WATER QUALITY ENHANCEMENT ASSESSMENT
OF AN EXISTING FLOOD CONTROL DETENTION
FACILITY IN THE CITY OF TULSA, OKLAHOMA

By

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1994

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 2006

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CHAPTER I

INTRODUCTION

From ancient civilizations to the present, waste streams have been directed to wetlands for treatment and disposal. During the early part of this century many wetlands were drained and altered, and their functions lost. Now wetlands are recognized as among the most productive and valuable ecosystems providing an abundance of flora and fauna, wildlife habitat and flood control. Constructed wetlands have been built to duplicate many of these benefits and functions, often times designed for a multitude of reasons to accommodate the need for human development (Kentula 2002; Lipa and Strecker, 2004; Strecker, et al. 2001; Carter Burgess, Inc., 2001). Stormwater has been identified as a source of pollution to urban streams, carrying any number of pollutants associated with various uses of the land. Since the promulgation of the Clean Water Act and the National Pollution Discharge Elimination System program, constructed wetlands have been added to the list of Best Management Practices (BMP) that Municipal Separate Storm Sewer System (MS4) utility managers can incorporate into stormwater management plans to address the impacts of human development on urban streams (City of Tulsa, 1994). This study's attempt to assess the effectiveness of this BMP testifies to today's awareness of the impact of stormwater runoff and the value of the beneficial uses ascribed to urban water bodies.

The City of Tulsa, as an owner and operator of an MS4, is required to evaluate the effectiveness of the management practices used to ensure that the stormwater discharged into waters of the state is of good quality and relatively contaminant-free. One such BMP is the Heatherridge Stormwater Detention Facility (Heatherridge). Heatherridge was constructed as a dual-purpose flood control facility and constructed wetland to mitigate the impact on wetlands due to the construction of the Creek Nation Turnpike through the southeast region of Tulsa, Oklahoma (BKL, 1991). Since its construction, the City of Tulsa has gathered data on samples taken from the influent and effluent structures of the wetland during several storm events, assuming a twelve-hour detention time based on an engineering estimate (City of Tulsa, 1999). The City has concluded from the data that water quality is enhanced by the wetland (Haye, 1999). This study will gather water quality data (as defined by the concentration of various elements and compounds) from both the influent and the effluent of this constructed wetland facility utilizing Rhodamine WT (RWT) dye as a tool to help identify the detention time.

Project Background

The City of Tulsa, with a population of 375,000, covers 200 square miles of gently rolling terrain in northeastern Oklahoma. Tulsa, located on the Arkansas River, contains some 56 creeks and drainage basins. Rainfall averages 42.42 inches per year (National Weather Service, 2005), with occasional heavy thunderstorms. Located in southeast Tulsa, Heatherridge is a constructed wetland, created as part of a plan to mitigate approximately 15 acres of wetland, wetland habitat, riparian forest, and associated wildlife habitat impacted by the construction of the Creek Turnpike in 1995 (Haye, 1995). Tulsa chose to build Heatherridge in response to Section 404 of the Clean Water Act mandate to compensate for impacted natural wetlands (EPA 1993). The drainage area is 240 acres, mostly residential and light commercial land use. The detention basin was designed for a 100-year frequency storm. As designed, the peak inflow is 1276 cubic feet per second (cfs), and the outfall is 38 cfs maintained by a water level control structure. The volume of flood storage is 115 acre-feet with a 12 hour design detention time. A permanent pool covers approximately nine acres of the facility. Four zones of wetland plants were installed. Consultation for plant selection was provided by the US Army Corps of Engineers, Lewisville Aquatic Ecosystem Research Facility, Lewisville, Texas (US Army COE, 1995). The survival rate of these plants was evaluated in 1999 and at the time, the rate was estimated to be "good" (Haye, 1999). The five-year Monitoring Plan for the site did not include a water quality component (HNTB, 1990).

The 1972 amendments to the Federal Water Pollution Control Act (Clean Water Act) prohibit the discharge of any pollutant to navigable waters from a point source unless the discharge is authorized by a National Pollutant Discharge Elimination System (NPDES) Permit. The Water Quality Act of 1987 broadens the requirements of the Clean Water Act to mandate a phased approach to regulate stormwater discharges, through coverage under the NPDES permit program. The first phase of regulation applied to the following stormwater discharges:

- Stormwater discharges associated with industrial activity;
- Stormwater discharges from a municipal separate storm sewer system (MS4) serving a population of 250,000 or more (a large system);
- Stormwater discharges from a MS4 serving a population of more than 100,000 but less than 250,000 (a medium system);
- Stormwater discharges regulated under an existing permit; and
- Stormwater discharges designated by EPA or the State as contributing to the violation of the water quality standard or as a significant contributor of pollutants to the waters of the United States.

The City of Tulsa, as an operator of a large MS4, filed a Notice of Intent to the USEPA seeking coverage under the NPDES Storm Water Discharge Permit in 1990. Under the issued permit, the City of Tulsa is required to meet certain terms and conditions, which include:

- Monitoring of representative stormwater discharges;
- Development and implementation of Pollution Prevention and Public Awareness Programs;
- Development and implementation of maintenance schedules and protocols for the stormwater management system;
- Assessment of existing flood control facilities for potential structural improvements to enhance water quality; and
- Completion and submittal of Annual Reports describing the progress/implementation of the programs listed above.

This study details an evaluation of Heatherridge, in the City of Tulsa, performed in accordance with the requirements of the City of Tulsa's current National Pollution Discharge Elimination System permit, Proposed Management Program (EPA 2002). The Flood Control Project section of the Storm Water Quality Management Programs for NPDES Permit #OKS000201 (Oklahoma Department of Environmental Quality, 2003) states:

> "Impacts on receiving water quality shall be assessed for all flood management projects. The feasibility of retrofitting existing structural flood control devices to provide additional pollutant removal from storm water shall be evaluated."

Retrofits are structural stormwater management measures for urban watersheds designed to help minimize accelerated channel erosion, reduce pollutant loads, promote conditions for improved aquatic habitat, and correct past mistakes. In order to determine if an existing structural control device can benefit from retrofitting, one must first determine which benefits to evaluate and the extent to which the facility is or is not affecting stormwater in its current condition.

Objectives and Scope

The primary objective of this study is to quantify the degree of natural attenuation of specific contaminants in stormwater as it passes through a constructed wetland. Retrofits to enhance water quality of runoff from the Heatherridge watershed will be discussed. The secondary objective will be to assess the effectiveness of the dye tracer as a tool to ensure the same parcel of water was sampled at both the influent and effluent and in quantifying the detention time of individual events.

Site Description

Heatherridge is an in-stream emergent vegetative constructed wetland in Tulsa, Oklahoma (Figure 1). The landscape design incorporated plants selected to improve water quality (Smart and Doyle, 1995; U.S. Army Corps Of Engineers, 1995). Heatherridge receives flow from Fry Ditch 2 which flows southerly from a mixed residential, commercial watershed and enters the west cell of Heatherridge via the influent structure which consists of a triple 8'X 8' reinforced concrete box culvert, with gabion structures flanking both the upstream and downstream sides. The west cell is connected to the east cell by an equalization structure consisting of two 24" reinforced concrete pipes that run under a utility road as required by the Oklahoma Turnpike Authority (OTA) as part of the wetland mitigation requirements established by the US Army Corps of Engineers (BKL, 1992). A road separates the west and east cells along a sanitary sewer line that remains in place due to the cost constraints related to moving the line (Figure 1). There is a sedimentation basin just downstream of the influent structure on the west cell. An effluent metering structure at the south end of the eastern cell drains the wetland through a 24” reinforced concrete pipe (BKL, 1992).

Figure 1: Aerial view of Heatherridge Wetland including latitude and longitude. The numbers identify the sampling locations monitored between events.

Historical data from Heatherridge provides evidence that the watershed is a typical urban type (Appendix C). This study analyzed data on constituents commonly of concern in stormwater for which there is a relatively large amount of data (Carleton et al., 2001; Pitt et al., 1995).

CHAPTER II

REVIEW OF LITERATURE

The science of wetland creation is a growing field of scientific endeavor (Whigham, 1999). Current regulatory policy has a goal of "No Net Loss" of wetlands, and the Corps of Engineers requires an assessment of the functions of a wetland as part of their permitting process. In some cases the debate of the success or failure of this policy revolves around whether a created wetland can replace a natural wetland in terms of value or function. Some restored or created wetlands mimic functions of natural wetlands, but the similarity depends upon the assessment procedure. Many wetland assessment methods emphasize the importance of the role the wetland plays in the ecosystem (Brinson, 1993; Whigham, 1999; Bidwell and Gorrie 1998). The success or failure of a constructed wetland project is relative to the goal of each project and what measurement criteria are used in the assessment. The design criteria for a created wetland may include the project goal of recreating a particular function. This being said, it is theorized that a constructed wetland in a residential watershed can decrease contaminant loading to the ultimate receiving body of water (Oklahoma Conservation Commission, 1996) and is often addressed during the design phase as a goal of the project. Pollution removal in a constructed wetland is highly dependent on runoff and wetland hydrology. Storms occur at irregular intervals, which affects the amount of runoff. They vary widely in intensity and duration, which affects pollution loading by affecting runoff volume. They occur in all seasons and impact wetlands at differing vegetative states. Wetlands vary widely in volume, surface area, and vegetation cover. The functions performed by wetlands are dependant on the above characteristics (Meshek and Associates, 1998). An understanding of these characteristics will help with the evaluation. This literature survey examines some of the many factors that must be addressed.

Factors Affecting Stormwater Wetland Design

Stormwater utility managers consider stormwater contaminants in urban watersheds as they choose appropriate management practices to match the goal of the management plan. When a specific contaminant is the focus of the management plan, the design of the wetland must optimize those functions which best attenuate that pollutant. Flood attenuation is often a primary concern. Wildlife habitat, passive and active recreation and a multitude of other factors can be considered. Research has helped to define the nature of stormwater runoff from residential land uses by identifying how many human influences, within the watershed, affect pollutant loading and the hydrologic regime. Table 1 (Monroe County, 2005) identifies typical pollutants and their impacts. These human impacts are site specific depending on population. The parameters chosen for this study and the historical data of the study site are similar to the conventional stormwater pollutants (Pitt et al., 2004; Carleton et al., 2001; Heatherridge Historical and Removal Efficiency Data, Appendix C). It is important to consider the impact stormwater pollutants have on the environment. This will help decide appropriate controls based on the overall objective of the management plan. For example, the interrelations of pollutants may make it advantageous to target suspended solids to capture a portion of the total phosphorous Carleton et al., 2001).

Inflow Characteristics

Water quality parameters frequently lump individual chemical compounds into a class of materials (Kadlec, 2002). For example: total suspended solids (TSS) can include an organic fraction and an inorganic fraction. Biological oxygen demand (BOD) can result from grass clippings or animal waste. Within these lumped parameters there are compounds with varying biological and chemical decomposition rates. The overall concentration of BOD and other lumped parameters tells only some of the story of the nature and quality of the stormwater runoff (Kadlec, 2002).

Table 1: Impacts of Urban Runoff Illustrating the Need for Stormwater Treatment

Category	Parameters	Possible Sources	Effects
Sediments	Organic & Inorganic: Total Suspended Solids Turbidity Dissolved Solids	Construction Sites Urban/Agriculture Landfills Septic Tanks	Turbidity Habitat Alteration Recreation/Aesthetic Loss Contamination Transport Bank Erosion
Nutrients	Nitrates & Nitrites Ammonia Organic Nitrogen Phosphorus	Urban/Agriculture Landfills Septic Tanks Atmospheric Deposition Erosion	Surface Water Algal Blooms Ammonia Toxicity Groundwater Nitrate Toxicity
Pathogens	Total and Fecal Coliforms Fecal Streptococci Viruses *E. Coli* Enterococci	Urban/Agriculture Septic Tanks Illicit Connections Boat Discharges Domestic/Wild Animals Sanitary Sewer Overflow	Ear/Intestinal Infections Recreation/Aesthetic Loss
Organic Enrichment	Total Organic Carbon Biochemical Oxygen Demand Chemical Oxygen Demand	Urban/Agriculture Sanitary Sewer Overflow Landfills Septic Tanks	Dissolved Oxygen Depletion Odors Fish Kills
Toxic Pollutants	Toxic Metals Toxic Organic Material Oil and Grease	Urban/Agriculture Pesticides/Herbicides Underground Storage Tanks Hazardous Wastes Sites Landfills Illegal Oil Disposal	Bio-accumulation Human Toxicity

Source: Monroe County, 2005

Meshek and Associates (1998) describe the phenomenon known as first flush stormwater to be the initial pulse of runoff from a storm event, which will wash off built-up surface pollutants in concentrations significantly higher than subsequent runoff flows. They then qualify this assumption to account for small sub-basins, which generally exhibit this effect and contribute to the flow of the channel that feeds directly into the facility at various times. This results in a variable pollutograph (which shows the concentration of pollutants in the inflow relative to time) into the facility. It is important to characterize the water quality of each sub-basin entering the treatment facility because that will help characterize the typical shape of the pollutograph.

It is relatively easy to design a flood control structure and assess the effectiveness. The tools used to measure the effectiveness of the design of such facilities are easily transferable to watersheds worldwide. Flooding is quite often associated with very large and relatively rare storm events, whereas much of the pollutant load from rain occurs during the first flush of each storm event, large or small. The varied goals of stormwater management programs and the varied land uses involved make design for water quality enhancement difficult and inherently more site specific. The first flush effect is not present in all land uses, and not for all constituents during any one storm event. Not only does the phenomenon of first flush depend on land use, it is also relative to the peak flow of the storm event (Maestre and Pitt, 2004). A detailed analysis of the nature of the watershed will allow for a more accurate prediction of inflow quality and contaminant removal potential.

Detention Time

Pollutant detention time and potential treatment efficiency depend on the shape of the inflow hydrograph to the system, the shape of the pollutograph, and the volume of the pool according to model simulations by Somes et al. (2000). The storm event hydrograph and pollutograph can take various shapes depending on watershed characteristics, rainfall duration and intensity, and the location of pollution sources relative to the treatment facility. The hypothetical triangular hydrograph shape with a constant antecedent and subsequent base flow is illustrative. Two triangular runoff hydrographs, one with a 'peaky' shape and the other a flatter shape, both representing equal volumes, were used to illustrate the effect these factors have on storm water detention time routed through a wetland (Figure 2). The sampling protocol utilized in this study allows one to estimate detention times based on the measure of rainfall duration and intensity similar to Figure 2.

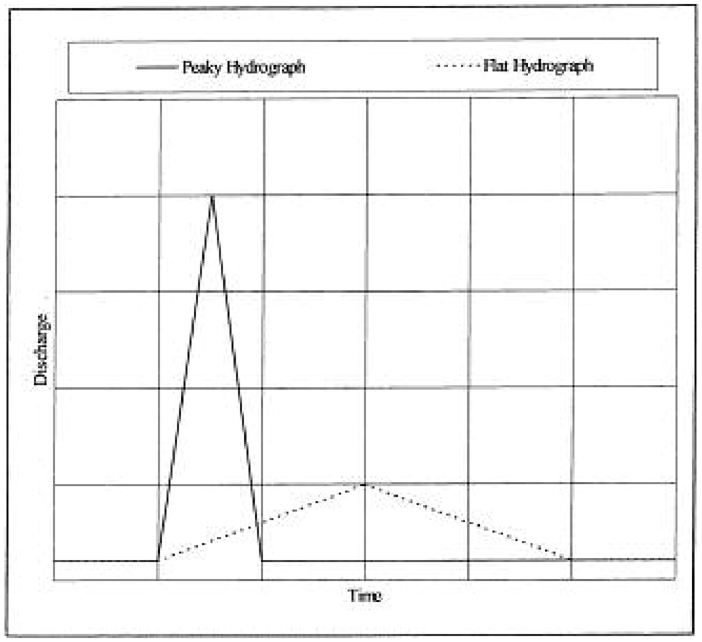

Figure 2: These typical hydrograph shapes illustrate the impact the hydrograph may have on detention times (Somes et al. 2000).

Figure 3 (Somes et al., 2000) shows how “parcels” of stormwater behave assuming ideal, uniform flow conditions when discrete water masses enter and leave the wetland on a first in-first out basis. However, other factors, which are typically found in wetland facilities, may induce a level of mixing contributing to less than first in-first out flow patterns (plug-flow). Somes et al. (2000) simulated a number of inflow hydrograph and pollutograph combinations to examine the effect on pollutant detention time and found that events that are less dynamic generally result in longer detention times. Wong et al. (1999) noted that the percentage of permanent pool volume to runoff volume affects detention time with large permanent pool volumes leading to longer detention times. The sampling procedure employed during this study benefited from this research as it allows for an estimation of the detention time based on the rainfall intensity and duration because the storm event criteria ensures the sampling of stormwater runoff and not base-flow.

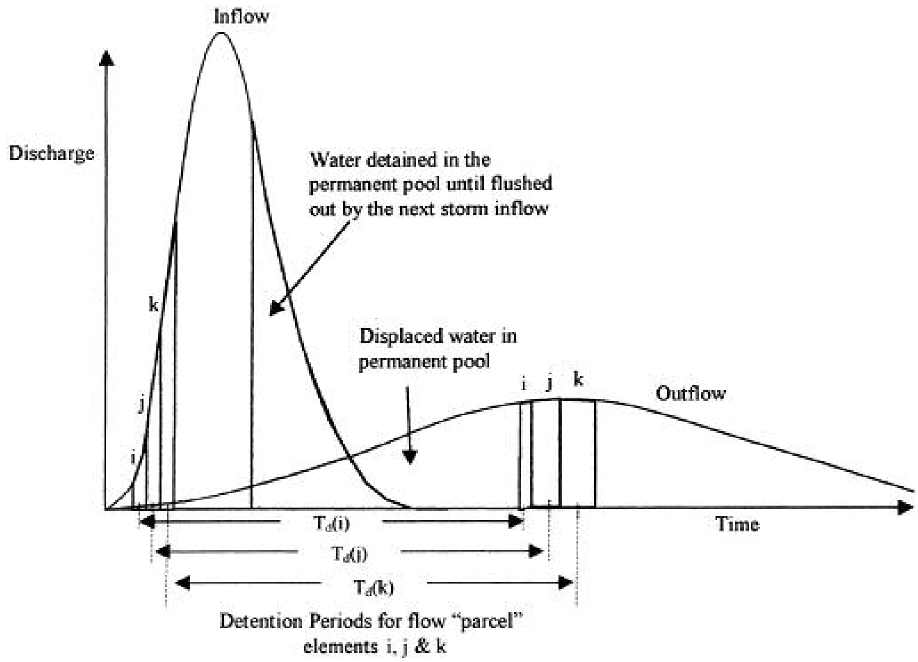

Figure 3: Illustration of detention period tracking of inflow assuming a "first in-first out" flow pattern (Somes et al. 2000).

Lee and Bang (2000) studied stormwater runoff characteristics in urban areas in Korea. They found that in highly residential, relatively small watersheds, the peak of 11 pollutant concentrations preceded the peak of the runoff, which is the general definition of a first flush effect. Samples were collected as a function of time beginning with the onset of the rain and ending when the flow receded to base. They found that as residential and commercial density and impervious cover decreased and watershed size increased, the first flush effect was less pronounced. They also found that the magnitude of pollutant mass loading rate is characterized in order of high-density residential watershed > low density residential watershed > industrial watershed > urban watershed.

Wetland Characteristics

Much research has been done to characterize wetland flow (Kadlec, 2000). To illustrate the various functions that act upon water as it travels through a wetland, Kadlec (2000, 2003) made the claim that the phenomena of distribution of detention times would occur as the result of stratified velocity profile effects, without any contribution from mixing attributable to various mixing processes including winds, preferential flows, islands of vegetation, or variations of the topography, but he did not elaborate on this claim. A slug injection (one time introduction) of a tracer dye into the influent typically produces a delayed, skewed bell-shape curve effluent concentration of dye when plotted as a function of time (Turner Designs, 2004a)

Kadlec (1994) slug injected dye into the inlet of a wetland. To ensure maximum mixing, the dye was poured into turbulent flow. Injecting a tracer into the wetland inlet and then measuring the tracer concentration as a function of time at the wetland outlet is a tool used to measure the residence time distribution. Kadlec (1994) concluded that the detention time of the studied wetland was intermediate between plug flow and completely mixed (ideal mixing pattern limits of water movement). The nominal detention time calculated from wetland volume and average flow (also called the detention time) can vary from that based on dynamic tracer studies (which are influenced by wetland functions such as sorption to wetland particulate materials and mixing) and flow measurements by as much as 50 percent (Kadlec, 1994). The seasonal variance of wetland vegetation is one of the variables that affect the volume of the wetland. Kadlec (1994) cites a study performed with RWT in a free water surface wetland that showed a peak dye concentration time equal to 67% of the mean dye detention time. This variance may be attributed to the space occupied by stems and litter as well as to wetland zones that do not mix with the main flow. This evidence justifies using an event-driven residence time factor to ensure the comparison of a parcel of stormwater at the influent with the same parcel at the effluent, thus accounting for the variable nature of each event rather than relying on calculated detention times based on the engineering design.

The state of vegetative cover affects the pollution removal potential of a constructed wetland treating domestic wastewater. Karathanasis et al. (2003) found that the average removal of total suspended solids (TSS) was significantly higher in vegetated systems than in unplanted systems. This removal of TSS was noted in all seasons. This information confirms that TSS removal is mostly a physical process involving filtration and settling. Yet, in cases where a high percentage of TSS is organic, systems that promote microbial activity can improve removal efficiency.

Shilton et al. (2000) stated, "The performance of wastewater stabilization ponds is essentially dependant on two broad factors: the rate of reaction of the stabilizing mechanisms within the pond environment and the time the wastewater spends in the pond environment." The rate of reaction of the stabilizing mechanisms is specific to conditions such as temperature and particle size, and the time spent in the pond environment can impact settling and biotic metabolism. Because treatment performance in a wetland depends upon the same two broad factors, these findings are relevant here. Shilton et al. (2000) performed two studies to compare hydraulic detention time distribution in a wastewater stabilization pond. The data showed the concentration of dye exiting the pond was similar for both studies, displaying a rapid rise to a peak followed by a long tail. This is typical of short–circuiting. The study demonstrated that much of the BOD and over half the coliforms discharged untreated come from the early part of the curves because of the effect of short-circuiting on the water through the system and the resultant shortened treatment time. The intermittent nature of the flow rate to the stabilization pond made it difficult to repeat the hydraulic detention time distribution. Shilton et al. (2000) concluded that a retrofit that could delay peak discharge would dramatically reduce the discharge of untreated coliforms.

Seaman (1956) ran a radiotracer through a settling basin three times in an attempt to determine the detention time. For the first attempt he divided the tracer into four parts and injected them simultaneously into four influent ports of the basin. The radioactivity of the sample taken at three of four effluent ports was so varied that only a slight indication of the detention time was possible. For the second run the entire radioactivity was injected into the center influent port. For this run the background level of radiation varied and had to be subtracted from the count of the samples pulled from the four effluent ports. The detention time was determined to be three to four hours at two of the four effluent ports with a "high degree of confidence" (Seaman, 1956). On the third run a different tracer was used and background level of radiation remained constant. The detention time of an increment of effluent from the inlet to the outlet of the settling lagoon was determined at all four effluent ports. This detention time ranged from two hours to five hours. The experimenters varied their procedure three times until they were convinced they had determined the detention time. This experiment illustrates the difficulty of determining the detention time of even a relatively small, structurally simple facility.

Bishop et al. (1993) used a tracer to study two drinking water clear well basins with the intent of assessing detention time. They were able to construct a model that correlated well with the full-scale performance. With this model they were able to add baffles to simulate optimal configurations such as length to width ratios, inlet-outlet locations, and depth fluctuations. Both slug and step dosage tests were useful in this study. The step-dose method entails introduction of a tracer at a constant dosage until the concentration at the desired endpoint reaches a steady-state level.

Sampling Methods

Harmel et al. (2003) point out that a sampling strategy which utilizes an automatic sampler and sets a high minimum flow threshold will reduce the number of samples taken, which will increase the difference (variability) between the measured and the true pollution flux of the storm water runoff by increasing the effect of sample error. Grab sampling taken at a single intake point in a stream is a generally valid representation of the water quality in the stream because of the well-mixed conditions during storm events. This is of concern for the effluent sampling also. Harmel et al. (2003) also emphasize the need to develop a sampling strategy that can satisfy project goals, such as evaluating water quality improvement following implementation of best management strategies or another goal. Implementing a sampling protocol using a tracer dye to determine detention time for each event assures comparing the same parcel of water at both the influent and effluent of the structure and attributes any water quality variation to the wetland treatment system.

Turner Designs (2004a) noted that severe cases of sorption of RWT on the streambed (typical of shallow, fine sediment) resulted in no plateau being found for studies that used constant-rate injection (step-dose). With slug injection, a correction factor or several downstream sampling points must be used to account for sorption. Dye may be lost due to the settling of solids. When a fluorometer and RWT dye have been used to perform flow rate studies on surface water, these calculations can be complicated by non-uniform dispersion (Turner Designs, 2004a)

Properties of Rhodamine WT & General Fluorometric Procedures for Dye Tracing

Rhodamine WT is recommended for use in water tracing because it is (1) water soluble, (2) highly detectable – strongly fluorescent, (3) fluorescent in a part of the spectrum not common to materials generally found in water, thereby reducing the problem of background fluorescence, (4) harmless in low concentrations, (5) inexpensive, and (6) reasonably stable in a normal water environment. Potential background interferences of Rhodamine WT in a wetland include algae, naturally occurring organics, certain minerals, man-made pollutants such as paper and textile dyes, certain petroleum products, and laundry-detergent brighteners. Fluorescence varies depending on temperature (a 0.86 correction factor per 10 degrees F can be used), pH, and other physical and chemical factors such as turbidity and chlorine concentration (Turner Designs, 2004a; Wilson et al., 1986; Richardson et al., 2004).

Fluorometric procedures have been used to investigate numerous water resources (Wilson et al., 1986, Richardson et al. 2004). The nature of the investigation dictates dye concentration, dosing and sampling procedures, and data analysis with each application. The appropriateness of the use of RWT in individual applications varies and should be established in advance of an investigation (Wilson et al., 1986). RWT adsorbs to organic carbon. This could be a problem in streams that exhibit unsteady flows with variable total organic carbon (TOC) concentrations. Temperature and pH of the samples can be ignored if comparative raw dye concentration data are used and the temperature variation during the event is negligible. Fluorescence of RWT is stable over a pH range of 5-10. Fluorescence varies directly with dye concentration.

RWT was determined to be a reliable tracer for wetlands systems that have a residence time of less than one week, are about 0.6 m deep, and have limited sediment contact (Yu-Chen et al., 2003). In a pilot test, RWT and a bromide tracer produced breakthrough curves that were similar. In a full-scale test of an open surface water wetland that received flow diverted from the Santa Ana River in California, RWT was used to calculate the mean residence time as 60 hours compared to the theoretical time of 69 hours. The underestimation was concluded to be the result of RWT mass loss due to sorption through a shallow section of the system where sediment contact is more intense (Yu-Chen et al., 2003; Jones and Jung, 1990).

Richardson et al. (2004) assessed the applicability of RWT to characterize wastewater flow through a marshland upwelling system in a coastal setting. They selected RWT based on research that determined it had limited toxicity to microbial populations which are important in the treatment of soluble wastewater constituents such as carbonaceous biochemical oxygen demand, nitrogen, and phosphorous which undergo biochemical transformation. They reported that RWT would underestimate the actual transport potential of the wastewater plume because the RWT tends to separate from the freshwater zone sooner as the salinity increases. RWT did separate from the fresh water it was injected with in response to variable salinities encountered in a two-dimensional laboratory study described by Richardson et al. (2004). The RWT behaved differently than the fresh water based on some chemical characteristic that mimicked sorption behavior and allowed it to migrate through the plume at a different rate. In time, evidence of desorption from the saline water was noted. Ghanem et al. (2003) noted the existence of a two-step breakthrough curve for RWT typical of the multiple isomers present in its molecular structure. Soerens et al. (2000) were able to detect and estimate the concentration of tetrachloroethylene (PCE) in groundwater using RWT. The study performed by Richardson et al. (2004) illustrated the potential for the RWT to migrate through a medium at a rate different from other constituents of the influent. Soerens et al. (2000) used five different dyes to characterize dense non-aqueous phase liquids and found that RWT behaved differently in the presence of PCE than it did in the absence of PCE. RWT consists of two isomers with different sorption properties in groundwater field tests (Sutton and Kabala, 2000). This could account for the resulting two peaks obtained in field tracer tests as seen by Richardson et al. (2004)

CHAPTER III

METHODOLOGY

Water Quality Analysis

Water quality was analyzed for 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total cadmium, total copper, total lead, total zinc, nitrate and nitrite nitrogen, ammonia and Kjeldahl nitrogen, oil and grease, total and dissolved phosphorus, total dissolved solids and total suspended solids. Samples were analyzed by the City of Tulsa Quality Assurance Laboratory using USEPA methods or the equivalent (Appendix B). Some data sets contain values given as "below the detection limit" (BDL) or "too numerous to count" (TNTC>200,000). The reported detection limits vary based on the method quantification limit of the analyzing laboratory (City of Tulsa, 2004). For calculations, BDL data are recorded as the detection limit and TNTC>200,000 as 200,000.

Sampling Procedures for Water Quality

Samples were collected with a stainless steel bucket at the influent structure just prior to dye introduction. Effluent samples were taken from the effluent structure for the January event and from the effluent discharge pipe for subsequent events. Sampling procedures complied with requirements for data collection and analysis contained in 40 CFR Part 136 (City of Tulsa, 1991; ODEQ, 2003). Storm event criteria and sampling protocol for collecting the influent samples assured sampling of stormwater (City of Tulsa, 1991; ODEQ, 2003). Rainfall totaling 0.10 inch within two hours is required to identify the start of a storm event. The runoff samples entering the wetland were collected within two hours of the start of each event. Precipitation was measured using a rain gauge located just south of the wetland (Appendix A).

Sampling Procedures for Dye Testing

All samples taken during the event and those taken during the interval between events were analyzed for fluorescence using a Turner Designs Model 10-AU-005 Field Fluorometer, equipped for RWT (low algae level) application with a Clear Quartz lamp 546 nm Excitation Filter and <570 nm Emission Filter. The far-UV lamp emits a "green line" at 546 nm, which is close to the peak excitation wavelength of RWT (Wilson et al. 1986). The same cuvette was used throughout the study. The fluorometer was set for automatic selection of sensitivity. A 12-volt marine battery was used as the power source (recharged between events). Raw fluorescence data from the meter display were used to measure differences in the fluorescence (equivalent to relative dye concentrations) between one sample and another. Wetland water and a blank composed of deionized water were analyzed periodically during the study period and served as assurance that the fluorometer was functioning properly through the entire study.

Fluorometer readings are relative values of the fluorescence intensity and they alone will be used to differentiate the relative fluorescence of each sample taken. No flow calculations will be required and no mass balance (other than approximate) will be attempted, hence no correction factor to account for the potential loss of dye will be used. The tracer tests were conducted with RWT dye (Cole-Parmer). Standard solutions of RWT dye at concentrations of 100 ppb and 50 ppb were made from water collected from Heatherridge and were used to calibrate the fluorometer from the limit of detectability (about 10 parts per trillion) to about 0.1 ppm (Turner Designs, 1993). One gallon of dye was used for each event during this study. One gallon will yield a concentration of 5 ppb at the effluent structure if a 50-year storm event occurs, based on the design stormwater volume of a 50-year storm (120 acre-feet). Slug dosage tests were used. The slug dosages were injected into the downstream end of the influent structure, where turbulent flow was observed, usually into the middle of the flow to ensure optimal mixing. The RWT was poured into a stainless steel sample bucket and then dumped into the flow (Figure 4) as a slug.

The effluent was monitored for fluorescence using discrete analysis techniques in the field

(Turner Designs, 1993). The first detectable level of fluorescence attributable to the dye (referred to here as the minimum detention time) was identified as a fluorescence higher than the previous reading. The peak fluorescence was identified as the reading followed by fluorescence readings which were less for at least one hour and two subsequent readings. When the peak concentration was identified, samples of the effluent were taken near the effluent structure following the above-mentioned protocol. This sampling procedure assumes a steady-state, plug-flow reactor (Carleton et al., 2001).

Figure 4. Dye introduction during 1/12/05 event.

A background level of fluorescence was determined prior to each storm event by taking a grab sample at the effluent structure of the wetland prior to dye injection and analyzing it in the laboratory. Within the range anticipated for this study, temperature and pH do not appear to be of concern; typical pH readings for stormwater in Tulsa are within the range where RWT is stable (Appendix C). The effect temperature has on RWT will not be of consideration for this study because effluent temperatures will likely be steady throughout each event and little effect on relative fluorescence is expected.

In the course of the study, samples were taken at various locations throughout the wetland. These samples were taken from five locations as described in Table 4 and shown in Figure 1.

Samples were taken by reaching to dip a 500 mL bottle, attached to a two-meter pole, into the water and then transferring to triple rinsed, 500 mL bottles. All samples were analyzed within 60 minutes of the time they were collected, minimizing the effect of any temperature change that may exist. Samples were taken at the surface of the water. Samples were taken from location 1 as near the point of dye injection as possible. Samples were taken from sites 2, 3 and 4 approximately three meters from the pond bank. Samples were taken from site 5 approximately one meter from the effluent riser structure in an effort to illustrate fluorescence at this end of the facility. This monitoring may provide insight into what portion of the wetland is involved in treating storm water. Negative readings for the de-ionized water are relative to the fluorescence of the blank which was calibrated with pond water. At the time of calibration, the pond water was set to zero and the standards were made using pond water. This near weekly analysis provides evidence that the fluorometer was functioning consistently throughout the duration of the study by assessing the steady fluorescence reading for the blank and for any samples that had a visible fluorescence (>999). This monitoring was performed during the intermittent period between storm events.

A t-test (alpha = 0.05) in Microsoft Excel 2000 was used to determine if a significant difference in pollutant concentration could be found between the stormwater at the influent and that same water tested again at the effluent.

Sampling Procedures for Subsequent Events

The effluent was sampled from the 24 inch effluent pipe for each of the events after the January 12, 2005 event. The background level of fluorescence was determined from the monitoring performed during the intermittent period between storm events after the January 12, 2005 event. The stage gauge data are in units of meters and do not represent the actual depth of the wetland but show the relative depth between readings.

CHAPTER IV

FINDINGS

Water Quality

Results of the study demonstrate removal of 12 of the 14 storm water contaminants. Table 2 summarizes the data for all five events. The red numbers in Table 3 identify values recorded as below or above the detection limit and are reported at the detection limit. The blue numbers show the lowest value reportable based on the set-up procedure for that sample. The results obtained for the influent and effluent sampling sites show a range of difference in contaminant concentration from a 99% reduction for fecal coliform to –66% (negative values represent an increase in concentration) for copper (Table 2).

A t-test was performed on the results. The average values for nitrate plus nitrite were significantly lower at the outflow as compared to the inflow ($p = 0.0045$). This represents a 60% reduction. Fertilizers in urban stormwater runoff are of concern to municipal managers. Tanner et al (2005) found removal efficiencies of 79% of nitrate/nitrite and organic nitrogen in a constructed wetland treating drainage for grazed pasture. Kohler et al (2004) found 97% removal of $N\text{-}NO_3/NO_2$ in a constructed wetland within a golf course during storm events. Huett et al (2005) found that vegetated subsurface flow wetlands can remove >96% of the nitrogen as NO_3 but an unvegetated wetland removed only 16% of the nitrogen from plant nursery runoff. Similar results were found by Shultz and Peall (2001) for removal of nitrate during wet periods. They found removal of nitrate to be 84% compared to the same wetland removal efficiency during dry periods of 70%. The relatively low number for the Heatherridge facility may have been influenced by the unusually dry spring.

Table 2: Water Quality Data Summarized For All Five Events

Parameter	Sample Site	Median	Mean	Minimum	Maximum	STDEVE
Chemical Oxygen Demand mg/L	Influent	47	62.4	25	150	51.4
Chemical Oxygen Demand mg/L	Effluent	27	26.6	11	36	11.6
Percent Difference of Means			57%			
Biochemical Oxygen Demand mg/L	Influent	11	20.62	4	50	19.2
Biochemical Oxygen Demand mg/L	Effluent	7	9.64	2	30	11.6
Percent Difference of Means			53%			
Total Suspended Solids mg/L	Influent	76	80.8	20	160	50.5
Total Suspended Solids mg/L	Effluent	42	51.6	12	130	48.2
Percent Difference of Means			36%			
Dissolved Solids (T) mg/L	Influent	230	254	100	400	132.6
Dissolved Solids (T) mg/L	Effluent	220	222	200	250	19.2
Percent Difference of Means			13%			
Ammonia-N mg/L	Influent	0.25	0.3352	0.046	0.94	0.36
Ammonia-N mg/L	Effluent	0.03	0.19722	0.0011	0.65	0.27
Percent Difference of Mean			41%			
Nitrate+Nitrite mg/L	Influent	0.81	0.812	0.57	1.06	0.26
Nitrate+Nitrite mg/L	Effluent	0.52	0.3288	0.04	0.52	0.21
Percent Difference of Means			60%			
Total Kjeldahl Nitrogen mg/L	Influent	2.36	2.472	1.27	5.03	1.72
Total Kjeldahl Nitrogen mg/L	Effluent	1.18	1.01	0.49	1.34	0.37
Percent Difference of Means			59%			
Phosphorous (T) mg/L	Influent	0.29	0.3252	0.096	0.74	0.26
Phosphorous (T) mg/L	Effluent	0.099	0.1334	0.063	0.24	0.08
Percent Difference of Means			59%			
Phosphorous (D) mg/L	Influent	0.15	0.2102	0.05	0.49	0.19
Phosphorous (D) mg/L	Effluent	0.049	0.0982	0.04	0.17	0.07
Percent Difference of Means			53%			
Cadmium (T) ug/l	Influent	1.1	1.24	1	1.7	0.00030
Cadmium (T) ug/l	Effluent	1	1.04	1	1.1	0.00013
Percent Difference of Means			16%			
Copper (T) ug/l	Influent	7.4	9.28	5	16	0.00498
Copper (T) ug/l	Effluent	5	15.4	5	43	0.01658
Percent Difference of Means			-66%			
Lead (T) ug/l	Influent	0.15	3.8	2	6.3	0.00175
Lead (T) ug/l	Effluent	0.062	2	2	2	0.00000
Percent Difference of Means			47%			
Zinc(T) ug/l	Influent	36	41.4	15	65	0.02050
Zinc(T) ug/l	Effluent	10	14.4	10	27	0.00737
Percent Difference of Means			65%			
Fecal Coliform N/100 ml	Influent	1320	70757.4	593	200000	97173
Fecal Coliform N/100 ml	Effluent	150	264.2	1	940	382
Percent Difference of Means			99%			

Table 3: 2005 Water Quality Data From Heatherridge.

Location	Time	DATE	Chemical Oxygen Demand mg/L	Biochemical Oxygen Demand mg/L	Total Suspended Solids mg/L	Dissolved Solids (T) mg/L	Ammonia-N mg/L	Nitrate+Nitrite mg/L	Total Kjeldahl Nitrogen mg/L	Phosphorous (T) mg/L	Phosphorous (D) mg/L	Cadmium (T) mg/l	Copper (T) mg/l	Lead (T) mg/l	Zinc(T) mg/l	Fecal Coliform N/100 ml	pH	Hardness as $CaCO_3$ mg/L	Temp °C
	Influent																		
	17:00	1/12/2005	25	3.7	76	380	0.10	0.81	1.27	0.15	0.027	0.0010	0.0050	0.0023	0.032	593	8	148	13.3
	Effluent																		
	9:30	1/13/2005	25	2	60	220	0.27	0.52	1.18	0.099	0.049	0.0010	0.0050	0.0020	0.0100	150	8.2	147	7.7
	% removal		0	46	21	42	-170	36	7	34	-81	0	0	13	69	75			
	Influent																		
	20:00	2/12/05	27	30	20	400	0.046	0.88	0.49	0.096	0.053	0.0011	0.0050	0.0020	0.015	874	7.4	312	11.1
	Effluent																		
	7:00	2/5/2005	13	30	12	250	0.030	0.17	0.47	0.063	0.062	0.0011	0.0050	0.0020	0.010	78	7.5	191	12.5
	% removal		52	0	40	38	35	81	4	34	-17	0	0	0	33	91			
	Influent																		
	4:00	3/21/2005	47	8.4	160	230	0.25	0.40	2.43	0.29	0.088	0.0017	0.0074	0.00390	0.036	1320	7.8	218	12.4
	Effluent																		
	14:15	3/21/2005	11	3	14	230	0.030	0.040	0.78	0.075	0.040	0.0013	0.0050	0.0020	0.010	940	7.8	156	13.6
	% removal		77	64	91	0	88	90	68	74	55	24	32	49	72	29			
	Influent																		
	21:20	4/25/2005	150	50.0	82	160	0.94	1.06	5.03	0.74	0.49	0.0010	0.013	0.00450	0.059	200000	7.6	156	16.2
	Effluent																		
	13:00	4/28/2005	36	6.7	130	200	0.65	0.040	1.26	0.24	0.17	0.0010	0.043	0.0020	0.015	1	8.8	170	23
	% removal		76	87	-59	-25	31	96	75	68	65	0	-231	56	75	100			
	Influent																		
	23:15	5/13/2005	65	11	66	100	0.34	0.57	2.36	0.35	0.15	0.0014	0.016	0.00630	0.065	151000	7.4	53.7	21.4
	Effluent																		
	6:00	5/14/2005	34	6.5	42	210	0.035	0.044	1.34	0.19	0.17	0.0010	0.019	0.0020	0.027	153	8.7	118	21.4
	% removal		48	41	36	-110	90	92	43	46	-13	29	-19	68	58	100			

Fecal coliform concentrations percent difference of means is 99.6%. They ranged from as high as TNTC>200,000 (Too Numerous To Count) CFU / 100 ml at the influent to <1 CFU / 100 ml at the effluent for the 4/25/2005 event (reported in the data as 200,000 and 1 respectively). The comparison between the two locations (influent and effluent) shows that there is no significant difference ($p=0.14344$) due to the variability.

The removal difference can be compared to bacterial removal of 90% from domestic wastewater by both planted and unplanted pilot scale constructed wetlands (Keffala and Ghrabi, 2005). Song et al. (2006) found removal efficiencies for fecal coliform similar to other municipal treatment wetlands of 99.6%. These data compared samples gathered from a constructed wetland inlet structure that was downstream from a primary settling basin to samples gathered from the effluent. The bacteria that entered the wetland were likely adsorbed to fine sediment and as such afforded little protection from biological agents.

A contaminant of concern in urban runoff is phosphorus from fertilizer. Huett et al (2005) found that planted wetland tubs can remove 88% P (as PO_4, the dominant species in plant nursery runoff) whereas unplanted tubs removed only 45% percent. Plant uptake was found to be the dominant removal mechanism in reducing total phosphorus. Song et al. (2006) found that phosphorus removal efficiencies exhibited seasonal variations. Total phosphorus removal was more efficient in the summer and fall. A seasonal monitoring regimen may discover re-suspension of phosphorus during high flow events.

The percent reductions for total and dissolved phosphorus were 59 and 53 respectively in this study (Table 2). The average values were not significantly lower at the outflow as compared to the inflow. Heatherridge performance can be compared to stormwater treatment area wetlands with either emergent aquatic vegetation or submerged aquatic vegetation constructed by the South Florida Water Management District (Juston and DeBusk 2005). Two to seven years of data indicated phosphorus mass removal efficiencies consistently above 85% adjusted for background contaminant concentration, with mass loading rates at or below $2 g/m^2 \bullet yr$.

Total P mass reduction of 59% (Kao and Wu, 2001) has been reported as stormwater passed through a natural wetland, comparable to results in this study. Kohler et al (2004) found phosphorus removal of 74% during storm events for a constructed wetland treating golf course runoff. This may be the result of fewer toxics entering the wetland than would be the case with runoff associated with a mixed-use urban watershed.

This study showed a 51% difference in influent to effluent for Kjeldahl nitrogen (Table 2). Though not significantly different, it can be compared to Kjeldahl nitrogen percent removal in a planted and an unplanted system of 27 and 5% respectively (Keffala and Ghrabi 2005).

Total suspended solids and total dissolved solids are generally agreed to be physical contaminants of concern for municipal stormwater managers. Heatherridge removal differences were 26% and –11% respectively (Table 4). The Heatherridge facility did not show a significant removal of either of these contaminants. One reason for the poor performance of the dissolved solids may be the relatively short duration of the detention time (6.75 hours) before the 5/13/05 event that did not allow for prolonged treatment. It appears counterintuitive that the longest detention time of 66 hours for the 4/21/05 event results in an increase of 59% total suspended solids.

Dye Testing

The average elapsed time from the time the dye was injected into the stormwater runoff at the influent structure until the time fluorescence was first detected at the outfall (the estimated minimum detention time) was 20.4 hours with a standard deviation of 24.1 hours for all sampling events. The 4/25/05 event accounted for the majority of the variability. The estimated average time to peak (most representative of the stormwater collected and analyzed at the influent) was 21.6 hours with a standard deviation of 23.8 hours.

The range of stage gage readings was 5.3 meters on 2/18 to 2.7 meters on 5/4/05 (Table 4). The lowering of the permanent pool through the duration of the study provides evidence of a dry spring.

Table 4 and Figure 5 summarize the background fluorescence through the wetland. The >999 readings are above the maximum allowable for the screen. For the purposes of this study, it need only be understood that there is enough fluorescence present to be visible to the eye. The sample from the north end of the east cell on 4/28/05 shows that the dye did not reach this end of the facility. These data provide evidence of short-circuiting and/or preferential flow patterns because the fluorescence of the sample did not appear to be influenced by the presence of dye. More could be learned from this measure if a detailed relationship could be made with the permanent pool volume. Additional monitoring sites would provide evidence of flow path.

Figure 5 illustrates the impact of the rainfall intensity on the flow of dye through the wetland. Rainfall totaled 0.2 inches in six minutes for the 4/25/05 storm event and the dye was introduced one hour and 13 minutes after the rain ended. The high fluorescence at the influent structure on 4/26/05 indicates the dye was added to the tail end of the hydrograph. The readings at sites 3 and 4 and at the effluent from 5/4 to 5/11/2005 indicate the dye lingered in the wetland until the 5/13/2005 rainfall caused it to be "pushed out".

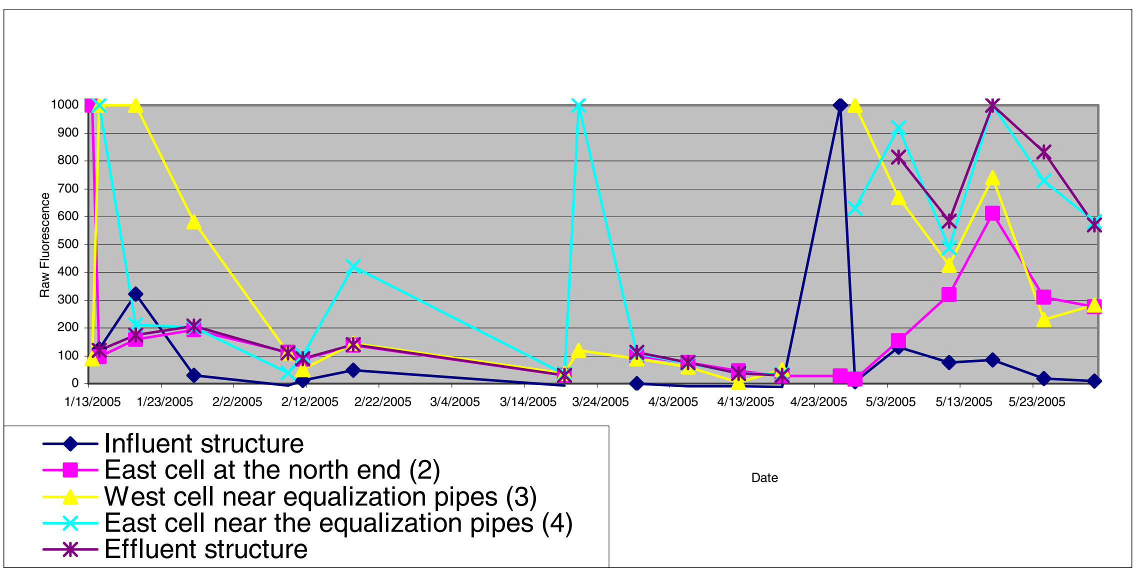

Figure 5. Fluorescence in wetland during study.

The data for the 5/13/05 event during this study (Figure 11), likely mimic the phenomenon of water detained in the permanent pool (Figure 3) due to low rainfall volume for the prior event and the relatively short (19 day) interval between events.

Table 4: Fluorescence Data Through the Wetland During the Spring of 2005

Date	Influent Structure	East cell at the north end (2)	West cell near equalization pipes (3)	East cell near the equalization pipes (4)	Effluent structure	De-ionized water	Stage gauge meters
1/13/05*		>999	90.0				
1/14/05	123	96.1	>999	>999	120	-15	
1/19/05	231	158	>999	211	175	-17	
1/27/05	31.0	192	582	203	207	-16	
2/9/05	-6.6	113	111	39.5	111	-16	
2/11/05	11.1	87.9	50.1	102	89.6	-16	
2/18/05	49.2	139	144	420	141	-17	5.3
3/19/05	-7.8	28.9	35.9	34.0	29.0	-17	3.0
3/21/05 at 1210			120	>999			3.8
3/29/05	0.307	100	88.7	108	112	-18	3.1
4/5/05	-10	76.0	58.8	73.4	74.6	-16	3.4
4/12/05	-10	45.0	5.20	36.0	36.1	-17	
4/18/05	-11	27.8	51.1	33.7	29.1	-16	3.3
4/26/05**	>999	28.3					3.4
4/28/05	7.22	16.8***	>999	629		-15	
5/4/05	130	155	670	919	813	-16	2.7
5/11/05	75.5 &>999****	320	426	488	584	-16	2.9
5/17/05	84.1	611	740	>999	>999	-16	
5/24/05	18.0	310	229	728	832	-16	3.6
5/31/05	9.12	275	282	582	570	-16	3.1

Notes: Units are in Raw Fluorescence equivalent to concentration.
Figure 1 shows where sites 2, 3 and 4 are. The stage gauge is very near site 4. Sites 1 and 5 are at the influent and effluent respectively. Each value represents a single reading.
*These samples were taken during the study. Ample time was available to perform this added monitoring.
**These samples were taken during the study. They provide evidence that the dye was injected into the tail end of the hydrograph for 4/25/05 event.
***Evidence of short-circuiting.
****This sample was taken after an exposed rock was splashed with water. The rock was obviously stained by the dye injection from the prior event.

Observations of the 1/12/05 Event

On 1/12/05, 0.12 inches of rain fell from 1550 to 1637, and then the rain stopped. Influent samples were taken at 1700 1/12/05 and the dye was injected into the flow at the influent structure (Figure 4).

Effluent monitoring began at 0330 on 1/13/05, 10.5 hours after the introduction of the dye, at 30-minute intervals (Figure 6). A stainless steel bucket, thrown out near the effluent structure, was used to collect samples. An elevated fluorescence at the effluent was first detected 15 hours after the introduction of the dye, when the meter read 95.8 compared to between 52.0 and 74.4 for the first four hours of monitoring, indicating a minimum of a 15-hour detention time, three hours longer than the engineering estimate (City of Tulsa, 1999).

The raw fluorescence at the effluent after 16 hours was 132.0. A grab sample was put in a stainless steel kettle and allowed to sit near the water's edge. Temperature and pH were recorded at this time. After one hour and two subsequent monitoring readings, the water quality samples were poured from the kettle and sent to the laboratory for analysis.

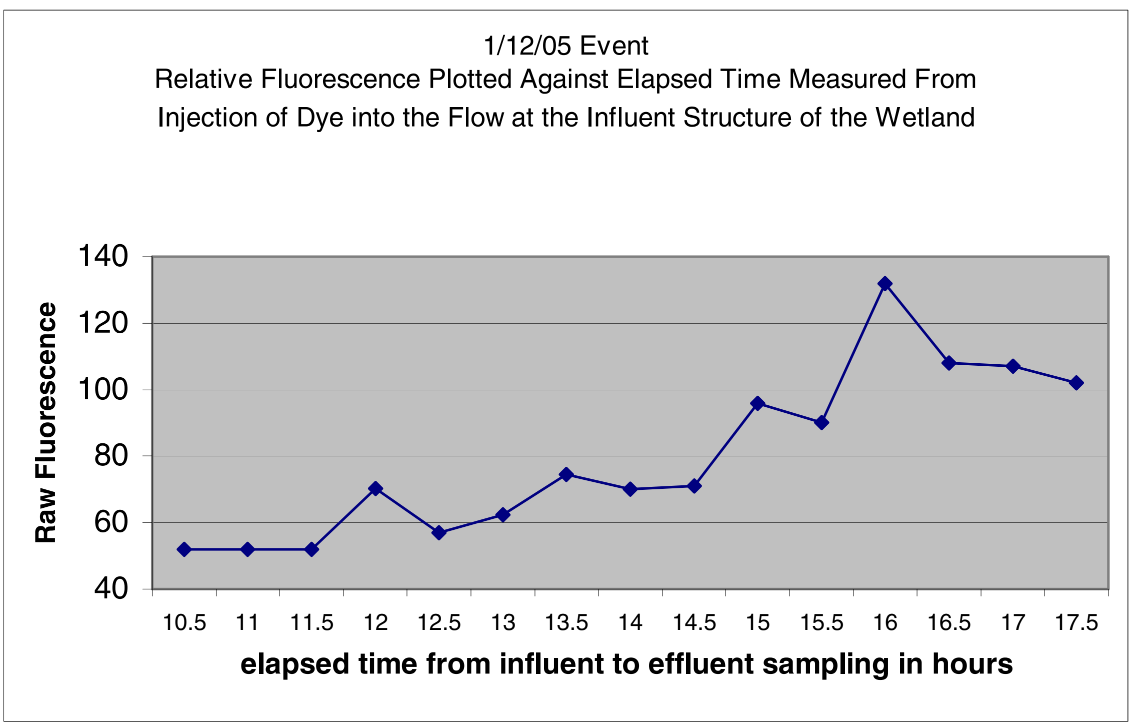

Figure 6. Raw fluorescence at the effluent during 1/12/05 event.

The tracer response during the first event displayed a detention period for the dye of at least 15 hours. The peak of the distributed dye detention period was estimated to be 16 hours. On 1/19/05 at 1000 a sample taken from the west cell (site 3) read >999 and one at the effluent read 175. This monitoring provides evidence that the effluent sample collected and analyzed on 1/13/05 did not account for all of the dye added.

Observations of the 2/12/05 Event

On 2/12/05, 0.12 inches of rain fell from 1805 to 1906 and continued until 2204, dropping another 0.16 inches. Influent samples were taken at 2004 and dye was introduced into the flow.

Effluent monitoring began at 0630 2/13/05, 8.4 hours later, at 30-minute intervals (Figure 7). The fluorescence after 8.4 hours was 244. The fluorescence in the effluent sample after 8.9 hours was 213. A grab sample was put in a stainless steel kettle and allowed to sit near the water's edge. Temperature and pH were recorded at this time. After one hour and the two subsequent monitoring readings, the water quality samples were poured from the kettle. After two and a half hours and subsequent fluorometer readings, the samples were sent to the laboratory for analysis.

The estimated time to peak for this event was half the time of the previous event. The rainfall which occurred after the introduction of the dye seemed to push it through unlike the previous event when no rain fell after the dye was introduced.

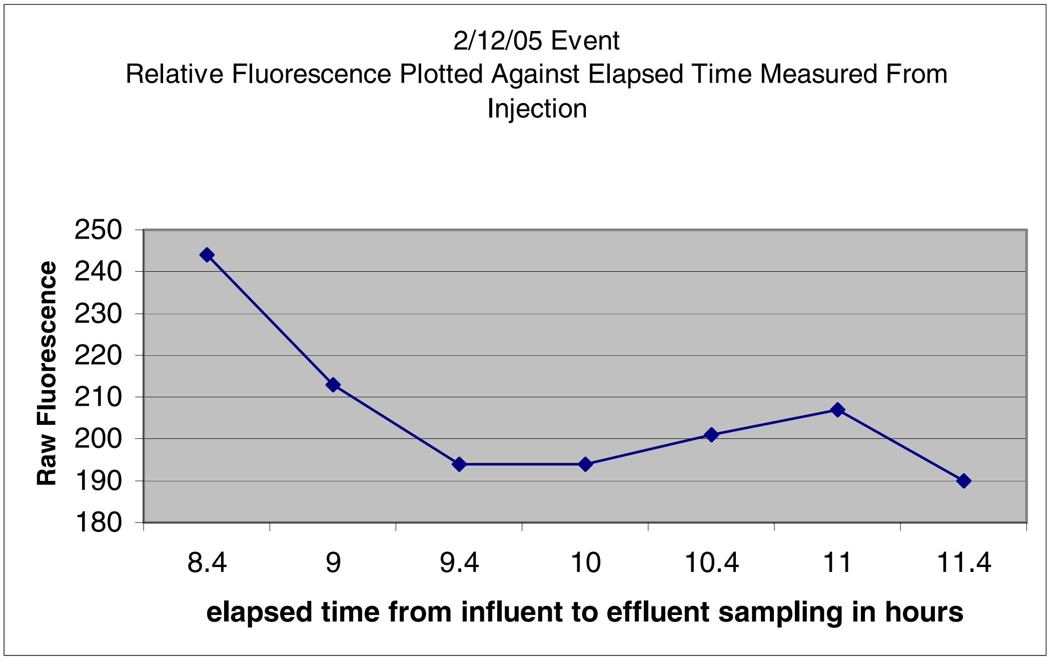

Figure 7. Raw fluorescence at the effluent during 2/12/05 event.

A sample from the west cell (site 4) taken 2/13/05 approximately nine hours after the dye was injected had a noticeable red tint to it and a fluorescence reading of >999.

On 2/18/05 at 1400 monitoring was performed at the identified background fluorescence sites (Table 4). The fluorescence at site 4 and the effluent, 420, and 141 respectively, provides evidence that the dye was on its way out by then because the fluorescence at both sites was less than it was on 2/13/05. No adjustment to the effluent sampling protocol was made. The estimated minimum detention time for this event was less than eight and one half hours, one and one half hours less than the engineering estimate (City of Tulsa, 1999).

Observations of the 3/21/05 Event

On 3/21/05 0.12 inches of rain fell from 0138 to 0253 and continued until 1055, dropping another 0.44 inches. Influent samples were taken at 0400 and dye was introduced into the flow.

Effluent monitoring began at 1130 on 3/21/05, 7.5 hours later, at 30-minute intervals (Figure 8). The fluorescence after 7.5 hours was 237. The fluorescence after 8.5 hours was 285 which was higher than the past two samples and is considered the first detection of dye. The fluorescence in the effluent sample after 10.25 hours was 317. A sample was grabbed and stored in a stainless steel kettle at this time. Temperature and pH were recorded at this time. After one hour and subsequent fluorometer readings, water quality samples were poured up from the kettle sent to the laboratory for analysis.

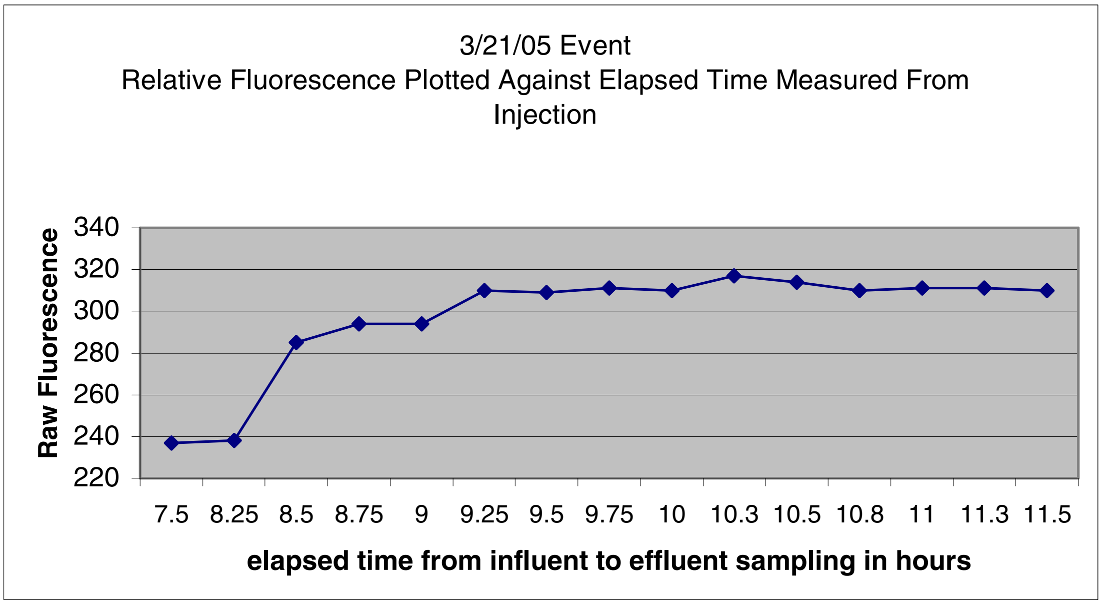

Figure 8. Raw fluorescence at the effluent during 3/21/05 event.

The estimated detention time for this event was approximately eight and one half hours, at least one and one half hours less than the engineering estimate (City of Tulsa, 1999). The rise in the relative pool volume as evident on the stage gauge reading of 3/21/05 at 1210 (Table 4), provides evidence a portion of storm runoff from the 0.56 inches of rain was detained in the facility. The flood control function of the wetland was apparent by the steady rate of the dye exiting.

On 3/29/05 at 1030 a sample taken from site 3 read 88.7 and one at the effluent read 112 (Table 4). These two sample results provide evidence that more of the dye cleared the wetland during this event than the first event. No adjustment to the protocol was made.

Observations of the 4/25/05 Event

On 4/25/05 0.12 inches of rain fell from 2001 to 2004 and continued until 2007, dropping another 0.8 inches. Influent samples were taken at 2120 and dye was introduced into the flow.

Effluent monitoring began on 4/26/05 at 0530, 8.17 hours later, at 30-minute intervals (Figure 9). The fluorescence after 8.17 hours was 93.4 and can be considered the first detection of dye. The fluorescence in the effluent after 63.67 hours was 197. A sample was grabbed and stored in a stainless steel kettle at this time. Temperature and pH were recorded at this time. After one and one half hours and a subsequent fluorometer reading at the effluent of 197, water quality samples were poured from the kettle and sent to the laboratory for analysis. Additional monitoring of sites 1, 2, 3 and 4 which showed fluorescence of 7.22, 16.8, >999, and 629 were used to identify the fluorescence at 1300 on 4/28/06 (63.67 hours after the dye was injected into the flow at the influent) as the peak fluorescence.

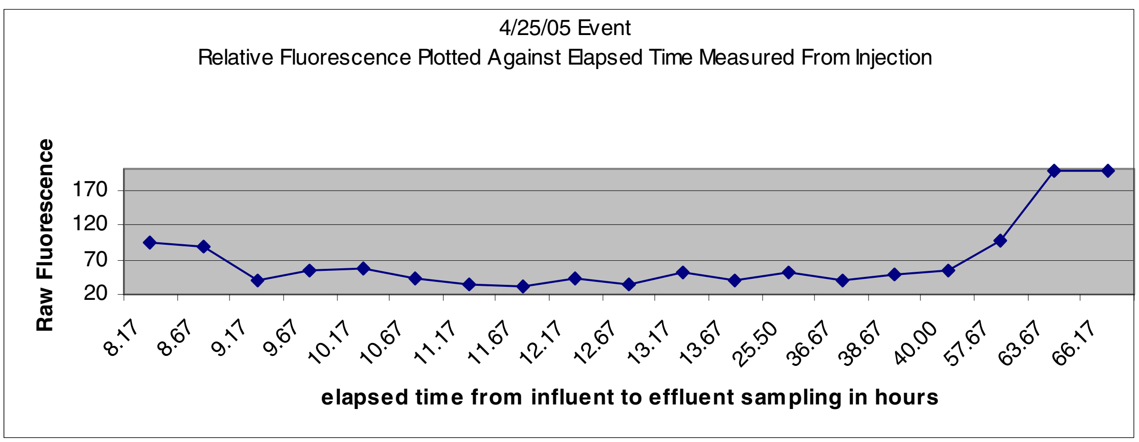

Figure 9. Raw fluorescence at the effluent during 4/25/05 event.

There are several factors that went into the decision to identify the peak fluorescence of this event at 66.17 hours. The visible presence of dye in the west cell (Figure 9), the fluorescence at site 4 led to the conclusion that the dye was "trapped" in the wetland. The dye was likely added to the trailing end of the inflow hydrograph and based on the research by Somes et al 2000, it was detained in the permanent pool until it would be flushed out by the next storm event. The small rise of the relative pool volume (Table 4) from 4/18/05 to 4/26/05 provides evidence the small rainfall volume and short duration had little impact on the facility and is consistent with an extended detention time of the runoff.

Several visual observations made during the 4/25 through 4/28/05 event are worthy of note. Fluorescence at site 3 at 1109 and site 4 at 1110 on 4/26/05 were >999 and 90.0 respectively. Apparently, the dye was 'trapped' in the west cell. Monitoring was discontinued until 4/27/05. Figure 10 is a view from the bank above the west cell, which shows that the dye was mixed in the eastern half of that cell but not in the western half. This may have been due to the effect of short-circuiting and/or preferential flow of the stormwater through the system. City of Tulsa Vegetation Management group applied an algaecide to the area around the effluent structure at 1530 on 4/26/05, roughly spraying 10 yards out into the pond from along the bank 20 yards either side of the structure. This is a routine practice. A schedule of all routine maintenance should be reviewed prior to any study such as this to assess the potential impact.

Figure 10: Dye observation during 4/25/05 event shows the heterogeneous nature of the dye dispersion in the wetland. The dye-tinged band of water in the background illustrates the preferential flow path.

Observations of the Heatherridge Study 5/13/05 Event

On 5/13/05 0.12 inches of rain fell from 2153 to 2220 and continued until 0019 on 5/26/05, dropping another 0.6 inches. Influent samples were taken at 2315 and dye was introduced into the flow.

Effluent monitoring began on 5/14/05 at 0600 at 30-minute intervals (Figure 10). The fluorescence after 6.75 hours was 650. A sample was grabbed and stored in a stainless steel kettle. Temperature and pH were recorded at this time. After one hour and subsequent fluorometer readings, water quality samples were poured from the kettle. Fluorescence was recorded for several more hours: no evidence of a subsequent peak was observed. The water quality samples were sent to the laboratory for analysis.

The lowest detention time for this event was likely less than 6.75 hours unless the dye from the previous event was that which was detected during this event.

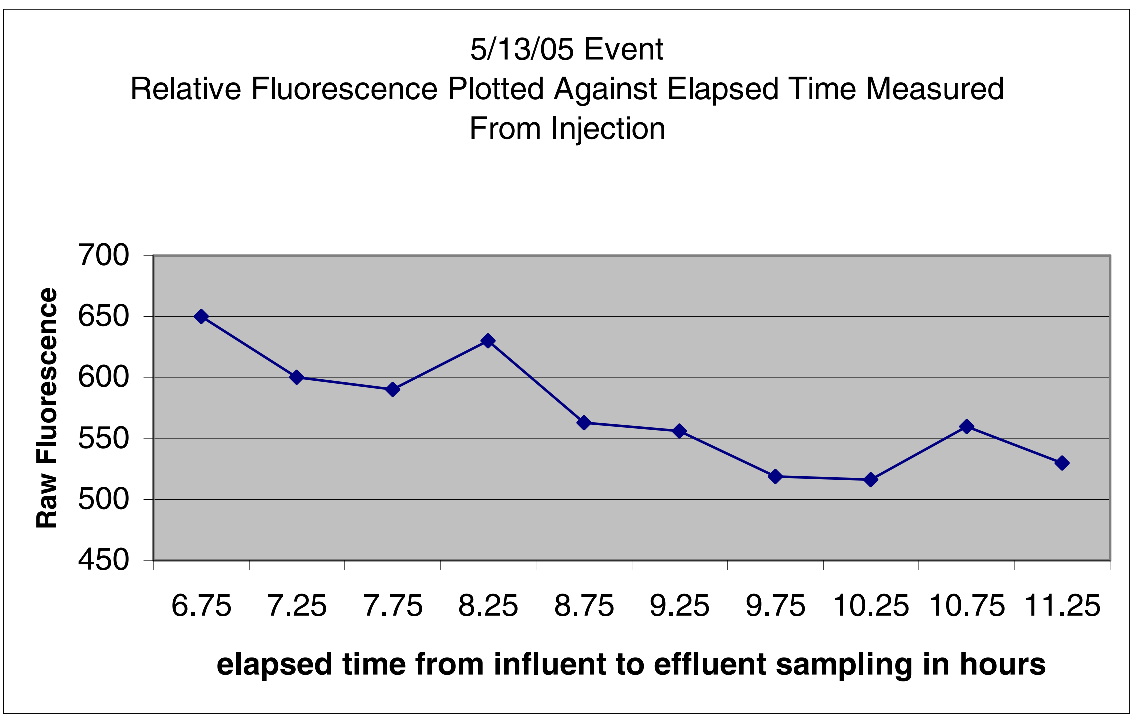

Figure 11. Raw fluorescence at the effluent during 5/13/05 event.

CHAPTER V

CONCLUSION

Water Quality

Constructed wetlands are increasingly popular for storm water treatment in urban settings. It is important to quantify the removal efficiency of these wetlands to assess their benefit and role in an overall storm water management plan. This study addresses the stormwater treatment efficiency of Heatherridge Stormwater Detention Facility, a constructed wetland created specifically for the dual purpose of retaining stormwater and mitigating wetlands impacted by construction of a highway. The City of Tulsa has added this facility to its Storm Water Management Plan due to the potential for wetlands to treat stormwater runoff and enhance the quality of water as it passes through the system. Results of the study demonstrate removal of 12 of the 14 stormwater contaminants.

The average percent difference of means for the nutrient (nitrate + nitrite, total Kjeldahl nitrogen and ammonia-N) stormwater pollutants showed reductions of 60, 59 and 41 percent respectively. Both total and dissolved phosphorus were also reduced over the course of this study. The reduction of these pollutants is essential to the health of the downstream section of the stream.

Potential Retrofits

A detailed study of the Heatherridge Stormwater Detention Facility catchment area is in order to determine if the runoff quality is in line with typical urban land uses and the time of travel of certain pollutants. These data could provide guidance in retrofitting measures. It would be advantageous to understand the source and nature of the TSS (and other lumped, or grouped, parameters) entering the system to target those functions that support water quality improvement (Kadlec, 2002). Retrofits that enhance settling of large particulate matter may miss the goal of reduced pollution concentration at the effluent due to the potential of small particulate matter having relatively greater sorption potential and longer settling rates. For a detailed discussion of the relationship of tracer testing and its applicability to assess the removal rates of lumped parameters see Kadlec (2002).

Dye Testing

The detention times, based on fluorescence analysis, show a distribution of estimated peak detention times from a minimum of 8.5 hours to approximately 63.5 hours. This variation can be attributed to rainfall intensity, duration, and time between storm events. The minimum detention time for the 3/21/05 event was eight and one half hours (Figure 7). The stage reading on 3/19/05 was 3.0 meters which represents the lowest level within the study period to date. The rainfall amount for this event totaled 0.56 inches. Wong et al. (1999) observed that small permanent pool volumes and large runoff volumes led to short detention times. The same behavior was observed during the 3/21/05 event. The maximum detention time was not identified during this study, but the 4/21/05 event provides evidence it could be as much as 63 hours (Figure 9). The likelihood of the dye being stuck in the wetland is high. A short, intense, rain event and a long delay until the dye was added predict a long detention time as modeled by Somes et al. (2000). Observations during the 4/25/05 event show that not all of the wetland waters mix with the main flow. This observation highlights the potentially severe impact that short-circuiting can have on treatment efficiency. Since many wetland reactions involve sedimentation and biota that are distributed unevenly throughout the facility, it would be advantageous to account for differential treatment potentials prior to suggesting retrofitting techniques. It would be advantageous to monitor the mixing of dye throughout the wetland in more detail to increase the confidence of the detention time. The use of an engineering estimate is an unreliable predictor of the detention time for a parcel of water through this facility due to the variable nature of rainfall in northeast Oklahoma. The data obtained by this monitoring may provide evidence relating to background fluorescence, potential short-circuiting or preferential flow patterns of the dye through the wetland, effective treatment capacity of the wetland, and how long the dye remains in the system.

Further detail should be given to study goals in relation to possible retrofits available to utility managers. More research is warranted with respect to lumped parameters to help choose BMPs to address the most abundant or threatening components.

Limitations

Water Quality

The historical data were gathered under the assumption that an engineering estimate of the detention time for the facility was 12 hours. The first indication of the origin of this estimate was discovered in unpublished City of Tulsa internal documentation that states, in a hand-written note, "Samples were obtained approximately 14 hours apart to compensate for detention time." Although the note states "14 hours apart", the time reported in the document records that the influent was sampled at "8:40pm 2/6/99" and the effluent was sampled at "6:35am 2/7/99" (City of Tulsa, 1999), which is approximately 10 hours. The average interval between influent and effluent sampling for the monitoring program referred to as the "Heatherridge Historic Data" is 11.8 hours, which is consistent with the engineering assumption that the detention time was 12 hours throughout previous monitoring periods. It would be beneficial to any further monitoring at this site to account for the effect of age on the overall volume of the facility to allow for a more accurate estimation of detention time. This could be accomplished by mapping the depth of the wetland. This information would provide additional evidence of potential flow patterns and the volume of the facility that affects detention time and treatment. It would also be beneficial to assess the runoff coefficient of the watershed to account for any development or change in land use to account for watershed hydrology.

The seasonal impact on the functions and values of an urban water body affects the water quality enhancement potential. Further study is warranted to account for treatment in each season of the year.

Dye Testing

The sampling of the effluent during the 1/12/05 event from the area around the effluent structure allows for variability based on where the bucket was thrown and how deep the bucket sank into the pool, among other things. A change in the effluent monitoring site to the 24 inch effluent pipe addressed these concerns. The effluent samples for this event appeared to identify peak fluorescence during this event.

The influent sampling during the 2/12/05 event and the effluent sampling during the 4/25/05 event exposed a limit within the peak fluorescence identification criteria, namely sampling must begin prior to the arrival of the dye at the sampling point and continue until all traces of dye have disappeared. Criteria must be set to identify peak fluorescence consistent with the nature of the study. The background fluorescence monitoring of 1/14/05 of sites 2 and 3 provides evidence that the effluent sample collected and analyzed on 1/13/05 accounted for a small fraction of the mass of dye added and may not have been the most representative parcel of water the dye was introduced into.

Although the Model 10-AU-005 Field Fluorometer User's Manual states that "you do not have to calibrate every time you read a new batch of samples," some criteria should be identified to assure the reliability of the readings. The identification of the first detectable level of fluorescence attributable to the dye must be defined by criteria that suits the investigation.

The target concentration of dye was set under the assumption that the facility is new. It is likely to be inaccurate due to a change in the wetland volume. A survey of the permanent pool volume measurements would allow further development of the relationship of the stage measurements taken during this study (Table 2) and may be used to better characterize the effect of RWT sorption on the streambed.

The literature review revealed a potential background interference of Rhodamine WT in a wetland. This study accounted for background fluorescence through periodic monitoring throughout the wetland. Although no evidence of massive variability of the fluorescence occurred during any of the monitoring, it would be prudent to set a criteria to identify any fluorescence outside that which is expected for any given study. The impact on fluorescence of temperature, pH, loss due to sorption, and the factors which may affect the readings and interpretation must be addressed in the method. Thus, further study should be done to characterize water quality of the permanent pool and account for the effect it has on the time of travel of RWT.

Assessment Techniques and Goals

The data collected during this research project have contributed to the understanding of the potential for a constructed wetland to perform water purification processes. Stormwater utility managers need this type of data to make informed choices between the abundant varieties of BMPs available for an equally large number of management goals.

A study performed by Pitt et al. (1995) found urbanization could impair beneficial uses. In an extensive literature review, these researchers cited studies that indicated increased urbanization correlated to decreased numbers of macroinvertibrates even if water-quality parameters did not identify a high degree of pollution. They concluded it is near impossible, due to all the variables and site-specific relationships between them, to predict the effect any will have on the receiving stream based solely on water column quality measurements. Perhaps an alternative assessment protocol, one which is inclusive of the biota and the location in the landscape, would be able to provide insight into whether Heatherridge is a successful water quality mitigation project. It is likely such an assessment would require an assessment of water quality issues as well and data like that collected during this study would contribute to the decision process. It is imperative to any wetland assessment exercise that the particular functions or parameters to be evaluated are clearly defined (Whigham, 1999).

Whigham (1999) suggests comparing a constructed wetland with natural wetlands, often referred to as reference wetlands, when assessing the success or failure of a system. Since water quality enhancement is but one function of a more complex system, it may be useful to study this aspect in conjunction with other important functions and values. At least with this forethought, an efficient, tailored protocol may be developed. Hager (2004) recommends utility managers focus resources on assessing the effectiveness of BMPs to address first flush contaminants. This article also pointed out the site specific nature of the runoff and BMP selection. The number of factors that must be considered is formidable.

Clear, quantitative monitoring objectives must be developed for stormwater monitoring. It is essential that one clearly determine the criteria for a successful wetland treatment facility while developing the water quality assessment strategy.

The assessment of any best management practice demands an understanding of the impact of the threat prior to control. Heatherridge Wetland was designed as a flood control structure and stormwater treatment facility to mitigate the loss of natural wetlands. It is likely an engineering formula can assess the physical impact that urbanization will have on the hydrology of a watershed. It is less likely that a water quality or hydrology formula can assess a stormwater quality BMP because stormwater utility managers must assess values other than just physical properties. Natural wetlands are credited for mitigating flooding and water quality enhancement. Natural wetlands provide value to the urban setting. It appears Heatherridge can successfully function as a flood control device. It is hoped that the value Heatherridge provides will mimic a natural wetland. Further study will shed light on the question.

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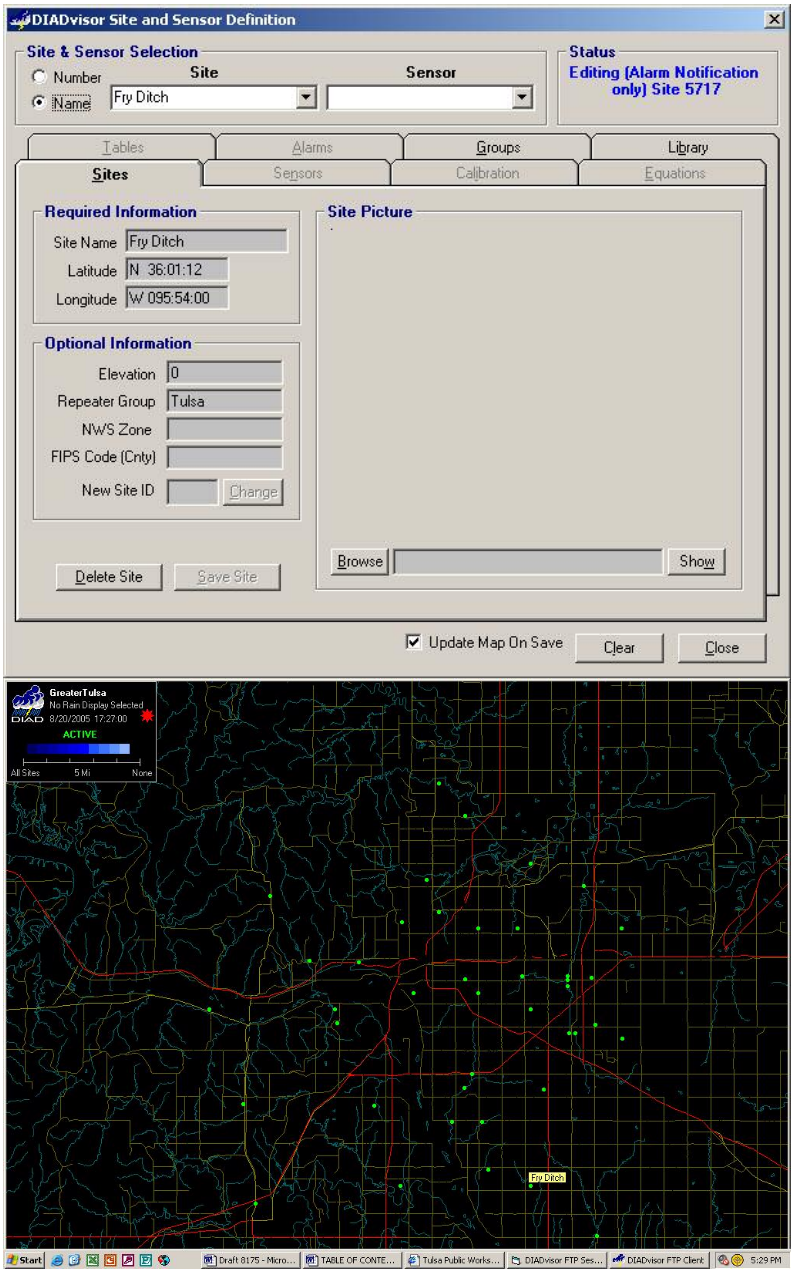
APPENDIX

Appendix A: Location of rain gauge used to measure precipitation.



Appendix B: Analytical methods.

Detection Limit	Units	Parameter	Method
(10)	mg/L	Oxygen Demand, Chemical	EPA 410.4
<2.0	mg/L	BOD(5) DAY	EPA 405.1
(2.0)	mg/L	Solids, Total Suspended	EPA 160.2
(10)	mg/L	Solids, Total Dissolved	SM 2540-C
(0.030)	mg/L	Nitrogen, Ammonia	EPA 350.1
(0.040)	mg/L	Nitrogen, Nitrate-Nitrite	EPA 353.2
(0.20)	mg/L	Nitrogen, Kjeldahl, Total	EPA 351.2
0.040	mg/L	Phosphorus, Total	EPA 365.1
0.040	mg/L	Phosphorus, Total Dissolved	EPA 365.1
(6.0)	mg/L	Oil and Grease HEM	EPA 1664 A
(0.0010)	mg/L	Cadmium, Total	EPA 200.7
(0.0050)	mg/L	Copper, Total	EPA 200.7
(0.0020)	mg/L	Lead, Total	EPA 200.9
(0.010)	mg/L	Zinc, Total	EPA 200.7
< 1.0	CFU/100mL	Coliform, Fecal	SM 9222D

Appendix C: Heatherridge historical and removal efficiency data.

Location	Time	DATE	Chemical Oxygen Demand mg/L	Biochemical Oxygen Demand mg/L	Total Suspended Solids mg/L	Dissolved Solids (T) mg/L	Ammonia-N mg/L	Nitrate+Nitrite mg/L	Total Kjeldahl Nitrogen mg/L	Phosphorous (T) mg/L	Phosphorous (D) mg/L	Cadmium (T) ug/l	Copper (T) ug/l	Lead (T) ug/l	Zinc(T) ug/l	Fecal Coliform N/100 ml
Influent	20:40	2/6/1999	66	5.8	310	147	0.27	0.841	2.12	0.408	0.184	5.5	20	5.1	93	3100
Effluent	6:35	2/7/1999	39	2.6	56	229	0.29	0.681	0.848	0.128	0.08	3	20	1.7	44	2600
% removal		2/7/1999	41	55	82	-56	-7	19	60	69	57	45	0	67	53	16
Detention time: hours		.90														
Influent	9:30	6/16/1999	29	8.8	731	126	0.44	0.677	4.49	1.01	0.287	3	20	14	60	76500
Effluent	21:40	6/16/1999	22	2	21.3	138	0.071	0.0659	0.816	0.0899	0.0576	3	20	1	20	30000
% removal		6/16/1999	24	77	97	-10	84	90	82	91	80	0	0	93	67	61
Detention time: hours		12.17														
Influent	3:55	10/30/1999	47	40	33.3	98.8	0.31	0.528	1.33	0.324	0.266	3.8	23	3.1	26	132000
Effluent	15:22	10/30/1999	20	2.5	10	162	0	0.153	0.666	0.0842	0.053	0	0	1.4	0	6909
% removal		10/30/1999	57	94	70	-64	100	71	50	74	80	100	100	55	100	95
Detention time: hours		11.45														
Influent	11:30	1/31/2000	18	3	4	470	0.25	0.729	0.702	0.030	0.028	3	20	6.3	20.000	220
Effluent	23:30	1/31/2000	25	8	18.2	260	0.073	0.121	1.21	0.041	0.028	3	20	5.2	20.000	10
% removal		1/31/2000	-39	-167	-355	45	71	83	-72	-37	0	0	0	17	0	95
Detention time: hours		12.00														
Influent	4:30	1/11/2001	24	6	44	273	0.64	2.10	3.250	0.19	0.10	0.51	10	1.0	0.230	3100
Effluent	16:30	1/11/2001	13	4	8	273	0.74	1.50	1.85	0.20	0.10	0.51	5.2	0.6	0.016	547
% removal		1/11/2001	46	33	82	0	-16	29	43	-5	0	0	48	40	93	82
Detention time: hours		12.00														
Influent	8:45	3/15/2001	56	7	28	318	0.13	1.40	1.020	0.07	0.03	4	10	1.4	19.000	109000
Effluent	20:45	3/15/2001	56	7.1	35	305	0.05	0.16	1.66	0.18	0.03	4	10	1.1	11.000	45
% removal		3/15/2001	0	-8	-25	4	62	89	-63	-147	0	0	0	21	42	100
Detention time: hours		12.00														
Influent	8:59	3/18/2003	70	9	280	510	0.29	0.77	2.10	0.36	0.07	1	9	9	180	6000
Effluent	21:59	3/18/2003	57	7	180	220	0.19	0.62	1.92	0.44	0.18	1	8	5	150	4100
% removal		3/18/2003	19	24	36	57	34	19	9	-22	-154	0	9	47	17	32
Detention time: hours		13.00														
Average - % removal efficiency			21	16	-2	-3	47	57	15	3	9	21	22	49	53	69
BDL values are reported "as is"																

Appendix D: Results of single factor analysis of variance (ANOVA) tests for each water quality parameter.

Anova: Single Factor BOD

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	103.1	20.62	369.832
Column 2	5	48.2	9.64	133.873

ANOVA

	SS	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	301.401	1	301.401	1.196736	0.305817	5.317655
Within Groups	2014.82	8	251.8525			
Total	2316.221	9				

Anova: Single Factor Total Suspended Solids

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	404	80.8	2553.2
Column 2	5	258	51.6	2322.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2131.6	1	2131.6	0.874323	0.377123	5.317645
Within Groups	19504	8	2438			
Total	21635.6	9				

Anova: Single Factor Dissolved Solids

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	1270	254	17580
Column 2	5	1110	222	370

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2560	1	2560	0.285237	0.607806	5.317645
Within Groups	71800	8	8975			
Total	74360	9				

Anova: Single Factor Ammonia

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	1.676	0.3352	0.128005
Column 2	5	1.015	0.203	0.073095

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.043692	1	0.043692	0.434531	0.528288	5.317645
Within Groups	0.804401	8	0.10055			
Total	0.848093	9				

Anova: Single Factor Nitrate+Nitrite

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	3.72	0.744	0.06783
Column 2	5	0.814	0.1628	0.042979

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.844484	1	0.844484	15.24212	0.004518	5.317645
Within Groups	0.443237	8	0.055405			
Total	1.28772	9				

Anova: Single Factor Total Kjeldahl Nitrogen

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	11.58	2.316	2.95228
Column 2	5	5.03	1.006	0.13618

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.29025	1	4.29025	2.778245	0.134112	5.317645
Within Groups	12.35384	8	1.54423			
Total	16.64409	9				

Anova: Single Factor Phosphorous (T)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	1.626	0.3252	0.064285
Column 2	5	0.667	0.1334	0.006029

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.091968	1	0.091968	2.615907	0.144459	5.317645
Within Groups	0.281258	8	0.035157			
Total	0.373226	9				

Anova: Single Factor Phosphorous (D)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	0.808	0.1616	0.035827
Column 2	5	0.491	0.0982	0.004357

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.010049	1	0.010049	0.500138	0.499518	5.317645
Within Groups	0.160738	8	0.020092			
Total	0.170787	9				

Anova: Single Factor Cadmium (T)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	0.0062	0.00124	9.3E-08
Column 2	5	0.0054	0.00108	1.7E-08

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.4E-08	1	6.4E-08	1.163636	0.31216	5.317645
Within Groups	4.4E-07	8	5.5E-08			
Total	5.04E-07	9				

Anova: Single Factor Copper (T)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	0.0419	0.00838	3.85E-05
Column 2	5	0.077	0.0154	0.000275

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000123	1	0.000123	0.786543	0.401022	5.317645
Within Groups	0.001253	8	0.000157			
Total	0.001376	9				

Anova: Single Factor Lead (T)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	0.019	0.0038	3.06E-06
Column 2	5	0.01	0.002	0

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.1E-06	1	8.1E-06	5.294118	0.0504	5.317645
Within Groups	1.22E-05	8	1.53E-06			
Total	2.03E-05	9				

Anova: Single Factor Zinc (T)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	0.207	0.0414	0.00042
Column 2	5	0.072	0.0144	5.43E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001823	1	0.001823	7.680152	0.024248	5.317645
Within Groups	0.001898	8	0.000237			
Total	0.003721	9				

Anova: Single Factor Fecal Coliform

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	353787	70757.4	9.44E+09
Column 2	5	1322	264.4	146514.3

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.24E+10	1	1.24E+10	2.631231	0.143438	5.317645
Within Groups	3.78E+10	8	4.72E+09			
Total	5.02E+10	9				

VITA

Steven Phillip Schaal

Candidate for the Degree of

Master of Science

Thesis: Water Quality Enhancement Assessment of an Existing Flood Control Detention Facility in the City Of Tulsa, Oklahoma

Major Field: Environmental Science

Biographical:

Education: Bachelor of Science in Agriculture from Southwest Texas State University, San Marcos, Texas in August 1994. Completed the requirements for the Master of Science degree with a major in Environmental Science at Oklahoma State University in July, 2006.

Name: Steve Schaal Date of Degree: July, 2006

Institution: Oklahoma State University Location: Tulsa, Oklahoma

Title of Study: WATER QUALITY ENHANCEMENT ASSESSMENT OF AN EXISTING FLOOD CONTROL DETENTION FACILITY IN THE CITY OF TULSA, OKLAHOMA

Pages in Study: 55 Candidate for the Degree of Master of Science

Major Field: Environmental Science

Scope and Method of Study: Stormwater utility managers use constructed wetlands to mediate flooding and enhance water quality in urban watersheds. The National Pollution Discharge Elimination System requires permit holders to assess the feasibility of retrofitting existing flood control devices to provide additional pollutant removal from stormwater. Chemical measurements from five storm event flows were taken of the influent and effluent of a constructed wetland in the spring of 2005, to quantify any change in water quality attributed to this multiple-use stormwater management facility. Results of the study demonstrate removal of 12 of the 14 stormwater contaminants. A dye tracer was used as a tool to ensure the same parcel of water was sampled at both the influent and effluent.

Findings and Conclusions: The average percent difference of means ranged from 99% to a negative 66% for fecal coliform and copper respectively. The percent difference of means for nitrate and nitrite nitrogen was 60% and the values were significantly lower at the outflow as compared to the inflow ($p=0.004$). The relative fluorescence of dye at the effluent was used as to tool in quantifying the detention time for individual events.

ADVISER'S APPROVAL: William W. Clarkson