MODELING AND COST-BENEFIT ANALYSIS OF RESTORATION ALTERNATIVES FOR THE LAKEFIELD WATERSHED

Joel A. Tillery[1] and Victor Jones, P.E.[2]

AUTHORS: Water Resources Engineer[1], Project Manager[2], CH2M HILL, 115 Perimeter Center Place NE Suite 700, Atlanta, GA 30346
REFERENCE: *Proceedings of the 2007 Georgia Water Resources Conference*, held March 27–29, 2007, at the University of Georgia.

Abstract. The Lakefield Watershed is one of the densest urban areas in all of Rockdale County. Large volumes of runoff and heavy pollutant loads from the landscape have degraded water quality, stream channels, and overall habitat conditions in downstream watersheds. Within the Lakefield Watershed, there are a limited number of best management practices (BMPs) that treat stormwater runoff; many of these are undersized or improperly designed. At the downstream terminus of the watershed, a small lake (approximately 4 acres) provides water quality benefits and some peak flow attenuation through regional detention. However, the lake is impounded by a Category I dam (probable loss of life and property upon failure) that is not in compliance with the rules of the Georgia Safe Dams Act. A study was initiated to determine whether rehabilitating the existing dam and retrofitting the existing lake or retrofitting existing upland BMPs combined with new BMPs or low impact development techniques was the most cost-effective means to achieve water quality and channel protection for the watershed. There were significant drivers for rehabilitating the dam including life and safety issues, economic development in the region, and transportation improvements through construction of a bypass road across the dam. The results of the study showed that due to the built-out nature of the watershed and the insufficiency of existing BMPs, that rehabilitating the existing dam was the most cost-effective means to meet the stated objectives.

INTRODUCTION

The Lakefield Watershed, located in the City of Conyers, Rockdale County, GA, is a small, highly urbanized area of approximately 150 acres. Approximately 70 percent of the watershed is comprised of impervious areas, resulting in relatively high pollutant loads and negative impacts to the hydrology of this small watershed. A significant percentage of the development and subsequent impervious area occurred in the 1980's and early 90's, prior to the development and adoptions of the water quality standards set forth in the Georgia Stormwater Management Manual. A majority of the stormwater runoff from the watershed is not treated by a best management practice (BMP).

In 2005, Rockdale County initiated a US Environmental Protection Agency (EPA) funded study to pursue restoration of the degraded Lakefield Watershed. The purpose of the study was to analyze various alternatives including: retrofit of the existing lake, retrofit of existing upland BMPs and installation of new BMPs, and a combination of lake retrofits and selected BMP retrofits. Due to the nature of the watershed (i.e., highly urbanized, inadequate onsite stormwater controls, presence of a 4-acre lake), the retrofit of the existing lake for regional detention was considered an appropriate means to achieve water quality and habitat improvement goals for the watershed. Additionally, utilizing the existing 4-acre lake for regional detention provided unique opportunities to achieve other goals related to public health and safety, economic revitalization of the area, and overall community improvement.

RESTORATION OBJECTIVES AND ALTERNATIVE EVALUATION CRITERIA

The primary objective of the watershed restoration was to meet the minimum standards for stormwater management as outlined in the GA Stormwater Management Manual. Most importantly, the watershed restoration project needed to meet minimum standards #2 and #3, water quality and channel protection as defined below:

Minimum standard #2 (stormwater runoff quality) states that "stormwater management systems must be designed to remove 80 percent of the average annual post-development total suspended solids (TSS) and be able to meet any other additional watershed- or site-specific water quality requirements" (GSMM, 2001). According to the design guidance in the manual, 80 percent removal of TSS is achieved by treating the water quality volume (WQv), which is the runoff generated during a rainfall event totaling 1.2 inches.

Minimum standard #3 (stream channel protection) states that "stream channel protection shall be provided by using all of the following three approaches: (1) 24-hour extended detention of the 1-year, 24-hour return frequency storm event; (2) erosion prevention measures such as energy dissipation and velocity control; and (3) preservation of the applicable stream buffer" (GSMM, 2001).

TSS reduction and channel protection, as measured by a peak flow equivalent to 24-hour extended detention of the channel protection volume were established as primary evaluation criteria for the restoration alternatives.

STUDY DESIGN

This study was completed in three primary tasks: (1) Field Survey and Site Reconnaissance, (2), Hydraulic and Water Quality Model Development, and (3) Cost Benefit Analysis of Restoration Alternatives.

Field Survey and Site Reconnaissance Task

A field reconnaissance task was conducted to inventory and evaluate existing conditions within the Lakefield Watershed including the area immediately adjacent to the lake, stream reaches upstream and downstream of the lake, and existing BMPs. The data collected on the existing BMPs and the network drainage observed were used to develop a hydrologic and hydraulic model and a water quality model to analyze the various restoration alternatives. Additionally, rainfall and flow data were collected for a six-month period to aid in calibrating the models.

Hydraulic and Water Quality Modeling Task

Two calibrated models were developed to analyze the water quality and channel protection benefits of the various restoration alternatives. The model ICPR (Interconnected Pond Routing) was used to simulate the watershed hydrology and detailed hydraulics of the various BMP outlet structures and lake outlet structure. ICPR was used to quantity the channel protection benefits. The LIFE™ Model, developed by CH2M HILL, was used to simulate the watershed hydrology and to quantity the water quality benefits in terms of TSS reduction of the various restoration alternatives.

Analysis of Restoration Alternatives

The alternatives analysis methodology was approached as a step-by-step process. The first step in the process was to establish the baseline conditions with regard to the evaluation criteria, total suspended solids (TSS) reduction, and peak flow reduction. The second step was to design the retrofits for the various alternatives. This step included a feasibility analysis that identified the most appropriate retrofit given the constraints surrounding the existing BMP. The third step was to utilize the models to analyze the effects of the retrofits on the two primary evaluation criteria. After determining the effect of the retrofits (i.e., benefits of alternative), a cost estimate was developed to determine the combined cost of the various components of each alternative. This information was used to establish cost-benefit values for each alternative for both evaluation criteria. The resulting values represent the cost to meet the water quality goals of the project, channel protection goals, and overall habitat goals.

MODELING METHODS

This section contains the methods used to quantify the water quality and channel protection benefits of the various restoration alternatives. Specifically, the methods used to generate TSS loads from the watershed and the methods used to calculate the removal of TSS via the lake and BMPs are discussed.

Modeling TSS Generation

The LIFE™ model utilizes different algorithms to generate sediment loadings from pervious and impervious land areas, which are then routed via the drainage system to the BMPs and the lake. The pervious portion in each drainage area uses the Revised Universal Soil Loss Equation, which is also used in the SWAT (Neitsch et al., 2000) model.

Since no TSS monitoring data were collected, the parameters were adjusted to make the equivalent annual loading rate similar to that for the Commercial land use in the Metro North Georgia Watershed Protection District study (CH2M HILL, 2002). Two sets of loadings were developed: 1) existing conditions, to be used in the base scenario, and 2) anticipated buildout conditions, to be used for analysis of alternatives. The loading rates are shown below in Table 1. The equivalent annual loading rates were estimated by multiplying the average daily load by 365.25 days/year. The rainfall data collected at the project site were used in the LIFE model. Estimated annual loading rate of TSS is approximately 80 tons per year.

Table 1. Simulated TSS Loading Rates

Pervious. (tn/ac)	Pervious. (tn/ac/yr)	Impervious. (tn/ac)	Impervious (tn/ac/yr)
0.364	0.832	0.213	0.488

Modeling TSS Removal

The timing of the release of stormwater from the BMPs is a critical part of the calculation of TSS removal. Since LIFE™ is not a detailed hydraulic model as is ICPR, the stage-discharge relationships for the BMPs and the lake modeled in ICPR were transferred to the LIFE™ model. This same method was used during the initial model setup and calibration. Explicitly modeling the TSS removal in the BMPs, lake, and sediment forebays was considered necessary since the removal efficiency assumed in the GA Stormwater Management Manual for different types of ponds (e.g., wet pond = 80% TSS removal) is not applicable if the sizing requirements are not met. That was the case for many of the existing BMPs.

In the water bodies, TSS loads are divided into sand (10 percent), silt (30 percent), and clay (60 percent) fractions, representing the expected average proportions in the edge-of-stream loads. These are generally shifted toward smaller sizes compared to the soil matrix itself, as overland transport processes should carry them more easily.

The dynamic treatment efficiency for the water bodies in the model are computed for each size fraction using the Hazen method as described in the EPA *Stormwater Best Management Practices Design Guide* (EPA, 2004).

$$TE = 1 - \left[1 + \left(\frac{V_s \times A}{n \times Q} \right)^{-n} \right]$$ where:

TE = treatment efficiency
Vs = settling velocity (ft/s)
A = effective surface area (ft^2)
n = a integer parameter indicating the degree of turbulence or short circuiting (1 – very poor; 2 – average; 3 – good; 5 – very good)
Q = outflow rate (cfs)

For the Hazen n parameter, a value of 2 (average) was assigned for all dry ponds, and a value of 3 (good) was assigned for all wet ponds. Also, the effective surface area is reduced linearly from the nominal value in order to account for dead storage. According to Griffin et al (1985), the appropriate reduction fraction depends on whether the length to width ratio is greater than 2:1.

As the LIFE™ model is a continuous simulation model, the equation is applied dynamically during each timestep, using the current outflow rate as the peak rate. This allows the model to react to the overall hydrograph, rather than back-calculate the average performance over an entire event.

Under quiescent conditions, the settling rate is applied directly to compute a drop depth during the interval, and any sediment falling below the active storage above the outlet invert is considered to be removed.

Modeling TSS Removal

Quantifying the level of channel protection based on extended detention volumes is difficult when analyzing a system of BMPs, such as is the case with the Lakefield Watershed. As an alternative to using channel protection volumes as a metric, the peak outflow from the lake that corresponds to providing the channel protection volume (CPv) was used to evaluate the benefits or level of protection provided by the various alternatives.

According to the calculations outlined in the Georgia Stormwater Management Manual (GSMM), the Lakefield watershed required a CPv of 20.3 ac-ft. This volume of water must be detained as extended detention storage (i.e., storage above the normal water surface or permanent pool) and released over a 24-hour period in order to meet channel protection goals. The average and peak outflows produced when these requirements are met were estimated at **13.2 cfs**.

SUMMARY OF WATERSHED RESTORATION ALTERNATIVES MODELED

Table 2 summarizes the alternatives modeled. An additional alternative (3b) that considered the construction of new BMPs in addition to retrofits to existing BMPs was not modeled, but was considered in the cost benefit analysis. It was assumed that installation of new BMPs at a defined cost would meet water quality and channel protection criteria.

Table 2. Summary of Watershed Restoration Alternatives Modeled

Alternative	Alternative/Model Components
Alternative 1: No Action	All structural BMPs and the lake.
Alternative 2: Lake Retrofit	All existing structural BMPs (no new or retrofit BMPs). Modified outlet control structure and modified normal water surface elevation in the lake. Sediment forebays at the pipe inlet and stream inlet.
Alternative 3a: BMP Retrofits	All existing structural BMPs modified to provide the greatest treatment given certain constraints (i.e., potential to cause flooding, freeboard, and land availability).
Alternative 4: Lake and BMP Retrofit	All existing structural BMPs with select retrofits. Modified outlet control structure and modified normal water surface elevation in the lake. Sediment forebays at the pipe inlet and stream inlet.

COSTING METHODS

All costs associated with the dam rehabilitation, retrofit of BMPs, pre-treatment works such as sediment forebays, and modifications to outlet structures were determined explicitly using generally accepted unit prices for earthwork and concrete structures. For new BMPs, the following cost equation was used (USEPA, 1999) for the construction, design, and permitting of new wet detention ponds:

$$C = 24.5V^{0.705}$$ `where:

C = construction, design, and permitting cost ($), dollar year 1999
V = storage volume of detention pond (ft^3)

These costs were adjusted to 2006 dollars. A land cost was also included in the cost of new BMPs.

It was also assumed that the cost of dam rehabilitation would have to be included in the cost estimates for each alternative since the dam is not in compliance with the GA Safe Dams Act. The existing water quality and channel protection benefit provided by the lake is dependent on the structural integrity of the dam. If the dam were to fail or if the County was required to breach the dam, all water quality and channel protection benefits would be lost.

COST BENEFIT ANALYSIS AND MODELING RESULTS

Table 3 shows the results of the cost benefit analysis and modeling runs. For Alts 1, 2, 3a, and 4, the lake provides 80% removal of TSS. The existing lake volume is much greater than the water quality volume and as a result, water quality and TSS reduction for the watershed as a whole is very good. The TSS loading to the lake for each alternative was an important consideration since a project goal was to prevent further degradation of lake water quality. Modeling of sediment forebays and upstream BMPs showed a reduction in TSS loading to the lake. For Alternative 3b, the 80% TSS removal efficiency results from retrofit of existing BMPs and installation of new BMPs to provide water quality and channel protection for the areas of the watershed that are not currently treated. The total cost for Alternative 3b does not include dam rehabilitation as do the other 4 alternatives.

Alternatives 2, 3b, and 4 are the only alternatives capable of meeting the channel protection criteria. The percentage of channel protection is a measure of the peak flow exiting the watershed during the 1-year, 24-hour storm compared to the peak flow equivalent to providing channel protection volume for the watershed. For Alternative 3a, retrofitting all of the upland BMPs only increases the channel protection benefit to 31% compared to the baseline condition (Alternative 1) of 21%.

Table 3. Cost Benefit Results of Watershed Restoration Alternatives

Alternative	Total Cost (million $)	TSS Removal Efficiency	Percentage of Channel Protection
1	$2.42	>80%	21%
2	$2.49	>80%	97%
3a	$2.77	>80%	31%
3b	$3.54	80%	100%
4	$2.61	>80%	100%

CONCLUSIONS

Based on the analysis of the alternatives, Alternatives 2 and 4, the lake retrofit alternative and lake retrofit plus BMP retrofit, are the most cost-beneficial solutions to meeting the water quality and channel protection criteria. The additional costs of retrofitting the select BMPs in Alternative 4 provides additional benefits that would enhance the overall restoration project by: (1) limiting the pollutant loading directly to the lake, (2) protecting the natural stream channel entering the lake at the north end of the lake, and (3) providing additional opportunities to remove nonfunctioning BMPs from the watershed and redevelop these areas to revitalize the economy of the area and beautify the areas marked by unsightly BMPs. Additionally, the selected BMP retrofits make this alternative the most appealing by taking advantage of BMPs that have good potential to provide treatment and opportunity for redevelopment at some point in the future. This analysis also demonstrates that implementing regional detention is a viable alternative to using onsite stormwater controls and is able to meet the larger goals of economic and community enhancement.

LITERATURE CITED

AMEC Earth and Environmental, Center for Watershed Protection, Debo and Associates, Jordan, Jones, & Goulding, and Atlanta Regional Commission. 2001. *Georgia Stormwater Management Manual, Volume 2: Technical Handbook, First Edition.* Atlanta, GA.

CH2M HILL, 2002. Modeling Results for Existing Conditions Technical Memorandum VI prepared for Metropolitan North Georgia Water Planning District.

Clar, M.L., Barfield B.J., O'Connor, T.P. 2004. Stormwater Best Management Practice Design Guide - Volume 1: Basin Best Management Practices. EPA, Washington, DC, Report No. EPA 600/R-04/121B

Griffin M.L., Barfield, B.J., Warner R.C. 1985. Laboratory Studies of Dead Storage in Sediment Ponds. *Transaction of the ASAE* 28(3): 799-804.

U.S. Environmental Protection Agency (USEPA). 1999. *Post-Construction Storm Water Management in New Development & Redevelopment.*