.

A variety of mathematical analyses were routinely performed on the data collected. Using rain gauge data and the plan area, the volume of precipitation that fell on the bridge could be computed. This volume could be compared to the volume of runoff that entered the pond. In this way an observed runoff coefficient, denoting the fraction of precipitation volume that ended as runoff, could be computed. This parameter is commonly designated as “C”.

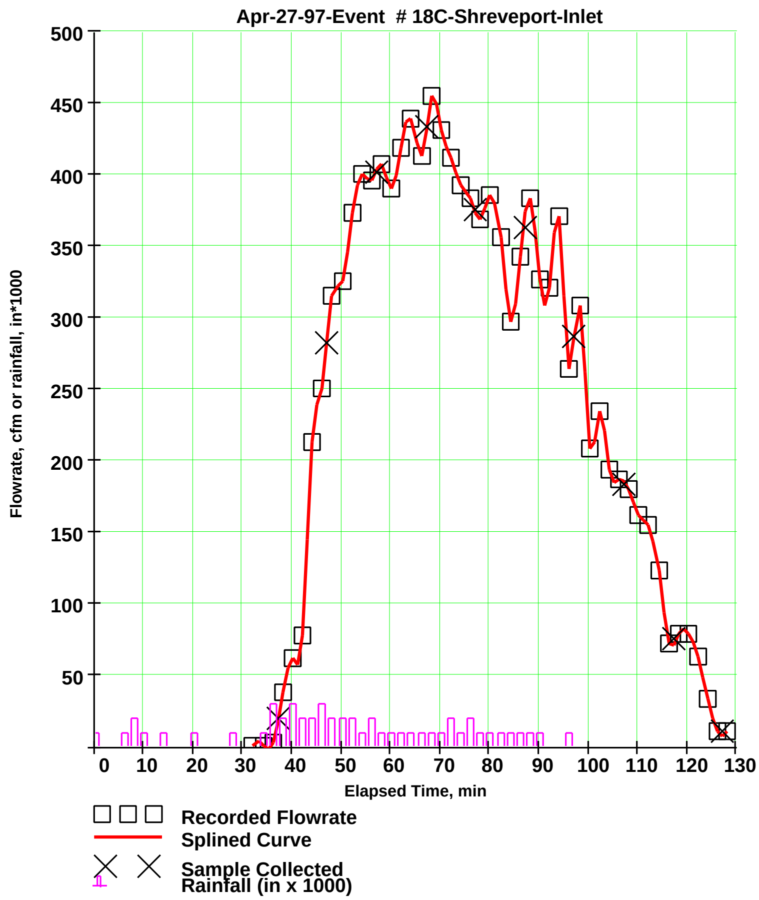


FIGURE 2 - Runoff Hydrograph showing Sample Collection and Rainfall Amounts

Contaminant Dynamics at the Basin Inlet

A graphical representation of the data collected from a single runoff event at the pond inlet is provided in figure 2. This figure shows the flow variation, sample collection history, and incremental rainfall amounts for event 18C, which occurred on April 27, 1997. These data were collected at the pond inlet. As demonstrated, the flowrate in cfm is plotted on the y-axis versus time on the x-axis.

The small rectangles, connected by lines indicate actual logged flow values. Crosses show the time and location on the hydrograph where discrete samples were collected. Incremental rainfall values of .01 inches have also been plotted along the x-axis corresponding to the time they occurred. Because of the relative scales involved, each incremental rainfall value (.01 inch) has been multiplied by 1000, as indicated in the legend.

Samples collected were returned to the Folk Lab at Louisiana Tech University and routinely analyzed for chemical oxygen demand (COD), total suspended solids (TSS), total phosphate (TP), ammonia (NH_3), nitrate (NO_3), oil and grease (O@G), and total petroleum hydrocarbons (TPH). Periodically, samples were also analyzed for total Kjeldahl nitrogen (TKN) and biochemical oxygen demand (BOD). Both runoff and sediment samples from the pond were periodically collected and analyzed for heavy metals and hydrocarbon compounds.

Contaminant Mass Balance

Once a sampler/flow meter was installed at the pond outlet it became possible to quantify the mass of pollutants entering and leaving the pond and thus establish what percentage of pollutants entering the pond remained there when the pond was emptied. As indicated previously, the holding pond was operated on a fill and draw basis. Runoff from one or more rainfall events entered and was stored until DOTD or Louisiana Tech University personnel emptied the pond. Because both the influent and effluent volumes could be measured and sampled, the treatment efficiency of the pond with respect to a variety of contaminants was computed.

Pollutant loads into and out of the basin were computed in two ways. When discrete samples were judged to have been taken uniformly across the runoff hydrograph, the resulting pollutant concentrations were then multiplied by the flow at the time the sample was taken. This resulted in a plot of mass flow of pollutant passing the measuring section versus the time of collection. The area under this curve could be integrated numerically to obtain the total pollutant load entering or leaving the pond. A second procedure involved combining the discrete samples into a flow-weighted composite sample once they had been transported to the laboratory. The total volume of runoff was then multiplied by the pollutant concentration measured in the flow-weighted sample, resulting in a pollutant load. In the process of performing the aforementioned mass balances, it was necessary to measure the volume of runoff entering the pond. This value was then compared to the volume of runoff that would be expected from the rainfall event causing the runoff, assuming that the bridge deck is impervious or nearly so. The ratio of the volume of rainfall on a catchment to the volume of runoff is given the symbol "C", and termed the runoff coefficient. The value of these coefficients for highly impervious surfaces, such as a bridge deck, should be near 1.0; however, observed runoff coefficients for the events monitored, averaged about 0.5. Discussions with local DOTD indicated that this was due to the fact that the drainage system which had incurred substantial leaks as a result of bridge pile movement over the years since the bridge was built.

ANALYSIS OF DATA

Initial Results

As mentioned earlier**,** during the initial portion of the study, only the basin inlet was instrumented and only inlet loads could be measured. During the period, eight events were monitored. The results are presented in table 2 below.

Table 2 - BOD, TSS and COD Loadings - Initial 8 events

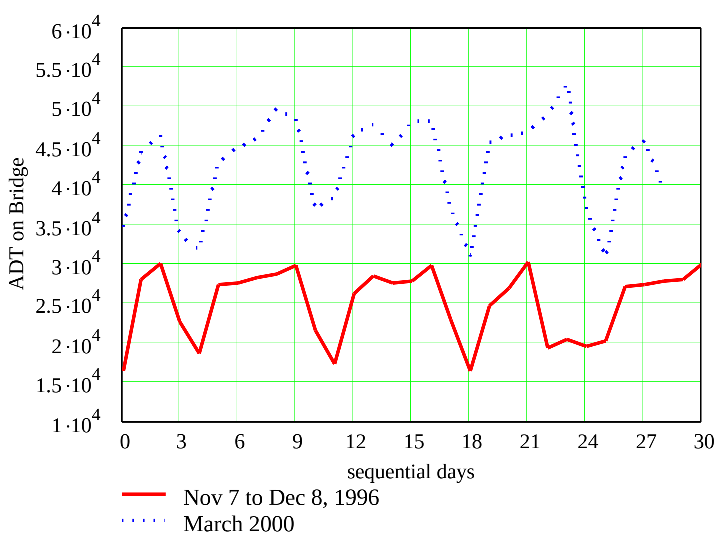
Date	BOD (lbs/acre/in)	TSS (lbs/acre/in)	COD (lbs/acre/in)
Nov 1 1996	1.48	41	5.77
Nov 1 1996	3.83	221.82	16.78
Nov 7, 1996	.67	N.A.	2.63
Nov 17,1996	3.05	5.61	12.1
Nov 17,1996	.28	.60	.16
Nov 24, 1996	1.03	10.9	5.84
Nov 29, 1996	.92	4.85	7.73
Nov 29, 1996	.28	1.98	1.58

These initial events were examined for relationships between the BOD and COD loads generated and other characteristics such as rainfall amount, maximum rainfall intensity, and time between runoff events. The highest correlation coefficient, .601, was between log(CBOD) loads and maximum rainfall intensity during the event. While this value is not exceptionally high, the fact that the pollutant loads correlated with maximum rainfall intensity is logical, particularly on an impervious surface since the kinetic energy of the falling rain is the primary factor responsible for loosening and transporting contaminants. No other linear relationships were found to exist. A report detailing how the raw data were collected and analyzed to produce pollutant loads was prepared, presented to DNR, and accepted.

Traffic Data

A small amount of traffic data was collected from November 7 to December 9, 1996, immediately after the traffic counters were installed. As shown in figure 3, the data exhibits a pronounced seven-day cycle with traffic counts increasing during the week and dropping off on the weekend.

FIGURE 3 Traffic Counts on Cross Lake Bridge



As indicated previously, it was not possible to obtain data traffic data from this site from late 1996 until early 1999. A small amount of traffic data collected in 1996 showed ADT values at or below 30,000. Traffic data collected in March of 2000 showed an average ADT value of 42,650 vehicles per day, as shown in figure 3. This is significant because runoff from roadways with an ADT above 30,000 is generally considered to produce adverse impacts on aquatic biota.

Study Results From January 1, 1997 to June 30, 1999

Mohammed Eslami, Shashi Shrestha, and Rishi Raj Bhattarai implemented and carried out a monitoring program over a twelve month period. Eslami monitored from November 1996 to January 1997. Shrestha continued from April through November 1997, and Bhattarai concluded the effort, sampling from December 1997 to April 1999. The sections below describe their combined work and results.

A total of 82 rainfall events were monitored for their hydrologic characteristics; however, only 64 of the 82 events contained enough reliable data to be used for analysis. Of the rainfall events, 41 were analyzed for at least some pollutant concentrations. EMC concentrations and pollutant loadings at the basin inlet as well as significant findings regarding contaminant concentrations in the runoff are shown in Table 3.

TABLE 3 – Pollutant Monitoring Results

Contaminant	No. of Events Monitored	Mean	Geometric Mean	Min.	Median	Max.
Mass Load BOD* (kg/curb mile)[1]	9	1.17	0.68	0	0.8	2.8
Mean Lab Conc.[2] BOD (mg/liter)	9	6.97	6.47	2.1	5.2	14.4
Mass Load COD* (kg/curb mile)	41	15.83	8.09	0.02	7.41	83.10
Mean Lab Conc. COD (mg/liter)	41	94.12	61.66	3.0	59.8	343.8
Mass Load COD-F* (kg/curb mile)	28	6.37	2.57	0.38	2.2	62.5
Mean Lab Conc. COD-F (mg/liter)	28	38.94	19.17	2.4	23.1	272.9
Mass Load NH_3-N* (kg/curb mile)	30	0.116	0.074	0.007	0.075	0.331
Mean Lab Conc. NH_3-N (mg/liter)	30	0.77	0.60	0.2	0.6	2.5
Mass Load Total P* (kg/curb mile)	31	0.058	0.036	0.004	0.040	0.182
Mean Lab Conc. Total P (mg/liter)	31	0.32	0.26	0.1	0.3	0.9
Mass Load TSS* (kg/curb mile)	40	17.15	7.68	0.02	9.26	88.01
Mean Lab Conc. TSS (mg/liter)	40	84.35	59.32	4.5	68.35	309.7
Mass Load VSS* (kg/curb mile)	24	5.62	2.56	0.27	3.24	22.79
Mean Lab Conc. VSS (mg/liter)	24	29.86	22.49	2.5	28.3	90.0

[1]For this site the entire 2-mile length of the roadway is curbed
[2]Mean concentration of the discrete samples based on laboratory results.
*Indicates a parameter impacted by leaking from the collection system

First Flush Analysis

Most runoff events exhibited some degree of first flush. Because the raw data could be transferred to MathCad and manipulated, it was possible to examine the flushing characteristics of the events that occurred. This was accomplished by plotting the fractional cumulative pollutant load versus the fractional cumulative volume of runoff for an event that occurred on April 27, 1997 as shown in figure 4. First flush occurs when a large fraction of the pollutant load is removed during the initial portion of the runoff. By examining figure 4, it is evident that over 70 percent of the total COD load for the event is removed in the first 45 percent of the runoff volume. Similarly, 50 percent of the total suspended solids load was removed. Thus, it might be concluded that this event exhibited first flush characteristics. Events that do not exhibit first flush characteristics would plot along or even below the y=x line. A summary table (table 4) of first flush analyses follows.

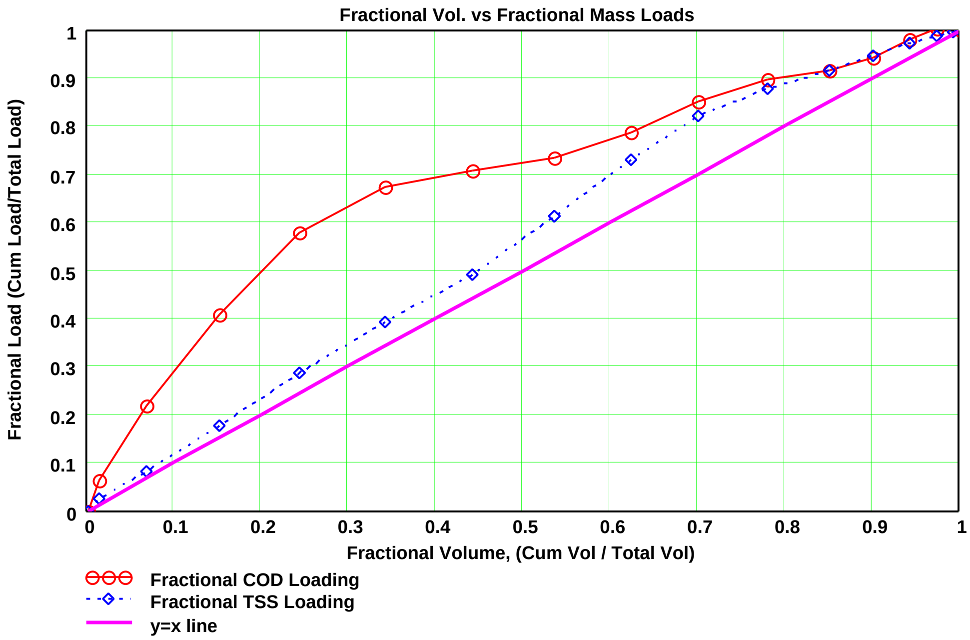


Figure 4- First Flush Analysis for Runoff Event Occurring April 27, 1997

Table 4 - percent Pollutant Mass Loads Corresponding to 25, 50, and 7 5 percent of Volume Sampled

Fractional Volume Sampled	2 5 percent	5 0 percent	7 5 percent
BOD	35	59	79
COD	34	59	80
COD-Filtered	34	57	81
NH_3-N	35	60	80
Total – P	32	56	80
TSS	34	61	81
VSS	35	61	79

Number of events = 41

The fact that all of the events monitored during this portion of the study exhibited some degree of first flush for both TSS and COD is significant because it suggests that a substantial fraction of the pollutant load may be removed by trapping and treating only the initial portion of the runoff volume.

Study Results From January 1, 1997 to June 30, 2000
Funded by LTRC and NCHRP

Because the graphical analysis of data collected during this period is essentially the same for all events monitored as that shown above, the data will be presented in the form of tables. Early in 1997, Washington State University was awarded an NCHRP grant to study pollutant removal in wet detention basins. Louisiana Tech University was a subcontractor on that grant. As a result a second American Sigma flow meter was installed at the outlet to the detention basin. It thus became possible, at least theoretically, to perform mass balances on conservative pollutants and water across the basin. This was not anticipated at the outset of the initial study. However, in terms of the types of best management practices DOTD may have to implement in the coming years, data on the removal efficiency from this type of facility is probably more valuable than data relating contaminant concentrations/loads to traffic and climatic characteristics since these cannot be controlled.

Hydrologic Data

Basic data regarding rainfall amounts and intensities as well as rainfall and runoff volumes are summarized in table 5.

Table 5 – Hydrologic Characteristics of Rainfall and Runoff from Cross Lake Bridge

Parameter	Arithmetic Mean	Geometric Mean	Minimum	Median	Maximum
Rainfall (in)	0.47	0.31	0.05	0.31	1.97
Avg. Intensity (in/hr)	0.35	0.22	0.04	0.21	2.1
Max. Intensity (in/hr)	1.43	0.83	0.12	0.90	5.7
Duration (min)	124	89	12	96	452
Rainfall Vol. (ft^3)	34,746	23,004	3,667	22,733	144,467
Runoff Vol. (ft^3)	18,063	10,676	594	11,592	84,545
Runoff Coeff. (RC = Runoff Vol / Rainfall Vol) (percent)	49	46	10	50	78

64 events monitored

The most important data in this table relate to the low observed values for the runoff coefficient. It should be noted that these were computed for individual rainfall events.

While there several possible reasons for these low values, the most significant for DOTD is the confirmed fact that the drainage system on the bridge is leaking, possibly substantially. A second possible reason is the fact that the runoff hydrograph at the basin inlet exhibits substantial tailing. It is difficult to measure the low flow in the receding limb of the hydrograph because at low velocities most of the solids settle out and there is nothing in the flow to reflect the Doppler flow meter signal. These data suggest that as much as 50 percent of the total pollutant load from the bridge could potentially be ending up in Cross Lake rather than the pond. The distribution of measured runoff coefficients is shown in figure 5.

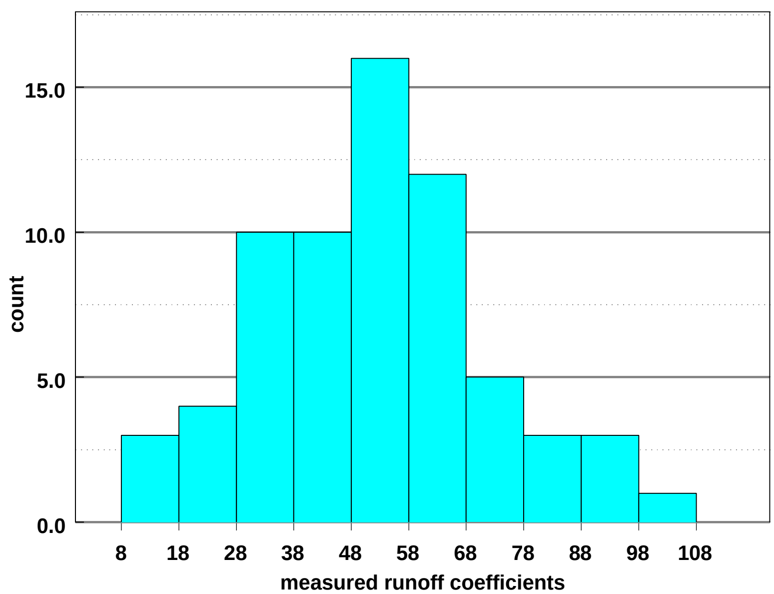


Figure 5 - Histogram of Observed Runoff Coefficients - Cross Lake Bridge

SUMMARY

On the average, only 50 percent of the rainfall that falls on the surface of Cross Lake Bridge is transported as runoff into the detention pond. This is low considering the 100 percent impervious bridge deck. Some loss is expected and can be attributed to splash off caused by vehicle traffic on the bridge, evaporation, and water remaining on the surfaces of the roadway and in the drainage channel. There is evidence of leaks through the drainage channel as reflected by discolorations of the concrete bridge piers underneath the drainage channel. Additionally, recent conversations with DOTD personnel in Shreveport, Louisiana, indicate that the drainage channel has a number of holes in it, causing part of the runoff to leak directly into Cross Lake.

Based on laboratory tests on collected samples for COD (Geometric Mean = 62 mg/L) and filtered-COD (Geometric Mean = 19 mg/L), it may be concluded that the majority (close to 70 percent) of pollutants are in suspended or settled form rather than in dissolved form. COD values ranged from 3 to 344 mg/L.

Concentrations of TSS (Geometric Mean = 59 mg/L) are more than one-half of the VSS concentration (Geometric Mean = 23 mg/L). This means that more than one-half (6 0 percent) of the suspended solids are made up of non-reactive or inert matter. This inert matter could be grit from the surface of the roadway. TSS concentrations ranged from five to 310 mg/L while VSS concentrations ranged from 2.5 to 90 mg/L.

There is a first flush of contaminant transport in rainfall runoff from Cross Lake Bridge. On the average, 35 percent of the mass load is transported in the first 25 percent of the runoff volume sampled, 60 percent in the first 50 percent, and 80 percent in the first 75 percent.

Comparison with other Data

Table 6 compares data of the Cross Lake site with those of several other bridge sites. As shown, the Cross Lake site has higher average ammonia and phosphorus concentrations than the other sites but lower average TSS concentrations. The mean COD concentration falls slightly above the Highway 27 site but substantially below the other two sites. This is reasonable since the ADT for Highway 27 during the study was only 5000 vehicles/day, while the other two sites had substantially higher ADT values than the data available at the time for Cross Lake.

Table 6 – Comparison of Bridge Surface Pollutant Runoff Concentrations (mg/l) at Three Different Sites with Pollutant Concentrations Associated with Cross Lake Bridge [*37to 36],[38 to37],[39 to 38],[40 to 39],[41 to 40]*

Constituent	Cross Lake Bridge *Min-Max Average (Geom. Mean)*	I-95 Miami, Fl.[1] *Min-Max Average*	U.S. Highway 27, Tallahassee, Fl.[2] *Min-Max Average*	Lubbock, Tx.[3] *Min-Max Average*
COD	3.0-344 94 (62)	26-530 223	36-64 51	73-740 268
NH_3-N	0.20-2.5 0.77 (0.60)	0.04-0.50 0.17	0.00-11 0.04	X
Total Phosphorous as P	0.1-0.9 0.32 (0.26)	0.02-0.66 0.17	0.01-0.30 0.15	X
TSS	2.9-309.7 81.17 (59)	X	X	26-533 143
TVS	X	X	X	13-280 143

The comparison above illustrates one of the major problems in attempting to generalize results obtained from runoff studies. Because of the myriad of factors affecting the quality and quantity of runoff from any specific site, it becomes very difficult to generalize study results. For this reason some investigators have concluded that every site is different and thus warrants its own investigation.

Cross Lake Basin Performance

Once it became possible to sample both the inlet and outlet of the basin, the focus of the study shifted from an examination of the dynamics of the runoff events entering the basin to that of examining the performance of the basin as a "best management practice" for bridge deck runoff. This was done for three reasons:

1. By this time, it was apparent that traffic data was not going to be forthcoming,
2. It was felt that data relating to the performance of the basin would be of greater practical value to DOTD, and
3. This was a primary requirement of the NCHRP subcontract.

The method of operation for the holding pond has been referred to as a "batch system". A batch system means that each runoff event was monitored and sampled as it occurred. Once the pond was deemed "full", a gate valve at the effluent end was opened and the contents released. As the release occurred, samples were collected and the flow rate logged at one-minute intervals. The number of individual events monitored between releases could range from one to as many as four or five. The period between sequential pond releases is termed a "drainage event". Twenty-eight separate drainage events (77 rainfall events) for which complete data is available were analyzed.

In order to determine the effectiveness of the basin in removing contaminants from the bridge runoff, the total load entering the basin was computed. This total load may be composed of loads from one or more runoff events. Then, the computed pollutant load leaving the basin is computed. The difference between these values is the amount of contaminant that was retained in the basin during that drainage event. Loads may be computed in two different ways. In one case, discrete samples are collected across the runoff hydrograph. The pollutant concentrations are multiplied by their respective flows to obtain a curve of pollutant flux versus time. The area under the curve is the pollutant load for that event. A second procedure is to create a flow- weighted, composite sample from the discrete samples collected. The pollutant concentrations from this sample, called event mean concentrations, are then multiplied by the flow volume to obtain the pollutant load. If discrete samples have been evenly collected across the runoff hydrograph, both methods produce similar results. Results are shown in table 7. Results for all individual drainage events for TSS are shown in table 8.

Table 7 Removal Efficiency – Cross Lake Holding Basin

Pollutants	Number of Drainage Events	Median EMC at inflow, mg/l	Median EMC at outflow, mg/l	Median Removal %
Total Suspended Solids (TSS)	32	61.99	9.00	85
Chemical Oxygen Demand (COD)	33	64.49	28.75	61
Total Phosphorus (TP)	33	0.28	0.15	57
Ammonia (NH_3)	33	0.59	0.13	77
Nitrate (NO_3)	25	1.62	1.05	38
Oil & Grease (O&G)	20	13.99	1.60	82
Total Petroleum Hydrocarbons (TPH)	20	8.56	0.00	100

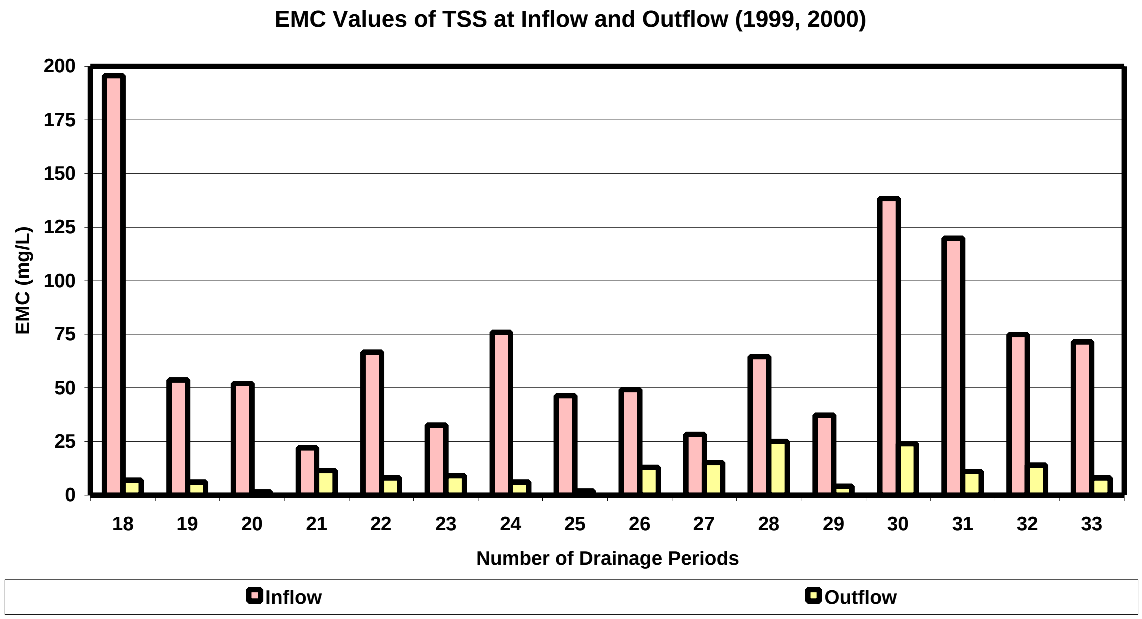
Note: Non-detectable concentrations are taken as zero for computation of median values and removal efficiencies.

Table 8 - Basin Performance for TSS Removals - 32 drainage events

DRAINAGE EVENTS	DRAINAGE PERIODS	TSS EMC AT INLET (mg/l)	TSS EMC AT OUTLET (mg/l)	EMC REMOVAL EFFICIENCY (percent)
1	6/17 to 7/8 1997	-	-	-
2	8/14 to 9/4 1997	73.71	24.62	67
3	9/5 to 9/27 1997	77.84	16.55	79
4	9/28 to 10/24 1997	67.98	8.59	87
5	10/25 to 11/6 1997	76.62	8.55	89
6	11/7 to 12/6 1997	57.00	10.14	82
7	1/10 to 1/30 1998	59.36	5.00	92
8	1/31 to 2/13 1998	32.41	7.49	77
9	4/2 to 6/15 1998	164.29	20.00	88
10	6/16 to 7/27 1998	95.85	18.00	81
11	7/28 to 8/7 1998	84.00	4.00	95
12	8/08 to 8/28 1998	57.21	25.00	56
13	8/29 to 9/12 1998	51.14	14.00	73
14	9/13 to 9/16 1998	22.00	11.3	49
15	9/17 to 10/8 1998	13.73	8.80	36
16	10/23 to 11/10 1998	45.61	3.00	93
17	11/11 to 11/15 1998	71.48	9.00	87
18	2/4 to 3/9 1999	195.61	7.00	96
19	3/10 to 3/14 1999	53.66	6.00	89
20	3/15 to 4/1 1999	52.03	1.50	97
21	4/2 to 4/12 1999	21.90	11.37	48
22	4/23 to 5/6 1999	66.67	8.00	88
23	5/7 to 5/24 1999	32.53	9.00	72
24	6/2 to 6/23 1999	75.90	6.00	92
25	6/27 to 7/18 1999	46.40	2.00	96
26	7/27 to 9/9 1999	49.08	13.00	74
27	9/10 to 10/21 1999	28.35	15.00	47
28	10/22 to 11/24 1999	64.61	25.00	61
29	12/4 to 12/20 1999	37.40	4.00	89
30	2/4 to 3/16 2000	138.30	24.00	83
31	3/27 to 3/30 2000	119.68	11.00	91
32	3/31 to 4/11 2000	74.85	14.00	81
33	4/12 to 4/24 2000	71.46	8.00	89
Median		**61.99**	**9.00**	**85**

As shown, mass balances were computed for total suspended solids (TSS), chemical oxygen demand (COD), total phosphorus, ammonia, nitrate, oil and grease(O@G), and total petroleum hydrocarbons (TPH). The number of drainage events varied from 20 to 33. The highest removal efficiency (100 percent) occurred for TPH. The actual concentrations for TPH measured were small in all cases and removal probably occurred largely as a result of volatilization. The same mechanism explains oil and grease removals. For the more common contaminants, TSS had the highest removals (85 percent), presumably due to settling. Removals of COD averaged 61 percent and tracked TSS removals reasonably well, suggesting that much of the COD may have been associated with suspended solids. The same is true for total phosphorous. Ammonia removal probably occurred as a result of microbial uptake and conversion to nitrate. This would explain the low removal efficiency for nitrate.

Inlet and outlet EMC values for some drainage events occurring in 1999 and 2000 are shown graphically in figure 6 below. Similar graphics are available for all drainage events for all pollutants mentioned.


EMC Values of TSS at Inflow and Outflow (1999, 2000)
EMC (mg/L)
200
175
150
125
100
75
50
25
0
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
Number of Drainage Periods
Inflow
Outflow

Pollutant Loadings

Pollutant loadings, normalized with respect to the bridge area and rainfall are listed in table 9.

Table 9 – Mean Pollutant Loadings – Cross Lake Holding Pond			
Pollutants	Total rainfall (Inches)	Loading Rate – Inflow Lbs/acre*inch	Loading Rate – Outflow Lbs/acre*inch
Total suspended solids (TSS)	71.39	13.75	2.39
Chemical Oxygen demand (COD)	75.01	13.20	5.79
Total Phosphorous (TP)	75.01	0.07	0.04
Ammonia (NH3)	75.01	0.10	0.03
Nitrate (NO_3^-)	56.48	0.44	0.41
Oil and Grease (O@G)	51.81	3.25	1.21
Total Petroleum Hydrocarbons (TPH)	51.81	2.23	0.42

COD exhibited the highest average inflow loading for the drainage events measured, while TSS had the second highest loading. These loadings can be used as a comparison to those created as a result of wastewater generation. For example, a 1-inch rainfall on the Cross Lake bridge results in a COD load equivalent to 100,000 gallons of untreated wastewater with a COD of 300 mg/L. The total mass of TSS that was measured entering the basin was approximately 20,000 pounds, equivalent to eight million gallons of wastewater with a TSS concentration of 300 mg/L. Assuming a three-year study period, this is approximately 6,600 pounds per year. The mass of solids discharged to the environment from the pond was approximately 3500 pounds over the same period. These numbers are important because they indicate the quantity of material that will have to be removed from the pond and disposed of elsewhere if the pond is to be an effective best management practice.

As noted previously, observed runoff coefficients suggest that as much as 50 percent of the rain falling on the bridge does not flow to the pond. Thus, pollutant quantities comparable to those above may have been discharged into Cross Lake over the same period.

Metals

Although the analysis of heavy metals was not part of the original work order, several water/sediment samples were collected and analyzed. The results are shown in table 10.

Table 10 Metal Concentrations in Liquid and on Sediment – Selected Events Cross Lake Holding Pond												
Collection date	Test Date	Sample type	Copper (ppb)	Lead (ppb)	Arsenic (ppb)	Selenium (ppb)	Cadmium (ppb)	Chromium (ppb)	Zinc (ppb)	Manganese (ppb)	Mercury (ppb)
9/29/99	10/8/99	Water (Outlet)	25.12	18.58	6.9	3.51	ND	14.67	116.94	-	-
11/12/99	2/16/00	Water	74.09	15.96	0.28	0.95	ND	0.68	65.64	-	-
		Solid	52,550	50,560	160	ND	1000	19,160	340,690	-	-
2/24/00	3/1/00	Water	109.24	22.2	2.34	99.33	ND	ND	496	234.68	928.6
		Solid	58,320	31,030	700	665	745	6300	227,515	50,935	21,606
3/12/00	3/14/00 to 3/17/00	Water (inlet)	7.9	2.55	0.23	1.68	0.09	1.54	158.65	112.99	6.13
		Water (outlet)	9.6	2.57	0.11	2.14	0.10	1.22	165.12	3387.06	7.82
3/24/00	4/9/00 to 4/12/00	Water	78.17	38.56	0.69	1.75	0.1	11.97	816	18.39	101.79
		solid	98,320	92,400	1,440	285	4,180	27,100	589,350	11,520	5,455

If it is assumed that the water/sediment samples collected were at equilibrium, then it is obvious that the great majority of the metals reside on the sediment. Partitioning coefficients are on the order of several thousand. This is significant because it means that if the solids can be removed from runoff, then a large fraction of the metals will also be removed.

DISCUSSION

The degree to which the objectives of this study were met is discussed below.

Objective 1 *[to determine a correlation between traffic flow and water runoff quality for this bridge and similar settings]* could not be met because of difficulties encountered in obtaining traffic data. While traffic counters were installed in early November of 1996, traffic data could not be obtained from DOTD until early 1999, just before the project ended, when the principal investigator and/or his students were given permission to download the traffic counters. However, the small amount of traffic data obtained at the start of the study (1996) suggested ADT values at or just above 30,000 vehicles per day. More recent data (March 2000) indicate average ADT values over 40,000 per day. This is significant because it suggests that traffic density on I-220 is rising and has passed the generally agreed upon value (30,000 ADT) where water quality deterioration is assumed minimal.

Objective 2 *[to determine the relationship between water runoff quality from the bridge and effluent quality from the detention pond, and to develop a predictive relationship for similar settings]* was met in part but not during the monitoring period specified in the original DNR agreement and probably not in the way anticipated by that agreement. The initial funding provided by DNR was not sufficient to purchase flow measuring and sampling equipment for the site. This equipment was originally provided by LTRC and later by Louisiana Tech University. However, additional funding during 1996/1997, primarily by LTRC and to a lesser extent by NCHRP, allowed American Sigma flowmeter/samplers to be placed at the inlet and outlet of the pond. This allowed for the evaluation of the efficiency of the pond in removal of contaminants over an extended period. While it is not possible to develop a meaningful predictive relationship, it has been shown that the Cross Lake basin is both effective and reliable in removing solids and the contaminants associated with them. The primary contaminant removal mechanism at the Cross Lake facility is settling, which proved quite effective in removing sediment and sediment associated contaminants such as metals. Such a process would be expected to provide similar results elsewhere. In addition, it was determined that the drainage system contained substantial leaks that may result in substantial leakage to Cross Lake. Both of these findings have considerable practical usefulness (perhaps more than the original objective) given that regulatory agencies are now interested in quantifying and managing runoff quantity and quality.

Objective 3 *[to quantify pollutant loads entering and leaving the Cross Lake Holding Pond]* was met. Pollutant loads into and out of the basin were computed and expressed as either pounds per curb mile or pounds per acre-in. These data can be used to estimate the quantity of material that will have to be removed from the basin and disposed of.

Objective 4 *[to assess the efficiency of the Cross Lake Holding Pond in removing contaminants from bridge runoff]* was met as it was realized that the efficiency of the basin in removing contaminants would be of critical, practical importance in determining the utility of holding basins as part of any best management practice scenario for a variety of existing DOTD facilities. As a result, later portions of the project concentrated on this characteristic of the basin.

One of the difficulties of research of non-point contamination is that there are very few aspects of this study that can be generalized to other sites. The efficiency of the Cross Lake holding basin with respect to TSS removal is similar to that obtained in other studies; however, additional generalizations could not be made when this study was compared to several others. This has led some researchers to suggest that every site should be studied individually.

CONCLUSIONS

1. Holding ponds such as the one at Cross Lake can be very effective in removing sediment [mean TSS removal 85 percent] and sediment bound contaminants such as heavy metals from runoff.

2. Holding ponds are relatively simple, low maintenance systems that can be employed as a best management practice (BMP) at a number of DOTD facilities and be a major factor in reducing non-point contamination at existing DOTD facilities such as district offices and maintenance yards.

3. Holding ponds appear to be a simple and relatively inexpensive way of complying with upcoming federal and state mandates regarding the export of non-point contamination from DOTD facilities**.**

RECOMMENDATIONS

1. It is recommended that a program be instituted to have the holding pond cleaned regularly.

2. It is recommended that leaks in the Cross Lake bridge drainage system be repaired. This will protect the lake and allow for better quality data to be collected should additional research be carried out on the bridge. Recent information from local DOTD personnel indicates this may have already been accomplished.

3. It is recommended that some type of structure be erected near the outlet of the pond to help minimize contaminant losses due to scour when the pond is emptied.

4. It is strongly recommended that DOTD investigate the economic and technical feasibility of similar systems at other DOTD facilities in Louisiana.

REFERENCES

1. Houck, O, A. The Clean Water Act TMDL Program: Law, Policy and Implementation, Environmental Law Institute, 1999.

2. Corbitt, A., *Standard Handbook of Environmental Engineering*, McGraw Hill, Inc, 1889.

3.Gupta, M. K., Agnew, R. W., and Kobriger, N. P., *Constituents of Highway Runoff Volume I, State-of-the-Art Report*, Report No. FHWA / RD-81 / 042, Federal Highway Administration, Washington, DC, 1981.

4. Kobrieger, N. P., and Geinopolos, A. *Sources and Migration of Highway Runoff Pollutants: Volume III-Research Report*. Report FHWA/RD-84/059. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. 1984.

5. Novotny, V., and Chesters, G*., Handbook of Non-point Pollution*, Van Nostrand Reinhold Company, New York, New York. 1981.

6. Metcalf and Eddy, Inc., *Wastewater Engineering: Treatment, Disposal, Reuse*, McGraw Hill Book Company, NY, 1991.

7. Research Results Digest, "Assessment of Impacts of Bridge Deck Runoff Contaminants on Receiving Waters," Number 235 National Cooperative Highway Research Program, January 1999.

8. Gupta, M. K.; Agnew, R. W ., Gruber, D.; and Kreutzberger, W., *Constituents of Highway Runoff Volume IV, Characteristics of Highway Runoff from operating Highways,* Report No. FHWA / RD-81 / 045, Federal Highway Administration, Washington, DC, 1981.

9. Kobrieger, N. P., and Geinopolos, A. *Sources and Migration of Highway Runoff Pollutants: Volume III-Research Report*. Report FHWA/RD-84/059. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. 1984.

10. Dupuis, T.V., et al., "Effects of Highway Runoff on Receiving Waters" Volume II: Research Report, Report No FHWA/RD-84/063, August 1985.

11. Dalton, Dalton, and Newport/URS, "Highway Maintenance Impacts to Water Quality - Executive Summary, Volume I" Report No. FHWA/RD-85/057, March 1985.

12. Dalton, Dalton, and Newport/URS, “Investigations of Impacts of Selected Maintenance Practices on Water Quality - Volume II” Report No. FHWA/RD-85/058, March 1985.

13. Versar, Inc., “Management Practices for Mitigation of Highway Stormwater Runoff Pollution - Volume IV: Executive Summary” Report No FHWA/RD-85/004, 1985.

14. Driscoll, E.G., et al, “Pollutant Loadings and Impacts from Highway Stormwater Runoff”, Volume I: Design Procedure”, Report No. FHWA/RD - 88-006, April 1990.

15. Young, G. K. et al., “Evaluation and Management of Highway Water Quality” Publication No. FHWA/PD 96-032, June 1996.

16. Dupuis, T.V., et al., “Effects of Highway Runoff on Receiving Waters” Volume II: Research Report, Report No FHWA/RD-84/063, August 1985.

17. Yousef, Y.A. et al., Fate of Heavy Metals in Stormwater Runoff from Highway Bridges”, Science of the Total Environment, Vol 33, Feb. 1984, pp. 233-244.

18. Wanielista, M. P., et al, “Management of Runoff From Highway Bridges, Report No. FL-ER-10-80, prepared for Florida DOT, 1980.

19. Dorman, M. E.; Hartigan, J.; Johnson, F.; and Maestri, B*., Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff-Interim Design Guidelines for Management Measures,* Report FHWA/RD-87/056, Federal Highway Administration, U. S. Department of Transportation, McLean, Va., June 1987a.

20. Dorman, M. E., Hartigan, J.; Steg, R.F.; and Quasebarth, T, *Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff: Volume I , Research Report,* Report FHWA/RD-89/202, Federal Highway Administration, U. S. Department of Transportation, McLean, Va., 1987b.

21. Burch, C. W.; Johnson, F.; and Maestri, B., *Management Practices for Mitigation of Highway Stormwater Runoff Pollution, Vol. II: Literature Review. Report* FHWA/RD-85-002, Federal Highway Administration, U. S. Department of Transportation, McLean, Va., Sept. 1985b.

22. Whipple, W., and Hunter, J. V., *Settleability of Urban Runoff Pollution*, Journal Water Pollution Control Federation, vol. 53, No. 12, Dec., 1981., pp. 1726-1731.

23. Randall, C. W.; Ellis, K.; Grizzard,T.; and Knocke, W. R.; *Urban Runoff Pollutant Removal by Sedimentation*, Proceeding Stormwater Detention Facilities, New England College, Henniker, N. H., August 1982.

24. Stanley, D. W., *An Evaluation of Pollutant Removal by a Demonstration Urban Stormwater Detention Pond*, Report No. APES 94-07, The Albemarle-Pamlico Estuarine Study, North Carolina Department of Environment, Health and Natural Resources, Raleigh, N. C., 1994.

25. Dorman, M. E., *A Methodology for the Design of Wet Detention Basins for Treatment of Highway Stormwater Runoff*, MS Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, January, 1991.

26. McCuen, R. H., *Water Quality Trap Efficiency of Stormwater Management Basins*, Water Resources Bulletin, Vol. 1, 1980, pp. 15-21.

27. Streigl, R. G., *Suspended Sediment and Metals Removal from Urban Runoff by a Small Lake*, Water Resources Bulletin, vol. 23, No. 6, pp. 985-996, Dec., 1987.

28. Kathuria, D. V.; Nawrocki, M. A.; and Becker, B. C.; *Effectiveness of Surface Mine Sedimentation Ponds*, EPA-600/2-76-117, U. S. Environmental Protection Agency, Cincinnati, OH, August 1976.

29. Stanley, D. W., *An Evaluation of Pollutant Removal by a Demonstration Urban Stormwater Detention Pond*, Report No. APES 94-07, The Albemarle-Pamlico Estuarine Study, North Caroliina Department of Environment, Health and Natural Resources, Raleigh, N. C., 1994.

30. House, L.B.; Waschbusch, R.J.; and Hughes, P. E.; *Water Quality of an Urban Wet Detention Pond in Madison, Wisconsin*", U. S. Geological Survey, Open-File Report 93-172, Madison, Wisconsin, 1993.

31. Dorman, M. E.; Hartigan, J.; Steg, R.F.; and Quasebarth, T.*; Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff: Volume I , Research Report,* Report FHWA-RD-96-095, Federal Highway Administration, U. S. Department of Transportation, McLean, Va., 1996.

32. U. S. Environmental Protection Agency, *Final Report of the Nationwide Urban Runoff Program* vol. 1, U. S. Environmental Protection Agency, Washington, DC, September 1983.

33. Wu, C. J*., Performance of Urban Wet Detention Ponds*, MS Thesis, University of North Carolina at Charlotte, N. C., 1988.

34. Kantrowitz, I. H. and Woodham, W. M., *Efficiency of a Stormwater Detention Pond in Reducing Loads of Chemical and Physical Constituents in Urban Streamflow, Pinellas County, Florida*, U. S. Geological Survey, Water Resources Investigations Report 94-4217, Tallahassee, Florida, 1995.

35. Martin, E. H. and Smoot, J.L., *Constituent-Load changes in Urban Stormwater Runoff Routed through a Detention Pond-Wetlands Systems in Central Florida*, U. S. Geological Survey Water-Resources Investigation Report 85-4310, Tallhassee, Florida, 1986.

36. Gain, W. S., *The Effects of Flow-Path Modification on Water Quality Constituent Retention in an Urban Stormwater Detention Pond and Wetland System, Orlando, Florida*, U. S. Geological Survey, Water Resources Investigation Report 95-4297, Orlando, Florida, 1995.

37. Holler, J. D., *Storm Water Detention Basin Nutrient Removal Efficiency*, Journal of Water Resources, Planning and Management, ASCE, 115(1), pp. 52-63, 1989.

38. MckKenzie, D.J., and Irwin, G.A., "Water-Quality Assessment of Stormwater Runoff from a Heavily Used Urban Highway Bridge in Miami, Florida", Water-Resources Investigations 84-4153, US Geological Survey, Tallahassee, Florida,1983.

39. Irwin, G.A., and Losey, G.T. "Water-Quality Assessment of Runoff from a rural Highway Bridge near Tallahassee, Florida", Water-Resources Investigations 79-1, US Geological Survey, Tallahassee, Florida 32303. January 1979.

40. Moe, R.D. et. al. "Characteristics of Highway Runoff in Texas", U.S. Department of Transportation and Development, Federal Highway Administration, Office of Research and Development, Washington, D.C. 1977.

41. Griffin, Jr., D.M.; Eslami – Nodushan, M.; Shrestha, S., "Investigation of Factors Affecting Non-point Source Contamination from the I-220", Cross Lake Bridge, Louisiana Transportation Research Center, DNR Interagency Agreement No. 25104 -96-01, OCR Interagency Work Agreement No. 435 – 600009, CFMS No. 506874, January 31, 1997.