Erosion Prevention and Sediment Control Computer Modeling Project: Executive Summary

Submitted To:

The Chattahoochee-Flint Regional Development Center
Dirt II Committee

By:

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The authors gratefully acknowledge the dedication and hard work of many individuals whose efforts during the past three years have greatly enhanced the real-world applicability of this project. The Erosion and Sedimentation Control Technical Study Committee ("Dirt 2") members generously shared their extensive knowledge and experience, actively participated through challenging discussions and provided an evolving philosophy of the paradigm shift that is needed to advance the multi-functionality of storm water, erosion prevention and sediment control system design and performance.

As Dirt 2 chair, Dr. Benjamin C. Dysart provided continuous real-world advice and guidance, evaluated and critiqued alternative design considerations, and provided an eye towards adoption, implementation, and policy. Dr. Terry Sturm was the chair of the Modeling Element Advisory Committee. He was always available for synergistic conversations, kept the multiple project components on target and always encouraged the systems approach and rigorous scientific inquiry. His reviews of the executive summary and this final report were extensive and always enhanced understandability. The computer modeling advisory group members, Ben Dysart, Phil Freshley, Vince Howard, Earl Jenkins, Bill Jordan, and Karim Shahlaee, actively participated in guiding site selection, individual erosion and sediment control component, monitoring decisions and modeling philosophy.

Two individuals substantially contributed to the critical start of this project by providing sites to monitor the performance of current-paradigm sediment control measures. Wayne Woodall arranged access and cooperation at both the residential and commercial sites. James Magnus provided us with one of his highway sites and opened doors for us to learn contractual arrangements that influence construction, maintenance and therefore performance, of sediment controls at highway construction sites. We would like to thank the site owners and project managers that provided not only site access but also support for in-field personnel during the monitoring timeframe.

The next large hurdle was to find a cooperator for the full-scale model demonstration site. This was difficult to accomplish because involving us in a project entailed several potential liabilities. The storm water, erosion, and sediment control plan would be quite different from current practice, thus potentially exposing the cooperator to potential cost increases and delays in permitting. The design philosophy of placing sediment control installation on the critical path could increase the overall timeframe for site development and delay completion. A comprehensive monitoring program, with results being readily available to the public, and a highly visible project were other perceived impediments to locating a cooperator. Michael Breedlove expounded the virtues of this demonstration effort. Although there were potential liabilities, there were many and large advantages. Michael secured the willing cooperation of the Fulton County Board of Education and especially the support and commitment of Marcus Ray and Ollis Townes. The Big Creek School site became available for the model demonstration component of the project. Scott Southerland the project architect was very supportive of advancing site capabilities. Michael, and his team of design professionals, worked hand-in-hand with us in every phase of designing and implementing the storm water, erosion, and sediment control plan. He was critically instrumental in creating and accomplishing an incredibly successful project.

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Eric Dawalt supervised and conducted soil sample analysis and was the lead contributor to Chapter 8, Cost Methodology of Alternative Erosion Prevention and Sediment Control Systems.

Two graduate students in Civil Engineering at Georgia Tech were responsible for on-site data acquisition and maintenance of the eight monitoring systems installed at the Big Creek School site. Diana Weber and Mindy Hoepner ensured that the database was as complete as possible through their dedication.

Fran Burst-Terranella documented the project through video production of “Getting the Dirt on Clean Streams: Straight Talk on Preventing Erosion”.

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The computer modeling project is part of the scope of work of the Dirt 2 Committee that was authorized by an act of the Georgia General Assembly in 1993 and supported with a Chattahoochee Basin Downstream Assistance grant authorized by the 1996 General Assembly. The Chattahoochee-Flint Regional Development Center, based in Franklin, Georgia, administered the grant. In addition, the Georgia Environmental Protection Division is recognized for their much-welcomed involvement and input throughout this project.

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Executive Summary

Introduction

The focus of this three-year effort was to develop and demonstrate cost-effective erosion prevention and sediment control systems that achieve excellent water quality. To accomplish this the performance of current sediment control devices was determined through on-site monitoring at a residential subdivision development, a large commercial construction site and a highway. Alternative sediment control devices were developed. Emphasis was placed on the effectiveness of the system of controls integrated with natural off-site riparian areas. Design methodology encompassed both storm water and sediment. Designs were developed and demonstrated that substantially reduced peak flow, runoff volume, peak sediment concentration and the total sediment load discharging from a construction site. The sediment controls at the Big Creek School construction site were monitored to demonstrate performance of individual devices and the complete system. Cost of all components was determined. The cost and performance of numerous alternative erosion prevention and sediment control systems were analyzed through computer analysis applied to residential, commercial and highway sites. Complete performance and cost information is detailed for the Big Creek demonstration site and the alternative control systems evaluated. Fourteen specific design and planning recommendations that were demonstrated at the Big Creek School site are illustrated throughout this report. Six short courses were taught to design professionals throughout the Metropolitan Atlanta area to introduce the systems design methodology. PowerPoint and video productions were completed and are available as separate documents.

Objectives

The Erosion Prevention and Sediment Control Modeling Component of the Dirt 2 Project Encompassed:

(1) Monitoring current sediment control technology to assess effluent concentration emanating from currently utilized devices,
(2) Determination of possible relationships between suspended solids (mg/l) and turbidity (NTU),
(3) Development of sediment controls that have the potential to cost-effectively reduce effluent concentration,
(4) Development of a comprehensive erosion and sediment control planning methodology that is consistent with recognized state-of-practice,
(5) Development, demonstration, performance monitoring and modeling of an erosion prevention and sediment control system at a major construction-site in the Chattahoochee River basin in the Atlanta metropolitan area, and
(6) Determination of the cost and performance of alternative erosion prevention and sediment control systems for residential, commercial and linear developments.

Overview of Final Report

Chapter 1- Introduction

Chapter one begins with a brief introduction to the report followed by a list of the project objectives. The remainder of the chapter consists of an overview of what is covered in the nine subsequent chapters of this report.

Chapter 2 – Monitoring Instrumentation

Extensive monitoring instrumentation was fabricated and installed at four sites during the course of this project. Monitoring equipment was almost exclusively installed to determine the effluent sediment concentration leaving construction-sites. Monitoring of the three "current control practice monitoring sites" focused on:

(1) residential development - silt fence monitoring,
(2) commercial development - large sediment basin with first flush sediment load provision, and a
(3) linear (highway) development - sediment basin.

A total of eight locations were monitored for the demonstration-site at Big Creek Elementary School. Seven locations monitored effluent concentration and turbidity. All four sediment basins were monitored. At three of the sediment basins monitoring was conducted at the outlet of the sand filter. At Basin B3 monitoring occurred at the outlet to the perforated riser. Besides the sand filter, Basin B2 was monitored at the plunge pool-energy dissipator inlet and at the outlet of the floating siphon or perforated riser (ability to switch) that discharged to the sand filter. Additionally, two effluent monitoring locations existed along the seep berm.

Sampling equipment consists of a standard rain collector connected to a single station logger. A pressure transducer mounted in a stilling well and connected to an in-house fabricated trapezoidal supercritical flow flume was connected to a data logger to record stage. A pre-calibrated rating curve was linked with the recorded stage and translated to measured runoff. A monitoring system was installed that detects when runoff is occurring and automatically samples and records at pre-programmed time intervals. The ISCO 3700 Standard sampler with solar panel and liquid level sample actuator was the chosen system for capturing sediment samples and was installed at each monitoring location.

Analysis encompassed effluent sediment concentration and turbidity of all samples and particle size distribution of selected samples. A maintenance and sampling protocol was developed for the two graduate students in Civil Engineering at Georgia Tech. The students assisted in initial installation and decommissioning of all sampling equipment. The students were responsible for periodic inspection and maintenance of monitoring equipment, acquisition of data and samples, site photo-documentation and initiating chain of custody and transfer of samples to the Surface Mining Institute for processing.

Chapter 3 – Site Soil Characteristics

Soil characteristics for the three current practice sites and the Big Creek demonstration-site are described in Chapter 3. The effectiveness of sediment controls and the quantity of sediment eroded depend on soil characteristics such as the erodibility factor and the primary and eroded particle size distribution. Likewise, sediment and erosion control modeling efforts require accurate databases for input parameters. Input values for the Chattahoochee River basin in the vicinity of Atlanta, Georgia were determined. These databases include; (1) erodibility factors, (2) primary particle size distribution, and (3) eroded particle size distribution.

Two soils are classified as sandy loam, one a sandy clay loam, and the fourth a clay classification on the USDA textural triangle. An erodibility value, K-factor, of 0.14 was determined for soils sampled in July. This translated to an average K-factor of 0.20 to 0.24. A K-factor of 0.24 was used in all modeling simulations. Both primary and eroded particle size distributions were developed for site soils. Laboratory determined primary particle size distributions and organic material were combined with an estimate of soil structure and permeability class to predict the erodibility K-factor.

For this project two storm intensities (the 2-year and 10-year, 24-hour storms) were generated for the four soils to be analyzed. Each soil (4) and generated storm events (2) were repeated for three repetitions resulting in a total of 24 experiments. The resultant eroded particle size distribution, used in the modeling effort, was generated from these experiments.

Chapter 4 – Current Sediment Control Practices: Site Descriptions and Monitoring Results

A thorough site description is provided for the three 'current practice sites' in Chapter 4. The description includes initial description of the site and a detailed documentation of construction activity progression throughout the timeframe from July 1988 through March 1999. Photo documentation is quite complete throughout this period.

For the residential site 4 storms were monitored resulting in 34 effluent samples passing through the silt fence. All samples yield turbidity greater than 1,000 NTU. Two storms were monitored at the commercial site. Since the sediment basin monitoring system was damaged and also taken out of commission for pipeline installation there were only two events monitored. The August storm effluent ranged from 300 to 900 NTU. The January storm yield 24 samples ranging from 125 to 240 NTU. The first flush portion of the basin was functional in January. Eight storm events were monitored at the highway sediment basin. The range of effluent sediment was between 100 and 3500 NTU for the 156 samples obtained during the monitoring period from July 22, 1998 through January 30, 1999. Peak values ranged from 325 to 3500 NTU and averaged 1,767 NTU.

Chapter 5 – Big Creek Erosion Prevention and Sediment Control Demonstration-site

The Big Creek School Site in Fulton County was selected as the test site for demonstrating state-of-practice erosion prevention and sediment control measures in Georgia. The design, installation, monitoring and modeling of this site are documented in Chapter 5. This test site illustrated in a demanding, full-scale, real-world situation that erosion prevention and sediment control systems can be designed, installed and maintained which are both cost-effective and perform reliably to protect the waters of the state. The focus of the chapter is the design and implementation of integrated controls performing as an effective system. Extensive documentation and description of designs is provided through drawings and detailed field photographs.

The primary philosophies illustrated through implementation of the demonstration project are:
(1) design for pre-, during- and post-development timeframes,
(2) mimic pre-development peak flow and runoff volume with respect to quantity and duration,
(3) integrate step-by-step erosion prevention and sediment controls into all documentation including the pre-bid package, detailed blue-line drawings, site visit prior to bid opening, all discussions, initial site walk-through, and weekly site visits,
(4) incorporate initial construction and stabilization of sediment control measures into the critical path for project completion,
(5) utilize perimeter controls that discharge through multiple outlets to riparian zones,
(6) design the complete system and evaluate its expected performance as part of the design and permitting process,
(7) employ elongated sediment controls that contain the runoff volume from 3- to 4-inch storm events and then slowly discharge to down-gradient areas,
(8) design a multi-chamber sediment basin with controlled outlets that decant the cleanest water,
(9) implement a secondary treatment (a sand filter) that increase the overall efficiency of the system,
(10) eliminate runoff from entering critical steep-slope highly-erosive areas,
(11) design controls that perform as sediment control devices during construction and as permanent storm water controls in the long run,
(12) design sediment controls that accommodate efficient sediment removal,
(13) conduct a daily walk-through ensuring runoff will not bypass controls, and
(14) instill a team synergism through considering all ideas to help improve and increase the effectiveness of the erosion prevention and sediment control system.

Chapter 6 – Total Solids – Turbidity Relationships

A total solids (TS) - turbidity (NTU) relationship was explored, in Chapter 6, for current practice site soils and soils emanating from various sediment controls demonstrated at the Big Creek School site. Such a relationship attempts to capture the interplay between weight of sediment and turbidity. A couple of factors will shed light on the methodology considered in developing a mg/l-NTU relationship. Turbidity is a measure of light scatter due to interference from impurities in the water. Sands are large particles that are angular in shape and have a high weight to surface area relationship. Conversely, clay is a plate-like particle that has a high light reflective surface area hence the weight to surface area relationship is low. Consider two soil samples that weigh exactly the same amount. One sample contains more sand particles than the other one that containing more clay particles. The weight, and thus mg/l, of each sample is identical but the turbidity of the sample containing a larger fraction of clay has a substantially higher turbidity, NTU, than the sample containing sand.

Based on such information, samples that have a significant fraction of sand, even over a relatively wide range of higher concentrations, will have a relatively good predictive relationship between mg/l and NTU. Fair to good linear relationships, R^2 ranging from 0.61 to 0.97, were developed for Georgia eroded soil samples obtained from rainfall simulators. These relationships are valid, for the specific soils tested, and for turbidities between 3,000 and 20,000 NTU.

An idea predictor of NTU would be based on mg/l and the sediment particle size distribution. As sediment is transported from the point of initial soil detachment, through the subwatershed, along conveyance channels and especially through sediment control structures the percentage of sand continually decreases and the percent of fines, silts and clays, increases. Thus one would expect a shift in the mg/l-NTU relationship.

Since the emphasis of this project was on determining the effluent concentration and turbidity emanating from the outlet of the most down-gradient sediment control another approach was developed. There was not enough data to base the prediction of NTU on mg/l and particle size distribution. Analysis of outlet samples showed that various ratios of NTU to mg/l were evident for samples obtained from the outlet of different sediment controls. Those controls that achieve the higher performance, the sand filter and floating siphon, exhibited a very, very low fraction of sand and therefore a NTU/(mg/l) ratio of 1.7. That is a 100 mg/l sediment concentration equals to 170 NTU. The perforated riser allowed a slightly higher fraction of sand to be discharged than the sand filter or floating siphon. This is directly reflected in a NTU/(mg/l) ratio of 1.4. The performance of a drop-inlet (riser-barrel) is related to hydrograph, sedimentgraph and basin hydraulic characteristics. One of the most critical parameters is the stage of water above the invert (top) of the inlet pipe. When water is just slightly above the invert a better efficiency is obtained than if a high head exists above the pipe invert. These considerations are beyond the scope and available database of this analysis. A constant NTU/(mg/l) ratio of 1.3 was used for all flow regimes of the drop-inlet.

Chapter 7 – Modeling the Performance of Alternative Erosion Prevention and Sediment Control Systems for Commercial, Residential and Highway Construction-sites

To extend the results, and illustrate the concepts learned, from the Big Creek School demonstration-site, alternative erosion prevention and sediment control systems were designed and evaluated for commercial, residential and highway developments. Chapter 7 contains details of the designs. Evaluation of the alternative control systems encompassed cost and performance. Additionally, for selective alternative control systems, assessments were expanded to include four size storms: (1) a historic 6-hour event of 1.7 inches, (2) a 2-year, 24-hour NRCS, Type II, design storm of 3.7-inches, (3) a 5-year, 24-hour storm of 4.8-inches and (4) a 10-year, 24-hour storm of 5.7-inches.

Sediment controls analyzed encompass sediment basins, seep berms, sand filters, flexible slotted pipe level spreaders, temporary earthen berms with down-gradient conveyance channels or piping, earthen channels, channels with porous rock check dams, rock protected channels, silt fence, silt fence with rock check dams, and riparian zones. Since sediment basins are so prevalent in storm water and sediment control plans attention was directed at increasing their performance through the use of an alternative spillway, namely a dedicated small perforated riser with a flow control valve. The performance of this alternative spillway system was compared to a standard drop-inlet and a standard drop-inlet with perforations. To further increase the performance of sediment basins alternative down-gradient controls such as a sand filter and a flexible pipe level spreader were investigated. Performance, for this analysis, was based on peak NTU. For all control systems a comprehensive cost analysis was completed and presented in Chapter 8.

Chapter 8 – Cost Methodology of Alternative Erosion Prevention and Sediment Control Systems

Unit prices were developed for calculating the expense of typical E&SC measures. Unit prices were developed using sources including, but not limited to: Environmental Protection Agency (EPA) documents, current erosion protection and sediment control applied research in the Atlanta, Georgia area, state transportation project bid prices, municipality project bid prices, professional estimating resources, personal interviews, and specific manufacturer quotes. These unit prices are combined with quantity takeoffs of individual components to evaluating the cost-effectiveness of alternative erosion protection and sediment control systems. Examples of unit prices and costs of erosion and sediment control measures are provided.

The costs associated with any erosion protection and sediment control system must also take into account design costs. A typical design fee schedule and an estimation of design cost for the Big Creek, watershed B, stormwater and sediment control system are provided. Design costs are given for the seep berm and basin B2.

Three components are needed to estimate the construction costs of a system of controls: (1) unit cost for materials, such as supplies, earthwork such as excavation, haulage, placement, including labor and equipment needed for installation were first developed,
(2) material and earthwork quantities for specific sediment controls were next calculated. Earthwork cut and fill quantities were specifically determined for all elements of the seep berms, channels, embankments, etc. using a proprietary suit of earthwork and material estimator programs, developed by the Surface Mining Institute, and
(3) linkage of unit costs with the quantity takeoff for specific controls results in the cost of a sediment control. This same methodology is extended to evaluate a system of controls by adding up the number or linear feet of each type of control used, based on detailed design dimensions. The sum of all control measures results in the total costs for the alternative system being evaluated.

An example of the design cost methodology was applied to the seep berm and sediment basin B2 used at the Big Creek demonstration project. The seep berm cost analysis was based on (1) estimated cut/fill, and mulch and seed quantities, (2) check dam earthwork quantities and excelsior mat. Detailed cost analysis sheets for the Big Creek seep berm and sediment basin is located in Chapter 8.

Separate costs categories for erosion protection and sediment control measures at the Big Creek elementary school was provided by Beers-Moody. A separate cost analysis was conducted by the outside contractor, Surface Mining Institute (SMI), and two major sediment controls were compared to Beers-Moody estimates. The comparison of basin B2 and the seep berm, shows good agreement between Beers-Moody and SMI's cost estimates. Beers-Moody estimated the cost of basin B2 at $100,000 and the seep berm at approximately $29 per linear foot. Table 8-11 contains SMI's detailed cost estimates for basin B2 and the seep berm. The cost of basin B2 that includes earthwork, sand filter, plunge pool, perforated riser, floating siphon and large drop inlet is $113,324. SMI's estimated cost for the seep berm was $34,373, or $27.50 per linear foot. The agreement between Beers-Moody estimates and SMI's detailed cost methodology is considered excellent.

Chapter 9 – Cost and Performance Results for Alternative Erosion Prevention and Sediment Control Systems

Cost and performance charts were developed for three types of developments: (1) commercial, (2) residential subdivisions and (3) highways. An in-depth effort was conducted for two commercial sites, one residential development and a section of a highway construction project. The focus of this investigation was to combine the performance, Chapter 7, and associated cost, Chapter 8, of a wide spectrum of alternative erosion protection and sediment control systems.

Sediment controls analyzed for costs and performance encompass sediment basins, seep berms, sand filters, flexible slotted pipe level spreaders, temporary earthen berms with down-gradient conveyance channels or piping, earthen channels, channels with porous rock check dams, rock protected channels, silt fence, silt fence with rock check dams, and riparian zones. Since sediment basins are so prevalent in storm water and sediment control plans attention was directed at increasing their performance through the use of an alternative spillway, namely a dedicated small perforated riser with a flow control valve. To further increase the performance of sediment basins alternative down-gradient controls such as a sand filter and a flexible pipe level spreader were investigated. For all control systems a comprehensive cost analysis was completed. The cost and performance of alternative design options are presented in Chapter 9 and selective case studies summarized in the executive summary. Alternative sediment control systems were developed to illustrate the scope, ability to adapt control measures to a wide spectrum of situations, and applicability of systems analysis.

Chapter 10 – Summary and Conclusions

The focus of this three-year effort was to develop and demonstrate cost-effective erosion prevention and sediment control systems that achieve excellent water quality. Designs were developed and demonstrated that substantially reduced peak flow, runoff volume, peak sediment concentration and the total sediment load emanating from a construction site. The sediment controls at the Big Creek School construction site were monitored to demonstrate performance of individual devices and the complete system. Complete performance and cost information is detailed for the Big Creek demonstration site and the alternative control systems evaluated. Fourteen specific design and planning recommendations that were demonstrated at the Big Creek School site are detailed throughout this report.

(1) summarizes the important findings,
(2) provides recommendations for implementing an effective erosion and sediment control design,
(3) provides impetus for conducting a systems design and analysis of the erosion protection and sediment control plan,
(4) provides examples of effective erosion and sediment control designs,
(5) provides selected cost and performance results with a discussion of parameters and implication of alternative design options, and
(6) provides guidance for developing legislative and regulatory policy.

Design and Planning Recommendations

The following recommendations summarize the key planning and design features that were successfully implemented in this study. The results of using these recommendations is that developers and owners can significantly reduce off-site storm water and sediment discharges from construction-sites, thereby decreasing business risk and overall costs.

1. Design a system of controls that results in mimicking the pre-development hydrologic site conditions.

This will result in inherently stable streams and sustainable aquatic and aesthetic environments. Designs today seem to only focus on pre- and post-development peak flow with little consideration being given to the duration of peak flow or runoff volume. The assumption is that as long as post-development peak flow can be reduced to pre-development peak flow we are successful. The fluvial system, stream and floodplain, has adapted over decades to accommodate peak flows and runoff volumes of a given frequency and duration. If we simply reduce the peak flow to pre-development conditions through the use of a retention basin, the duration of the peak flow and certainly the volume of runoff have not been adequately addressed; and the fluvial system will adjust, normally by degradation. Design techniques, detailed herein, exist to accomplish both peak flow and volume reductions.

2. Design a system of controls that results in mimicking the pre-development sediment yield and effluent sediment concentration.

Pre-development effluent concentration (mg/l) and sediment load (tons/ac) are usually quite low from lands prior to disturbance. Designs today predominantly focus on pre- and post-development peak flow conditions paying only minimal attention to the design of effective sediment control systems that truly functions to nearly meet pre-development sediment yields. Design techniques, detailed herein, exist to vastly decrease effluent sediment concentration and total tonnage leaving a site.

3. Specifically integrate erosion protection and sediment controls into the critical path of scheduled construction activities.

There is a lot of pressure by owners and developers to concentrate construction effort on those items that directly translate into on-site and bottom-line dollars. This is quite reasonable since, to be successful, house lots need to be sold, commercial buildings need to be leased, schools need to be occupied by a certain date, highway contractors need to meet schedules, etc. Oftentimes sediment controls are partially constructed, constructed after a large portion of the site has been disturbed, or not properly constructed and maintained. If effective sediment controls are specifically identified on blue-line drawings and requirements are clearly spelled out as to when the particular groups of controls must be completely installed and stabilized prior to disturbing a designated area, then erosion protection and sediment controls are on the critical path. With this simple procedure, if there is a delay in completing sediment controls the entire project is delayed. Consequently, erosion protection and sediment controls become much more visible components of the overall project. As soon as sediment control structures are completed they should be stabilized using natural materials or erosion control products. The Big Creek School demonstration project successfully implemented this approach.

4. Utilize perimeter controls.

It is easy to pay lip service to the need for immediate erosion controls and general statements about staging construction; but at many sites a fairly large area, even with staging, must be denuded in order to efficiently conduct earthwork operations. Disturb only those areas needed for preliminary clearing, operation of earthwork equipment and conducting safe operations prior to constructing and stabilizing perimeter sediment controls. It is best if elongated sediment controls are employed. Such controls provide a safeguard against inadvertently bypassing a control. Also, elongated controls provide numerous opportunities to more efficiently reduce sediment load, use the down-gradient natural buffer, and enable reducing both the peak flow and runoff volume to pre-development conditions.

5. Design and evaluate a system of controls.

If we simply go to a book and pick 2 or 3 of these, 4 of these, a small one of these and 1 big one of these, this length of this one and then place all of the sediment controls on a drawing, what do we know? How do we know how well each control will perform? How do we know if it is big enough, or way too big? How do we know if this is the right or most effective location? How do we know what is the interaction among various controls? How do we know what is the expected performance of the entire system? How do we know what size storm can be safely accommodated? What size storm will cause a failure of a given control? How do we know what is the expected effluent concentration leaving the site? How do we know if this mix of controls provides a cost-effective solution or is it unnecessarily redundant and too costly? And what does “cost-effective” mean if a collection of controls does not perform? Qualified design professionals provide detailed professional designs for all other site components such as buildings, roads, utilities, storm water drainage pipes, etc. Why not provide professional designs for erosion prevention and sediment control systems? Recognized state-of-practice techniques enabling comprehensive design and evaluation of erosion prevention and sediment control systems are utilized throughout this report.

6. Design sediment controls systems that contain and slowly release a specified design storm.

If we are to achieve relatively clear streams for most of the time, then sediment from the vast majority of storms must be retained on the construction-site and/or in the adjacent natural or functioning buffer area. To have very effective controls, sediment must be given sufficient time to settle and either receive enhanced settling such as flocculation, or be slowly discharged to a down-gradient sediment control that provides additional treatment. Such down-gradient controls are the natural riparian zone or, where construction encroaches too closely to a stream, this can be a sand filter. If we can obtain high effluent water quality for all but the largest storm events, then the goal of a clear stream is essentially realized. There are tradeoffs among the treatment efficiency of a sediment control system, the cost of treatment technology, and the frequency of attaining various levels of stream water quality throughout the year. What size storm should be completely retained and effectively treated? This is a legislative or regulatory decision. Consideration should be given to two facts: (1) the vast majority of storms are relatively small and (2) construction-sites often rapidly transition from denuded to stabilized areas. Guidance to help make a more informed decision is provided herein.

7. Design elongated sediment control systems that slowly discharge to multiple locations thereby utilizing adjacent buffer zones.

Design a system of controls creating a symbiotic relationship between storm water and sediment control structures and the surrounding vegetation. Preserving a functioning vegetal buffer zone provides many benefits. Instead of conveying runoff to a single discharge point and then "firing down the barrel" at the stream, elongated control measures slowly discharge to dozens of outlets. The discharge rate is designed such that the lower-turbidity waters infiltrate within the buffer zone prior to entering the stream. With a large enough buffer area and a low design discharge rate, the total runoff volume can be infiltrated, thus eliminating all turbid waters from flowing into the stream. If the buffer is not sufficiently large, doesn't have a relatively high infiltration rate, or the discharge rate is not low enough to accomplish complete infiltration, the buffer area still provides additional valuable passive treatment thereby further reducing the sediment concentration and volume of runoff.

The symbiotic relationship is such that the buffer zone provides additional passive treatment and the discharged water slowly entering the buffer area provides needed moisture and nutrients to enhance growth and vegetal productivity. The effects of such a control system upon the stream are that peak flow is greatly reduced, runoff volume is partially or totally infiltrated reducing turbidity, and infiltration is increased enabling groundwater recharge and increased base flow. Refer to the Big Creek section, chapter 5, and Model Simulations, chapter 7, for detailed ways of designing and evaluating elongated discharge systems.

8. Eliminate runoff from eroding steep slopes.

Slope steepness is the predominant factor affecting high erosion rates. Sites that have steep natural slopes are particularly difficult to successfully implement effective erosion and sediment control measures. Such sites will need higher level, and more expensive, sediment control measures. Many construction-sites have cut-fill earthwork that results in the construction of structural fills with steep slopes. Examples of such steep fill slopes are along a highway, at commercial building sites, and residential developments that can not follow the natural contour of the land. Uncontrolled runoff flowing over a steep slope not only causes high erosion losses but creates gullies that need repair, damages construction work in progress, causes difficulty in stabilizing the final slope, increases the sediment load and concentration to sediment controls, and increases the need for maintenance of sediment controls. Fortunately there is a simple technique that eliminates all of these problems.

A temporary earthen berm can be constructed up-gradient of the fill slope. This berm acts as a small temporary sediment basin and eliminates runoff from flowing down the fill slope. Various outlet configurations can be used with the temporary earthen berm. Runoff can simply be diverted to a stabilized channel, or temporary flexible pipes can be connected with perforated drop-inlets. As the fill slope height is increased the down-drain pipes are extended and reconnected to the perforated drop-inlets. The beauty of this solution is that soil is being transported to the fill slope anyway as part of earthwork activities and the temporary earthen berm is simply incorporated as part of the structural fill.

9. Design a system to control storm water and sediment during construction and to function in the long run as a permanent storm water control system.

An integrated system design can accomplish multiple objectives and reduce the overall on-site project cost. Controls, such as seep berms, are very effective sediment control techniques and can also accommodate peak flow and volume reduction after construction has been completed and the site has been stabilized. Additionally, elongated controls can be incorporated into the overall landscape design as bike trails, walking paths, etc. Compared to a sediment basin or storm water retention basin that may require dedicated land, a seep berm can be planned as a part of the landscape and dedicated as a permanent easement. The multi-purpose function of control techniques can reduce cost, provide for a better off-site environment, enhance site aesthetics, and increase profitability.

10. Recycle tree branches and stumps on-site.

During timber removal approximately 60 % of the tree remains as unmarketable timber and stumps. Three options normally exist: burn, haul offsite, and grind on-site. Burning causes air pollution and complaints from neighbors. Hauling cost money, and tipping fees can be even more costly. Recycling using a tub grinder, for example, provides the opportunity to create mulch that can readily be used for erosion control. Additionally, mulch enriches the soil by increasing the water-holding capacity, infiltration rate, and organic material, as well as adding nutrients. Rough-graded mulch has many uses such as adjacent to and down-gradient of interior roads which experience repeated disturbance and along outslopes of sediment controls. Use of natural wood products reduces the need for large quantities of commercial erosion control products.

11. Seek out opportunities to expeditiously complete and stabilize sub-areas throughout all phases of construction.

As soon as a sub-area reaches final grade it should be stabilized using natural on-site produced materials, such as wood mulch, commercially available erosion control products, straw mulch and either temporary or permanent grasses. Such products decrease the potential rate of erosion by a factor of approximately 20, substantially reducing the need to maintain sediment controls and reducing the overall potential liability of discharging sediment-laden flow.

12. Design sediment controls to cost-effectively accommodate sediment removal.

Often-times channels feed a sediment basin that is partially dewatered or dewatered through a 6-inch diameter hole located at the bottom of riser pipe and is completely ineffective at sediment retention. No, or little, design foresight is given to efficient sediment removal. Subsequently sediment removal is often delayed to the point where the sediment control is essentially ineffective. Unfortunately this seems to be standard practice on-sites visited. Cleaning-out a sediment basin consisting of soupy mud is very costly and unproductive. Therefore a basic design rule is simply to ensure a mechanism to passively dewater all sediment controls while minimizing the discharge of sediment.

Sediment controls should be designed to encourage frequent and easy sediment cleanout. A multi-chamber sediment basin, where sediment is predominantly removed in the first chamber and passively dewaters to the second chamber, is such an effective design. Once the first chamber is nearly filled with sediment, the design enables rapid and cost-effective sediment removal. Refer to the Big Creek chapter for a detailed description of sediment basin B2. In the initial design of sediment controls, provisions should be made for easy egress and access to the controls. Consideration should be given to equipment size, reach, location and capabilities during initial design of controls. A distinct advantage of elongated controls is that they are readily accessible and enable rapid and very cost-effective sediment removal by a large range of common on-site equipment.

13. **Conduct a daily site walk-through ensuring that sediment-laden storm water will be directed to sediment controls.**

Well-planned, designed and installed control structures only work if runoff is directed to them. This is common sense. Yet it is so easy for an equipment operator to simply lower a blade cutting a channel or creating a berm that diverts flow, bypassing a control. Sediment control is only one of dozens of on-going concerns that a project or site manager needs to juggle and is usually considered a low priority since it has already been "taken care of" during installation. Near the end of the workday and before weekends, especially prior to forecasted rainfall, the superintendent should walk the site envisioning the path runoff will take. It is very common for a site to need some small earthwork adjustments to ensure that runoff will be directed to controls. This is one of the cheapest measures to reduce potential problems and liability. After a while, heavy equipment operators will incorporate this "end-of-work-day" activity and it will become a habit. When this happens the probability of a successful operation is significantly increased.

14. **Develop a team synergism based on trust, open communications and eagerness to incorporate ideas of others.**

Many of the recommendations and specific designs detailed in this report are "different" or "new" to many developers and earthwork contractors. Our experience is that just blue-line drawings and a site walk-through will not be enough. Communications need to be established early on and continued such that all critical parties obtain a high comfort level with each other and readily pick up the phone asking questions and sharing ideas to improve individual designs and discuss all details of construction and earthwork. Flexibility in sediment control modifications and locations go a long way in establishing a good working relationship and providing for dynamically changing staging and working areas.

Cost and Performance of Alternative Erosion Protection and Sediment Control Systems

Three types of development are prevalent in the Atlanta metropolitan area: (1) commercial, (2) residential subdivisions and (3) linear such as highways and utilities. An in-depth modeling effort was conducted for two commercial sites (large and small), one residential development (infrastructure and completely disturbed) and a highway (cut and fill sections). The focus of this investigation was to assess the cost and likely performance of a wide spectrum of alternative erosion protection and sediment control systems. Selected control systems were subjected to a 1.7-inch, 6-hour historical storm and 2-, 5- and 10-year, 24-hour NRCS Type II design storms of 3.7, 4.8 and 5.7-inches, respectively.

A wide spectrum of sediment controls were analyzed encompassing sediment basins, seep berms, sand filters, flexible slotted pipe level spreaders, temporary earthen berms with down-gradient conveyance channels or flexible pipe down-drains, earthen channels, channels with porous-rock check dams, rock-protected channels, silt fence, silt fence with rock check dams, and riparian zones. Since sediment basins are so prevalent in storm water and sediment control plans, attention was directed at increasing their performance through the use of an alternative spillway, namely a dedicated small perforated riser with a flow control valve. The performance of this alternative spillway system was compared to a standard drop-inlet and a standard drop-inlet with perforations (large perforated riser). To further increase the performance of sediment basins, alternative down-gradient treatment devices such as a sand filter and a slotted-pipe level spreader were investigated. For all control systems, a comprehensive cost analysis was completed. Performance, for this analysis, was based on peak NTU. The cost and performance of selected alternative design options are presented herein. These examples were chosen to illustrate the scope, depth and diversity of analysis.

Cost and performance of control systems for a large commercial site.

The watershed being investigated is considered to be a portion of a larger commercial development that drains to two streams prior to their confluence. The analysis is just as applicable to a residential subdivision that completely denuded a 35-ac watershed. This commercial site was used to illustrate alternative control systems applicable to a relatively large area that required complete disturbance to the limits of construction. Three sediment control systems are schematically shown in Figure 1, Scenarios 2, 3 and 4, and their associated cost and performance is shown in Figures 2a through 2c. The graphs are for the design storms shown in the legend. All control systems utilized a sediment basin. A fourth system is shown in Figure 1, Scenario 5 and compared to Scenario 4 in Figure 3. Seep berms were analyzed for the large commercial construction-site, Table 7A-7, and the residential development scenarios of limited disturbance, Table 7B-6, and complete site disturbance, Table 7B-7. For each of these three case studies, a seep berm, or family of seep berms, was designed to replace a sediment basin. Additionally, seep berms can be used in conjunction with a downsized sediment basin as assessed in scenario 4, simulations 26 through 35 for the large commercial site, Table 7A-7. The Big Creek School site used such a combination of seep berm and sediment basin, Chapter 5.

Large Commercial Site: Descriptions and Schematics of Erosion Prevention and Sediment Control Systems Incorporated in Cost and Performance Charts

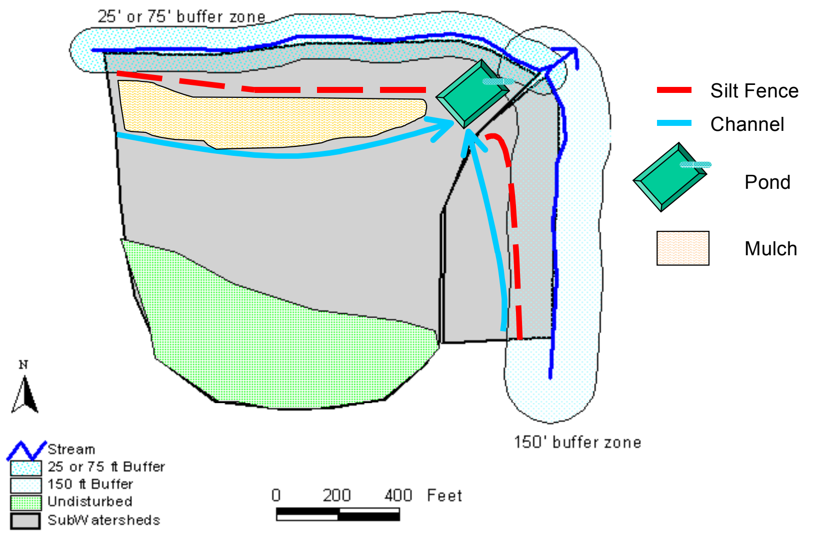
Scenarios 2 through 4, shown in Figure 1, have a sediment basin with either a drop inlet principal spillway (Scenario 2 and Figure 2a), a drop inlet and small perforated riser (Scenario 3 and Figure 2b), or a drop inlet, small perforated riser and sand filter (Scenario 4 and Figure 2c).

The control systems and costs shown in Figure 2 are summarized below.

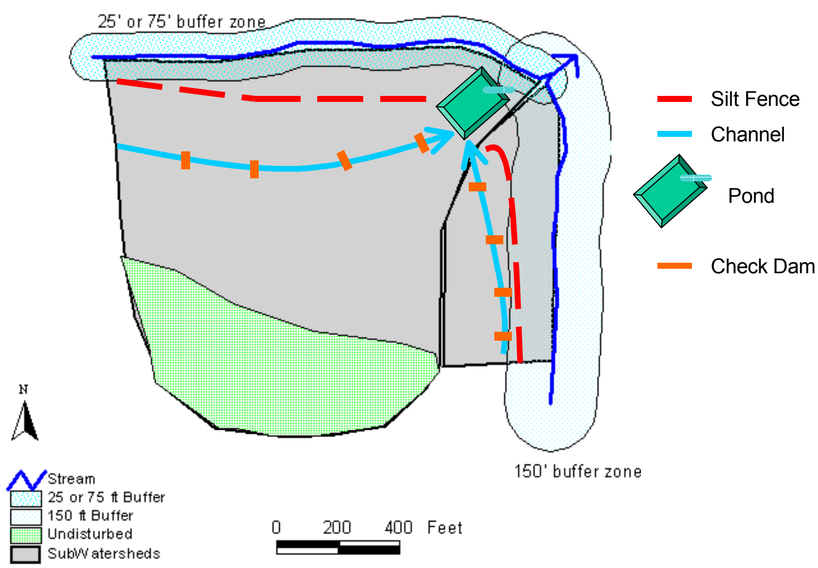
- **Data Column 1:** North and East earthen channels conveying runoff to a sediment pond. System cost- $121,311-$122,990. Refer to (1) results Table 7A-7, scenario 2, simulations 5-13, and (2) schematic Figure 7A-3.
- **Data Columns 2 & 3:** Used only for spatial emphasis of cost differentials between systems.
- **Data Column 4:** Same as #1 with the addition of 1.5-ft rock check dams in each channel and subsequent increase in channel depth to 2.5-ft. System cost- $135,205-$136,884. Refer to (1) results Table 7A-7, scenario 3, simulations 14-25, (2) schematic Figure 7A-4.
- **Data Column 5:** Same as #1 with the addition of 4-ft high seep berms with perforated riser spillways in lieu of the channels. System cost-$135,748-$137,427. Refer to (1) results Table 7A-7, scenario 4, simulations 26-35, (2) schematic Figure 7A-5.

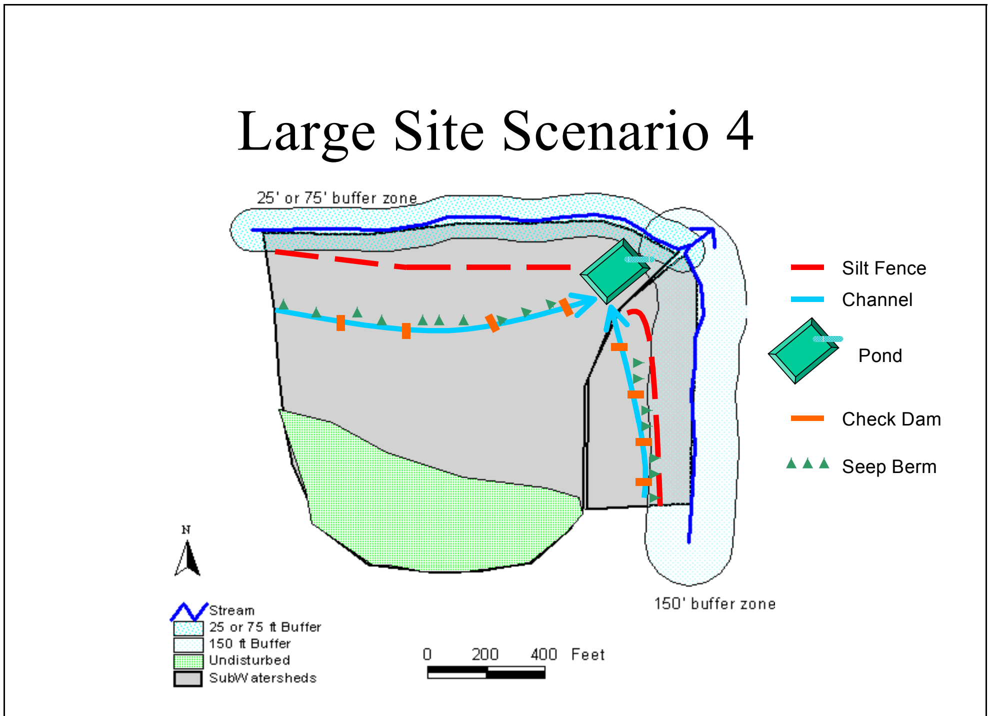
The control system, illustrated in Scenario 2, consists of the North and East diversion channels that convey runoff to a sediment basin located at the lower construction boundary. In Scenario 3, 1.5-ft high porous rock check dams are added to the channel that was deepened to 2.5-ft. The seep berm system, of Scenario 4, is also similar but instead of rock check dams, earthen check dams were utilized to detain runoff that is slowly discharged through perforated risers spaced along the length of the seep berm. The berm height is 4 ft and the earthen check dams are 2.5 ft. Note that the sediment basin was downsized in Scenario 4 since the seep berm system discharged down-gradient through the seep berm to the riparian area, completely bypassing the sediment basin.

Large Site Scenario 2



Large Site Scenario 3





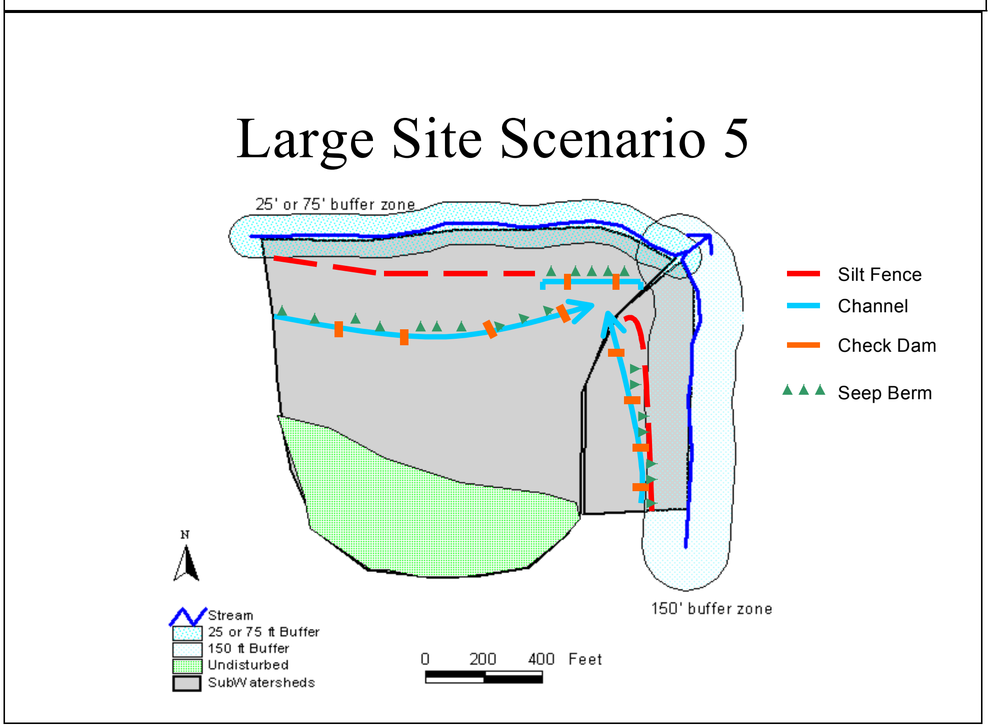


Figure 1 Large commercial site schematic drawings of scenarios used for cost and performance charts (scenarios 2-5).

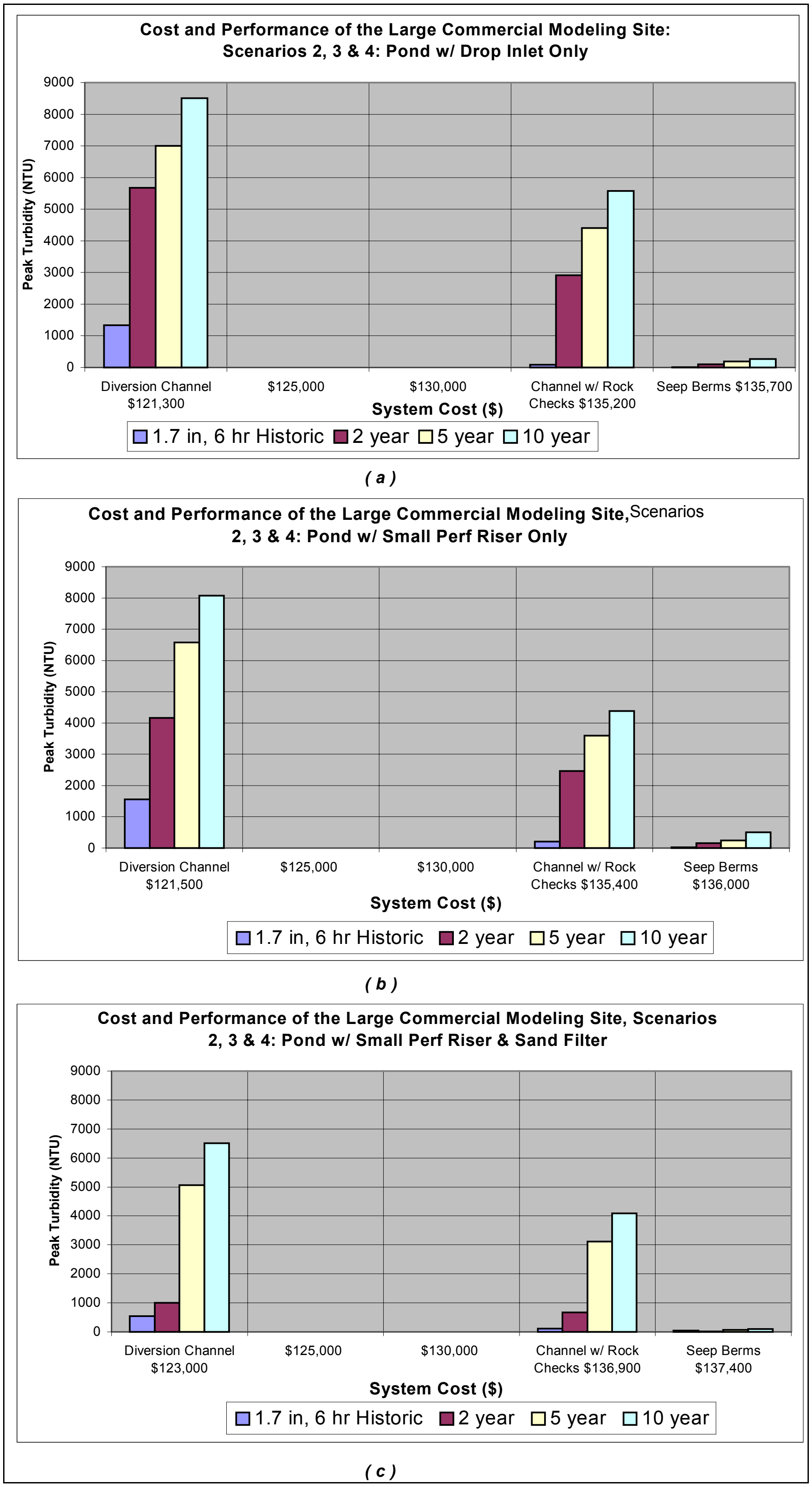


Figure 2 Cost and performance charts for the large commercial modeling site (scenarios 2-4).

For the 35-ac denuded site, the diversion channel-sediment basin control system, Scenario 2, discharge exceeded 1,000 NTU for all modeled storms for the drop-inlet and small perforated riser basin outlet design options. Refer to Figure 2a through 2b. As shown in Figure 2c, the small perforated riser-sand filter combination reduced the peak NTU to 539 and 998 for the historic storm of 1.7 inches and the 2-year design storm of 3.7 inches, respectively. Incorporating rock check dams, Scenario 3, reduced peak effluent NTU for all storm events. The best performing sediment control system, for the three methods evaluated, was the combination seep berm-sediment basin-sand filter system using a small-valved perforated riser, Scenario 4, Figures 1 and 2c. Peak effluent outlet values, for all storms, were less than 100 NTU.

The performance of a sediment basin with a drop-inlet principle spillway and dedicated small perforated riser that discharged to a sand filter, Table 7A-7, scenario 2, simulation 11, is contrasted with a series of 3 seep berms, Table 7A-7, scenario 5, simulation 36, for the large commercial site. Such a sediment basin is considered to be state-of-practice. For the 2-year design storm, the resulting peak flow, runoff volume, and peak turbidity exiting the site are 2.78 versus 2.49 cfs, 1.03 versus 0.47 ac-ft, and 924 versus 79 NTU for the sediment basin and seep berms, respectively. Costs for the conveyance channels and sediment basin was about $123,000 whereas the seep berm system cost about $103,592. The performance of the sediment basin could be enhanced by placing it in combination with 2 seep berms as analyzed in Table 7A-7, scenario 4, simulation 33. The results, for the 2-year design storm, are peak flow equals 2.49 cfs, runoff volume equals 0.47 ac-ft and peak effluent turbidity equals 16 NTU. The cost of this system is $137,427.

The sediment basin was removed and replaced with a 3-seep berm system (refer to Figure 1, Scenario 5 schematic drawing). The performance of this system is compared to the 2-seep berm-sediment basin alternative, Scenario 4, in Figure 3. As can be seen, the 3-seep berm system is about $34,000 cheaper but does not perform as well as the 2-seep berm-sediment basin alternative. Depending upon the regulatory climate, the 3-seep berm system may be considered quite adequate.

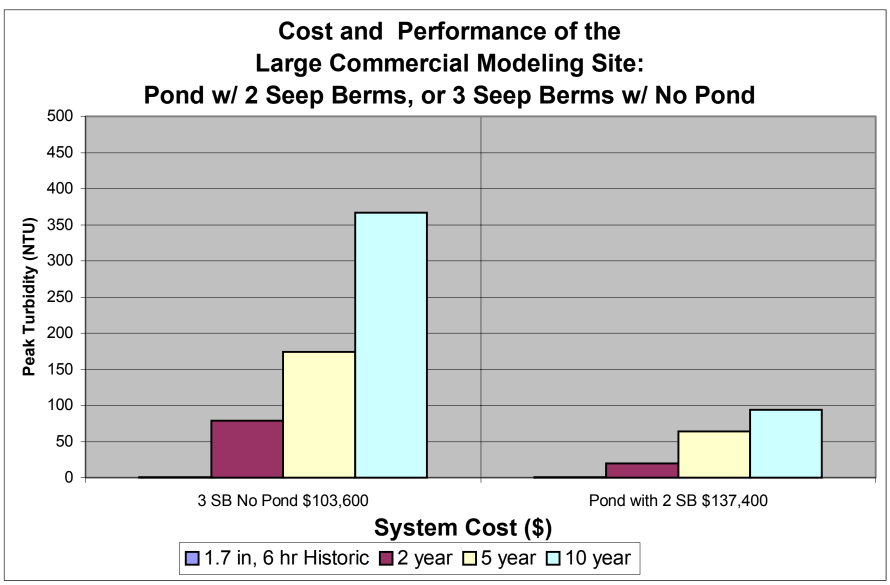


Figure 3 Cost and performance comparison of the best performing systems of the large commercial site modeling (scenarios 5 and 4).

Cost and performance of control systems for a small commercial site.

Many construction-sites involve cut-fill operations to develop a level area on the property. To accomplish this, often a steep, 3:1 to 2:1, structural fill is required. The primary purpose of this example is to compare a lack of runoff control to erosion prevention and sediment control systems that preclude up-gradient runoff from traversing the steep fill slope and afford erosion protection to the fill slope. Refer to the three schematic drawings in Figure 4 showing the three alternative modeling approaches addressing the steep fill slope. The assessment is based on a 10.5-ac construction-site. Approximately 5.8 acres exist on a 3 % slope. Runoff from this flatter section, if not controlled, would proceed to erode the steeper 1.43-ac. 3:1 slope watershed. As seen in Figures 5a, b, and c, the option with no control measure at the break in slope, left column, exceeded 1,000 NTU for all sediment pond spillway configurations, including using the sand filter, for all storm events. For the high-intensity 2-yr design storm event of 3.7 inches, the predicted peak sediment concentration is approximately 400,000 mg/l, generating nearly 140 tons of sediment that entered the down-gradient sediment basin. Although this seems like a very large number, it represents only an average of ½ inch of soil loss over the entire steep slope.

Two temporary sediment controls were designed and evaluated in chapter 7A. Since soil is being transported from the cut to the fill as an everyday operation at such a site, a temporary earthen berm was constructed slightly up-gradient of the steep fill slope. The location of such a temporary sediment control can be readily adjusted as the fill slope is increased in height. The soil used for the temporary berm is simply incorporated as part of the fill. The function of the temporary earthen berm is to prevent runoff, generated from the flatter up-gradient area, from entering the steep portion of the slope. The second component of this system is a method to convey up-gradient runoff downslope without eroding the steep slope. Two alternative conveyance systems were investigated: (1) a rock-protected channel and (2) temporary drop-inlets with flexible pipe down-drains. The temporary earthen berm-rock channel system generated a peak sediment concentration of about 161,000 mg/l without the aid of erosion control stabilization along the steep slope. Both earthen berm methods were successful in achieving a large reduction in peak sediment concentration entering the down-gradient sediment basin. The peak sediment concentration entering the pond from the earthen berm-rock channel control method was 55,000 mg/l. For the temporary earthen berm-down-drain control method there was a further reduction to 28,000 mg/l, partially due to some sediment settling behind the earthen berm. Based on analysis of these alternative control systems, peak sediment concentration entering the sediment basin was reduced from about 400,000 to 28,000 mg/l. Similarly, sediment load entering the sediment basin was decreased from about 140 tons to 50 and 25 tons for the berm-channel and berm-down-drain controls, respectively.

Small Commercial Site; Descriptions and Schematics of Erosion Prevention and Sediment Control Systems Incorporated in Cost and Performance Charts

All systems have a sediment basin with either a drop inlet principal spillway (Figure 5a), a drop inlet and small perforated riser (Figure 5b), or a drop inlet, small perforated riser and sand filter (Figure 5c).

The control systems and costs shown in Figure 2 are summarized below.

- **Data Column 1:** Lower channel conveying runoff to a sediment pond. System cost- $35,662-$37,321. Refer to (1) results Table 7A-8, scenario 4, simulations 9-13, and (2) schematic Figure 7A-11.
- **Data Column 2:** Used only in Figure 5b. Channel at break in slope conveying runoff to lower channel. No erosion control cover on fill slope below channel. System cost- $40,723. Refer to (1) results Table 7A-8, scenario 6, simulations 27a-27d, (2) schematic Figure 7A-13.
- **Data Column 3:** Same as #1 with the addition of a 1.5-ft temporary earthen berm and rock-lined slope channel. System cost- $43,431-$45,090. Refer to (1) results Table 7A-8, scenario 6, simulations 21-26, (2) schematic Figure 7A-13.
- **Data Column 4:** Same as #1 with the addition of a 4-ft temporary earthen berm with temporary perforated risers attached to flexible-pipe slope drains. System cost-$45,727-$47,386. Refer to (1) results Table 7A-8, scenario 5, simulations 15-20, (2) schematic Figure 7A-12.

In Scenario 4 the steep slope is not protected from runoff entering and traversing it. Also the steep slope is not afforded any erosion protection. The peak effluent turbidity, shown in Figures 5a through 5c, exceeds 1,000 NTU for all sediment pond spillway configurations and for all four modeled storm events.

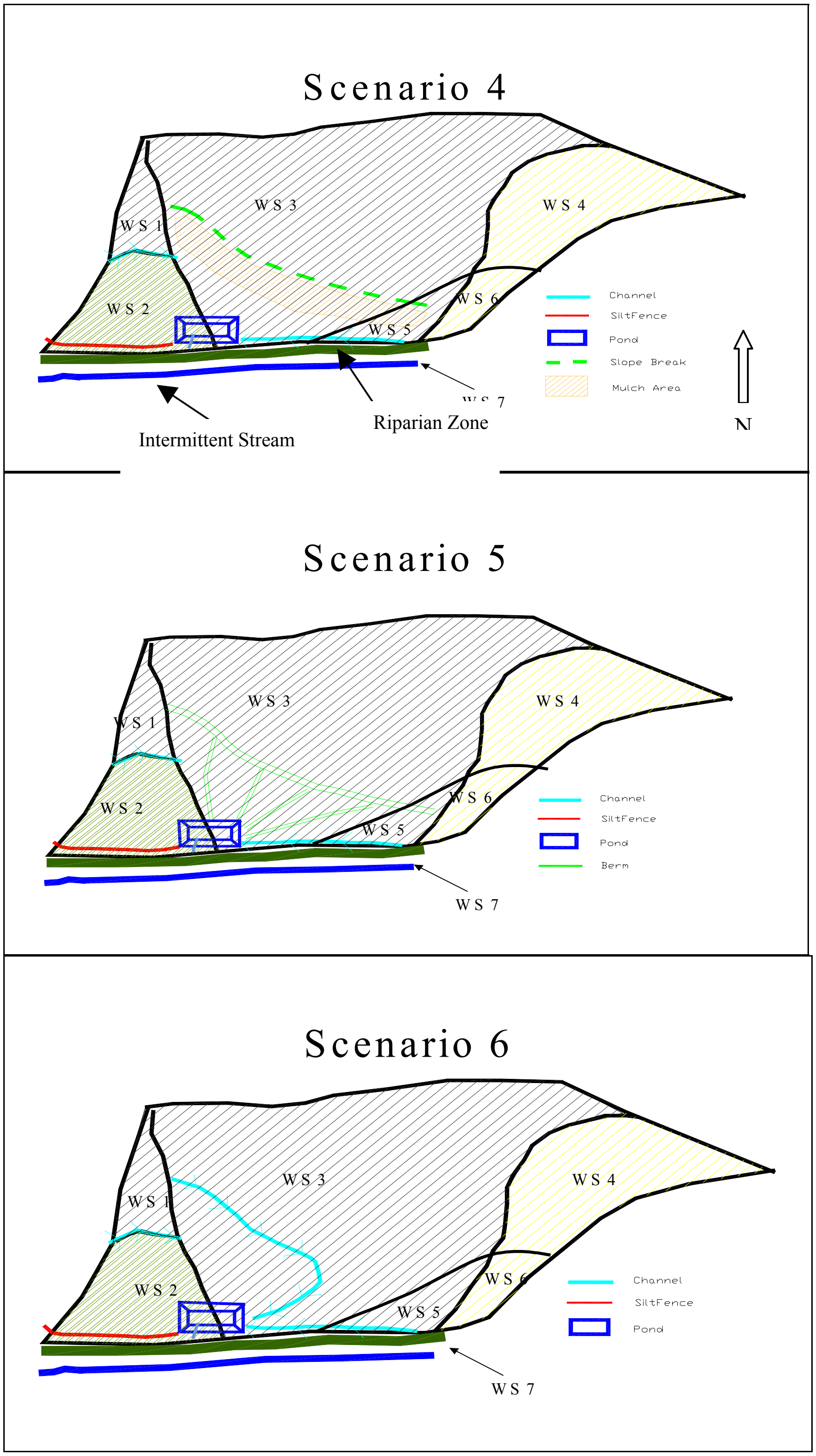
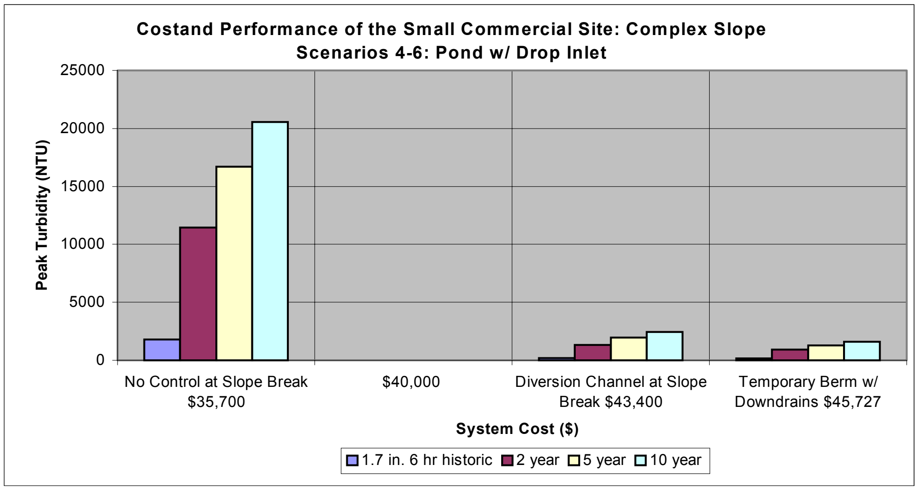
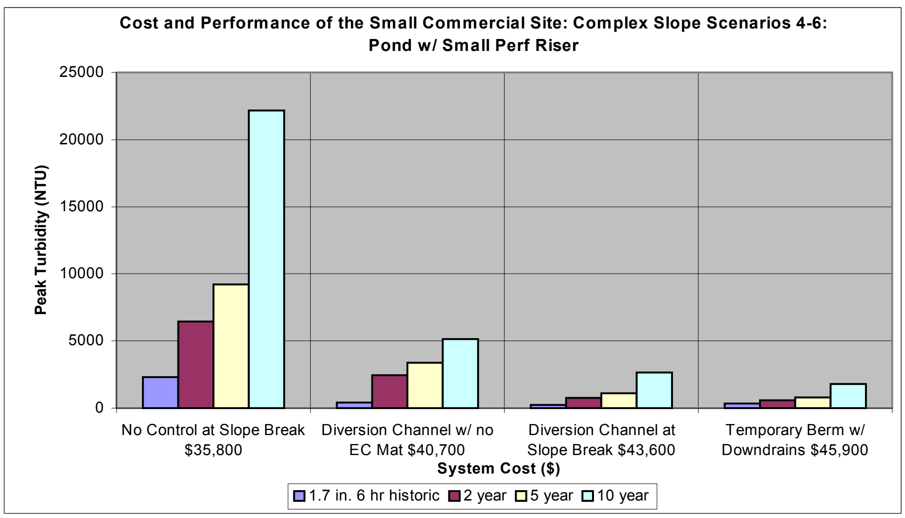


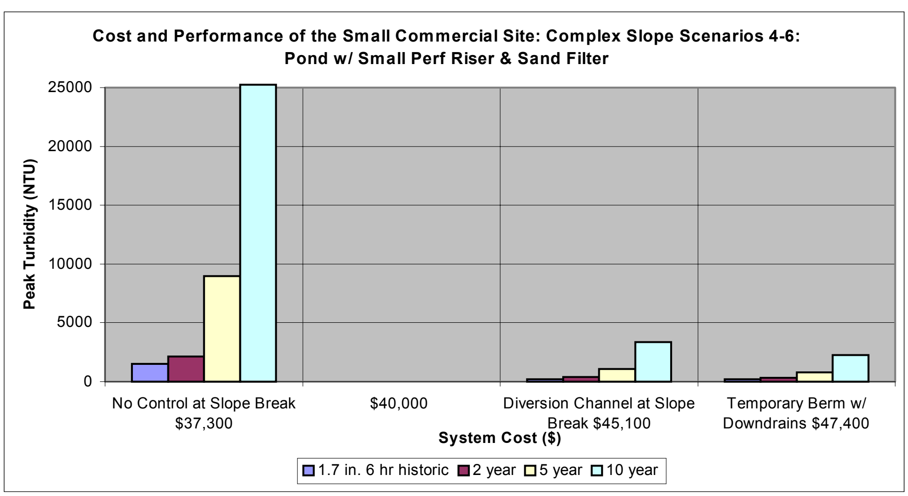
Figure 4 Small commercial site schematic drawings of scenarios used for cost and performance charts (scenarios 4-6).



(a)



(b)



(c)

Figure 5 Cost and performance charts for the small commercial site modeling scenarios 4-6.

A temporary earthen diversion was modeled just up-gradient of the slope break. This temporary channel diverted up-gradient runoff to a rock-lined channel (Scenario 6) and then to a sediment basin with the alternative spillways and down-gradient control options.

Two options are shown in Figure 5b. The $40,700 system has no steep slope erosion control measures, whereas the $43,600 temporary diversion system incorporates slope protection erosion control measures. As expected with the additional expense of buying and incrementally installing erosion protection on the steep slope, peak NTU values were reduced compared to the without-slope-erosion-control alternative.

A further reduction in peak NTU is realized with the control system that includes slope erosion protection, a temporary earthen berm with drop-inlets and flexible pipe down-drains and a sediment basin, Scenario 5. Marginal changes in expected performance and costs are readily evident in Figure 5.

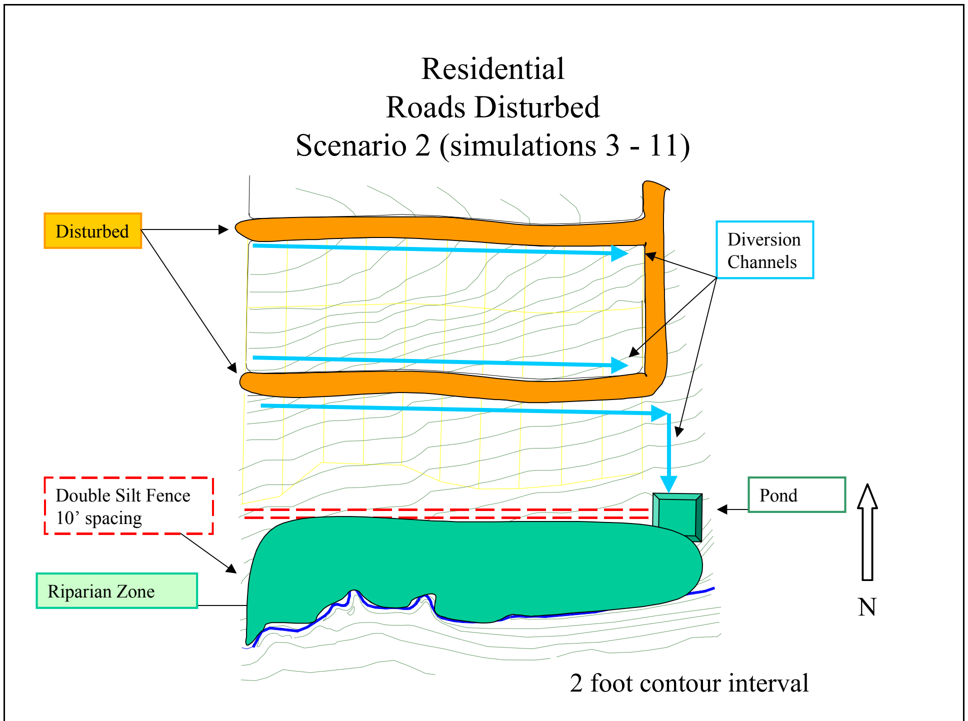
Comparing the four systems, displayed in Figure 5b, it is evident that peak effluent turbidity can be substantially decreased as the design of erosion prevention and sediment control systems are upgraded. All of the systems that preclude runoff from traversing the steep slope exhibited substantial improvement beyond the without-steep-slope-runoff prevention option. The incremental cost between the no-runoff-control option and that of a simple slope-protecting diversion channel, even without any slope erosion control, is $4,900 or about a 13.7 % increase in cost. With the addition of slope erosion protection the peak effluent turbidity was reduced from 417, 2442, 3392 and 5140 to 257, 769, 1113, and 2667 NTU for the historic, 2-, 5-, and 10-yr, 24-hr design storms, respectively. This significant reduction was achieved at an incremental costs of $2,900, or a 7 % increase in cost beyond the without-slope-erosion-protection control. The temporary berm with drop inlets attached to down-drains provided the best overall protection. Peak effluent turbidity values for the historic 1.7 in, 6-hr and 2-yr, 24-hr design storm was 179 and 314 NTU, respectively. The entire system cost was $47,400.

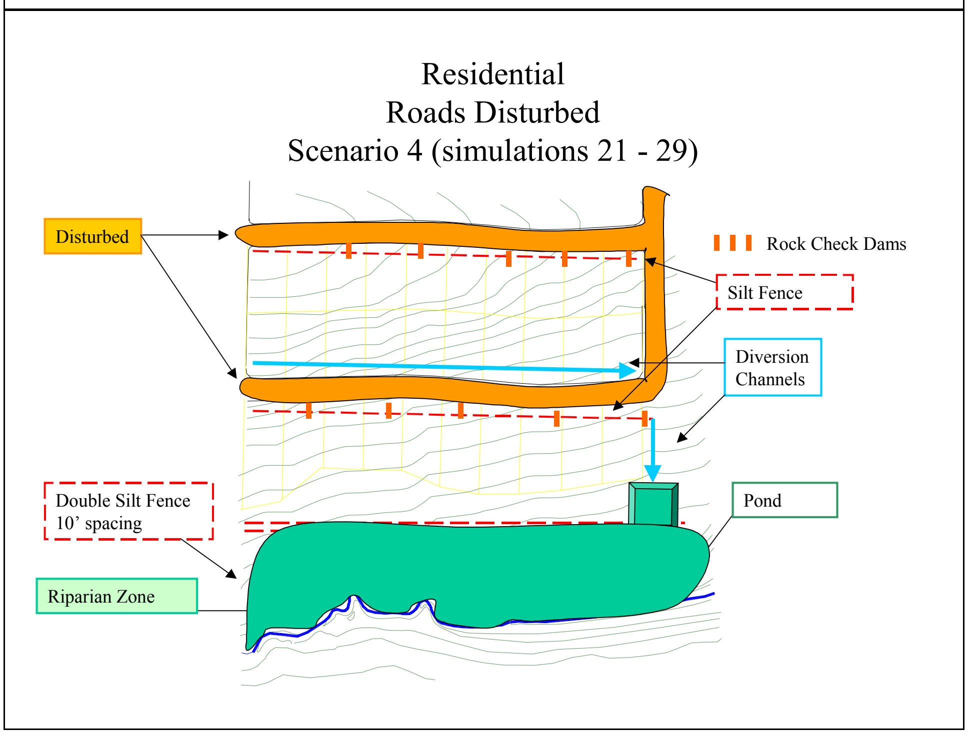
Cost and performance of control systems for a residential subdivision-site.

Two alternative sediment control systems, shown schematically in Figure 6a (Scenario 2) and 6b (Scenario 4), are contrasted in Figure 7a-d. A nominal 10-ac section of the subdivision, with thirty 90-ft by 150-ft lots, is modeled. Numerous 10-ac sections are being planned and constructed along the stream. For the assessment shown in Figure 7, staged construction was employed where initially only the roads and associated infrastructure was disturbed.

One simple control practice would be to install diversions slightly down-gradient of the road to convey runoff to a sediment basin (Figure 6a, Scenario 2). An alternative control scheme was devised to take advantage of the undisturbed pastureland as an existing filter. Instead of the diversions, a silt fence was installed, paralleling the road, and sloping at 1 %. Ordinarily the silt fence, so installed, would function just like the diversion channel and simply convey runoff to the sediment basin with only a very minor quantity of runoff proceeding through the silt fence. To enhance the functionality of the silt fence, small rock check dams were spaced at about a 150-ft interval along the silt fence. The function of the small rock check dams is to detain runoff so that it will proceed through the silt fence, thereby enabling sediment-laden water to passively receive additional treatment as it proceeds along the natural, and undisturbed, pastureland. To avoid runoff from simply bypassing these controls and proceed along the road, gravel water bars were installed forcing road runoff towards the individual chambers created by the rock check dams. Refer to Figure 6b, Scenario 4.

Analysis of these combined controls helps the design professional visualize how the system of controls, for this portion of the construction-site, synergistically function to reduce sediment load to down-gradient controls. Specifically, values for identical sediment basins, comparing a channel that diverts road runoff (Table 7B-6, scenario 2, simulation #3) with a system of waterbar-silt fence with rock checks-existing pastureland filter (Table 7B-6, scenario 4, simulation 21), for a 2-yr design storm, are peak flow into the sediment basin was reduced from 7.19 to 1.95 cfs; discharge peak flow was reduced from 2.36 to 0.45 cfs; runoff volume was reduced from 0.81 to 0.19 ac-ft; and peak turbidity was reduced from 1825 to 341 NTU for the respective control systems. Furthermore, through utilizing these innovative control measures, and the undisturbed pastureland as a free grass filter, construction cost was reduced from $50,630 to $47,462.


Residential
Roads Disturbed
Scenario 2 (simulations 3 - 11)
Disturbed
Diversion Channels
Pond
Double Silt Fence 10' spacing
Riparian Zone
N
2 foot contour interval


Residential
Roads Disturbed
Scenario 4 (simulations 21 - 29)
Disturbed
Rock Check Dams
Silt Fence
Diversion Channels
Pond
Double Silt Fence 10' spacing
Riparian Zone

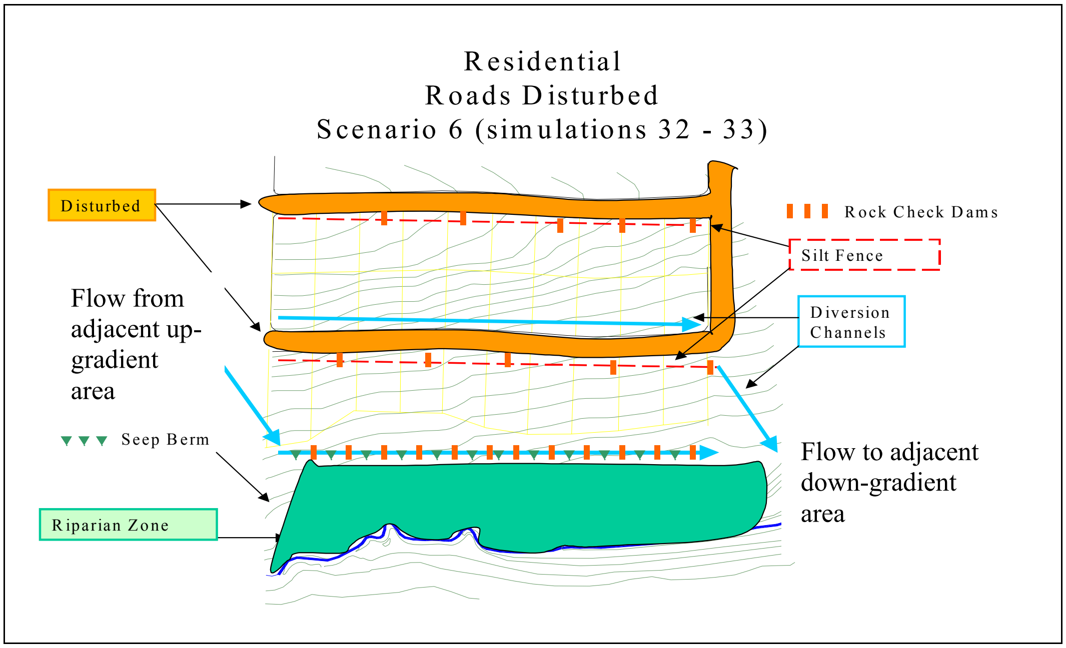


Figure 6 Schematic drawings of scenarios used for cost and performance analysis of the residential site with limited disturbance (scenarios 2, 4, and 6).

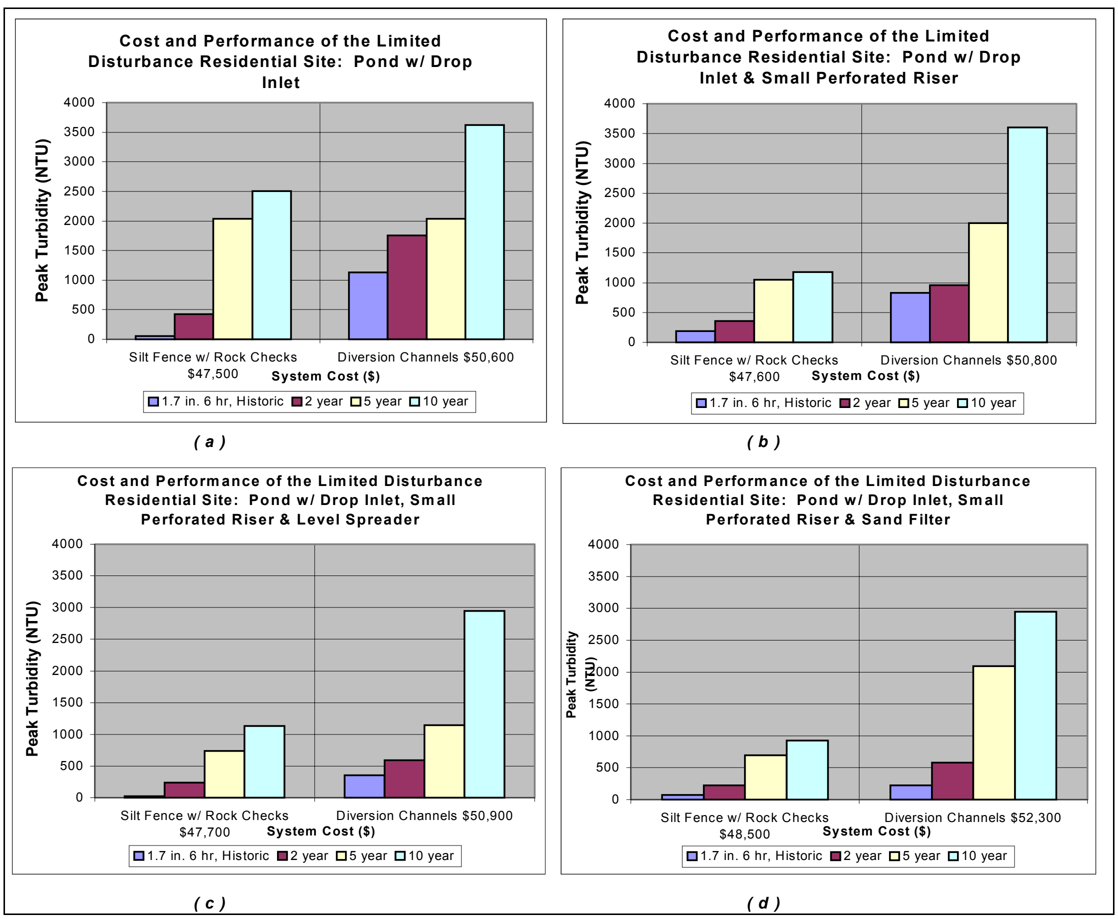


Figure 7 Cost and performance charts for scenarios 2 and 4 modeling of the residential site with limited disturbance.

As is sometimes the case with innovative control systems, the cost of achieving better performance was reduced. As seen in Figure 7a through 7d, a lower peak NTU was realized through the silt fence with rock checks-pastureland-sediment basin combination of controls than that attained by the diversion-sediment basin control scheme. This is true for all sediment basin outlet configurations and for all storms analyzed. Also evident, the increased performance was achieved at a lower cost. The savings was $3,200 or about a 6% decrease in cost.

Another alternative was devised for the residential site that incorporated the silt fence with rock check dam scenario. The sediment basin was replaced by a seep berm (Figure 6c, Scenario 6). In this case a substantial saving is realized through the use of the seep berm in lieu of the sediment basin with sand filter. Refer to Figure 8. Comparing these two control systems the seep berm design reduced cost by $22,842 or nearly a 50 % savings.

Design professionals are encouraged to explore alternative, and perhaps non-traditional, design schemes. The authors are convinced that there are systems that have lower cost with increased performance for many sites. The money saved by considering alternative erosion prevention and sediment control systems will pay large dividends, well beyond the increment increase costs of design.

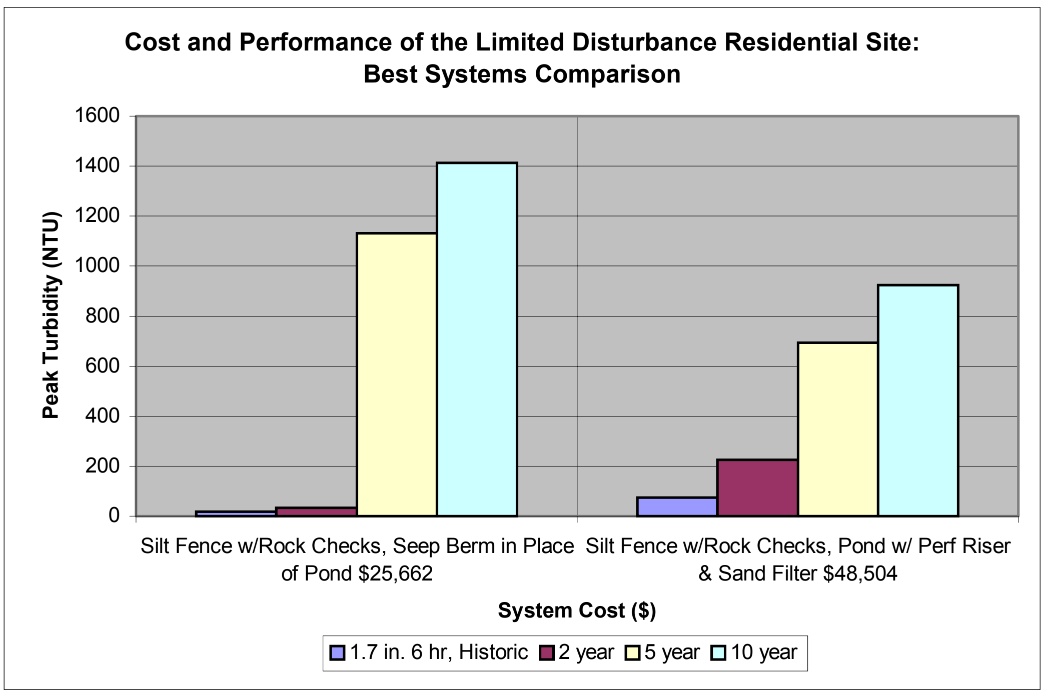


Figure 8 Cost and performance comparison of the best performing systems of the residential site with limited disturbance (scenarios 6 and 4).

Advantages of Systems Approach

Why Conduct a Systems Design Analysis of Erosion Prevention and Sediment Control Measures?

This discussion presents ideas illustrating the many benefits of using a comprehensive, coherent “system's approach” when designing an erosion prevention and sediment control program. Inherent to the discussion is both the systems approach to problem solving and the concept of conducting a comprehensive design. Although the focus is on erosion prevention and sediment control, storm water (peak flow and runoff volume) is the fundamental driving force of many erosional processes as well as influencing the performance of sediment controls. Some of the numerous alternative scenarios examined in chapter 7 and applied at the Big Creek site, chapter 5, will be used to exemplify benefits of conducting a systems design. Utilizing a systems design approach accomplishes the objectives that follow.

Encourages the design professional to think about the system.

This perhaps is just simply common sense. If the design professional is required, or encouraged, to do a systems analysis, then the design professional will start to consider what individual components will be used, where they will be located, how big will they be and how they may inter-link with other controls. Many aspects will quickly become quite evident. Does the entire site have adequate coverage? What effect does an up-gradient control have on down-gradient components with respect to peak flow and runoff volume reduction, removal of sediment load or reduction of peak sediment concentration? What is the interplay among controls? What are the cost and performance tradeoffs? What is the influence of storm size? Does a certain set of controls perform well for smaller storm events but not for larger ones? Does another control system perform better for a wider spectrum of storm events? What are the total and on-site cost considerations for this better performance? What is the incremental cost of obtaining better performance? Do some systems provide better performance and at a lower on-site cost then other systems? Using a systems analysis enables a quantified response to each of these and many other valid questions.

Focuses attention on critical site characteristics.

We all know that long, steep slopes are highly erosive. Subjecting these slopes to additional runoff from up-gradient areas exacerbates the problem. Many site designs require relatively large flat areas. Earthwork projects are often cut-fill operations resulting in structural fills with sideslopes of 2:1 to 3:1 (horizontal:vertical). This was the case at the Big Creek School site (chapter 5) and the small commercial development that was analyzed in chapter 7A. Also the fill portion of the highway design, chapter 7C, required a steep structure fill slope.

A system design readily yields very useful insights to the liability of having uncontrolled water moving across a flat slope to a steep slope. For the small commercial site, chapter 7A, a complex slope was constructed consisting of a relatively flat 3 % slope and a 3:1 outslope, 60-ft in length and 1.43 ac. Recall from the cost and performance section that the unprotected slope generated nearly 140 tons of sediment at a peak concentration of 400,000 mg/l for a 2-yr event. Based on this assessment; a design professional would consider alternative erosion prevention measures and/or sediment control methods to reduce sediment loading.

The use of an earthen berm provides an added opportunity to incrementally stabilize the steep slope as it is being constructed instead of waiting until the entire fill slope has been completed. The location of such a temporary sediment control can be readily adjusted as the fill slope is increased in height. The soil used for the temporary berm is simply incorporated as part of the fill. Such concurrent erosion protection affords a greater reduction in peak sediment concentration. The second component of this system is a method to convey up-gradient runoff downslope without eroding the steep slope. Two alternative conveyance systems were investigated: (1) a rock-protected channel and (2) temporary drop-inlets with flexible pipe down-drains. Both earthen berm methods were successful in achieving a large reduction in peak sediment concentration entering the down-gradient sediment basin. Design calculations of the unprotected steep slope being inundated by up-gradient runoff helped to focus the design professional's attention on the need for additional control measures and assisted in visualizing potential solutions.

Indicates Opportunities for Merging Control Measures with Undisturbed On-site Lands During Staged Construction.

The residential site was used to illustrate the advantages of staged construction and opportunities to blend controls with the undisturbed portions of the site to further reduce sediment concentration. Two primary alternatives were investigated: (1) limit initial land disturbance to installation of the roads and associated infrastructure and (2) clear the site to the limits of construction. The advantages of limiting construction area are well known and, as expected, are realized throughout this example.

More importantly, limiting construction to roads enabled evaluation of a system consisting of combining a modified silt fence with undisturbed pastureland to significantly reduce runoff and sediment-laden flow. A silt fence was installed sloping down-gradient at a 1 % grade, approximately 20 feet from the limits of road disturbance and parallel to the road. With traditional installation of a silt fence, runoff with either flow along the road or flow along the silt fence that is acting like a diversion (due to its' sloped installation) with only a very limited flow going through the silt fence. To increase the effectiveness of the silt fence, rock check dams were placed approximately 150 apart causing runoff to be detained, directing flow through the silt fence and subsequently through a 270-ft strip of undisturbed pastureland that functions as a vegetative filter. To avoid runoff from flowing along the road, gravel waterbars were located such that runoff was forced to the multiple chambers of the silt fence created by the rock checks.

Analysis of these combined controls helps the design professional visualize how the system of controls, for this portion of the construction-site, synergistically function to reduce sediment load to down-gradient controls. Refer back to the cost and performance discussion of this control system in the previous section and in chapter 7 of the final report.

Creates the Opportunity to Evaluate the Cost and Performance of Alternative Control Systems.

A typical control system consists of runoff conveyance and sediment detention controls. Most likely, detention is typically achieved by a sediment basin that has been designed to reduce the peak flow to the pre-development level. Discharge is directed to one location, often through a drop-inlet spillway with weirs fabricated to help mimic pre-development peak flows for a variety of storm events.

Using a systems approach encourages a prospective of envisioning alternative control measures working in unison. For instance, the outlet of a sediment basin can be configured to decant the uppermost, and therefore cleanest, water by using a floating siphon spillway. Perforated risers can discharge to either a sand filter or a level spreader. The sand filter provides a secondary treatment system for water that slowly discharges from the sediment basin. Similarly, to take full advantage of the down-gradient riparian zone, a simple flexible slotted pipe can distribute water relatively uniformly along the upper boundary of the riparian zone. A small-diameter perforated riser or a floating siphon can be valved to further control discharge to a sand filter or piped level spreader. If dewatering is slow enough, the riparian zone can infiltrate all discharged water, thereby avoiding any risk of a violation.

System tradeoffs are readily evaluated using a computer model with built-in sediment controls. For example, a higher dewatering rate being discharged to a sand filter increases the head on the filter that, in turn, reduces its performance. To maintain the desired performance, various design parameters can be assessed, such as increasing the sand filter's surface area or decreasing the flow rate. A decreased flow rate implies a longer dewatering time and increases the probability of having standing water in the sediment basin when the next storm occurs. Other alternatives exist outside of the realm of the sediment basin or sand filter. Up-gradient controls that store and slowly release storm water can allow downsizing of down-gradient system components or alternatively increase overall effectiveness. Controls such as seep berms extend the concept of a system since runoff is not only detained but is discharged through multiple outlets to down-gradient forest or pastureland instead of being conveyed to the sediment basin. Such alternative systems have been designed and evaluated for small and large commercial sites, Tables 7A-7 and 7A-8, residential sites with staged construction (Table 7B-6) and the full extent construction (Table 7B-7). Similarly, a highway site was designed and alternative systems evaluated (Table 7C-1). Such a system was installed, monitored and modeled at the Big Creek School demonstration-site. Predominantly, alternative systems encompassed sediment basin spillway configurations, the use of sand filters and piped level spreaders in conjunction with riparian zones and seep berms, and temporary earthen berms with slope conveyance components and erosion protection methods.

Combination of Elongated Perimeter Controls with the Adjacent Riparian Area.

Depending on-site characteristics, a seep berm may replace the traditional sediment basin. A seep berm consists of a channel and earthen berm. The channel is separated into compartments by small earthen check dams. Small outlets are located throughout the length of the seep berm such that discharge is slowly released to down-gradient areas. Outlets may be perforated risers, fixed siphons, internal or external sand filters or rock French drains protected by geotextile. The seep berm functions best when discharging to pasture or forested areas. Depending upon the width and infiltration rate of the riparian zone, the seep berm discharge rate can be designed such that all water will infiltrate within the riparian area. The seep berm can be designed to function as a hiking or bike trail separating the development from the stream. A flexible pipe level spreader can be connected below the outlet pipes of the seep berm to distribute flow along a larger portion of the riparian zone, thereby increasing overall performance of the system. The seep berm can be designed to function very well for a wide variety of design storms. For small storms, less than 3 to 4 inches, a seep berm-riparian zone system provides an excellent level of treatment efficiency with respect to reducing peak flow, runoff volume, effluent sediment concentration and discharged sediment load. For larger storm events, shallow flow travels across the top of the stabilized berm and is distributed along the entire length of the berm.

Contrasting the seep berm with a sediment basin we see many potential advantages. The seep berm uses a much longer down-gradient buffer zone than the sediment basin, thereby enabling infiltration and passive treatment of low sediment concentration waters emanating from the seep berm. The seep berm consists of multiple chambers such that, if failure of the berm occurs, only the volume of water contained within a single chamber would be released. A sediment basin inherently exhibits a much higher level of liability. Depending on site characteristics seep berms, as elongated protection measures, may provide numerous advantages either with or without a sediment basin.

Regulatory Options for Georgia

Storm water, erosion protection and sediment control regulations.

There are regulations being formulated for storm water and a different set for erosion prevention and sediment control. Perhaps it would be more efficient to integrate the two programs or have the erosion prevention and sediment control regulations be a subset of the storm water regulations. At the very least, there should be a linkage between the two programs. There are many potential benefits to such an arrangement.

Design calculations, utilizing hydrology computer software, are conducted for pre-development and post-development timeframes. This analysis results in sizing and locating inlets, drainage pipes, culverts and detention basins. Controls are analyzed as a system with peak flow being the predominant design consideration. A complete set of design drawings is developed as part of this analysis.

For during-construction timeframe, there appears to be minimal, or no, design calculations used. Instead, various controls are selected from an erosion protection and sediment control manual; and these are placed on a plan view sheet along with reference to typical design drawings. There are some guidelines for sizing selective individual controls; but unlike the rigorous storm water designs, there is not an assessment on how individual controls influence each other, or a determination of the expected performance. Whereas in storm water designs there is a determination of the peak flow and oftentimes the inflow and outflow hydrographs for various sized storms. In sediment control, no such determination is conducted.

If the two regulations were merged or somehow linked, then hydrology, erosion and sediment control could be effectively analyzed during construction. It is believed that there would be an overall savings with this approach. Consider the prevalent detention basin design that consists of a drop-inlet with a tapered weir and a 6-inch diameter hole located near the bottom of the drop-inlet riser. Such a design is based strictly on mimicking the pre-development peak flow of various sized storms in the post-development assessment. A large hole near the bottom of the pipe is completely useless for sediment control. If the two analyses were linked, then this would become very evident. Temporary modifications to the spillway could be implemented such as placing steel plates over the bottom hole and the lower section of the weir. Dewatering devices could be added such as a floating siphon, to decant and discharge only the cleanest water, or a small dedicated perforated riser enabling dewatering at a controlled rate. Such an analysis may provide additional insights to post-development storm water control. For instance, is it really enough to mimic pre-development peak flow without considering the increased duration of peak flow or the increased volume of runoff that is generated from a paved and roofed site? What influence does the increased runoff, both in quantity and duration, have on downstream flooding and the entire fluvial system with regard to bank stability and stream degradation?

Another potential benefit of linking storm water with sediment control analysis is that alternative sediment controls, as detailed throughout this report, present opportunities to readily transition to permanent storm water controls. A control, such as a seep berm, which functions effectively for sediment control during disturbed site conditions, significantly reduces peak flow and runoff volume. A seep berm, incorporated into the final storm water plan, can also perform just as well in the long run.

There has been a lot of discussion in preceding sections of this report on how do we know if a storm water, erosion and sediment control system will work if we do not conduct an analysis? How do we develop a cost-effective system if we don't even analyze the system? What liability, or business risk, does an owner, developer or design professional incur without an assessment of expected performance?

The Design Storm - What is the appropriate size?

Legislation and promulgated regulations are often set at an arbitrary storm size such as a 10-year or 25-year, 24-hour event. Such a sized storm is set with the belief that, if we 'protect' to such a rare occurring event, then we have protected societal values and the environment. The basis of such a large storm is often given little thought and is deemed acceptable, without debate, simply because other regulations require it. The 10- or 25-year storm event makes sense for situations where structural failures may cause property damage or even loss of life. Indeed, for such instances, even a 25-year event may not be considered to provide an adequate margin of safety!

Let's consider two different size design storms, one to provide due diligence for safety and one for erosion prevention and sediment control. When an embankment is one of the storm water and sediment controls used in a system, a large design storm is required to protect down-stream property owners. If it is a permanent structure, and its failure can potentially cause significant down-stream damage, now or in the future, a 100-year storm with at least a 1-ft freeboard, provides a good level of assurance. How can this be economically achieved? An open-channel emergency spillway, with an acceptably designed transition to the natural stream, is often the most economic solution. Such a large storm should be used where an embankment failure would rapidly release large quantities of detained water.

Let's now consider what size storm should be used for protecting the stream, lakes and downstream owners from being subjected to sediment as a pollutant. **The premise here is that we do an excellent job in designing a system that removes a very high quantity of sediment for the most frequently occurring storms throughout the year.** We do a good job for the large storms that might occur within any year. Accomplishing both of these provides a good overall cost-effective and environmentally sound solution to the entire fluvial system and adjacent and downstream landowners. Table 1 in "Policies To Prevent Erosion In Atlanta's Watersheds: Accelerating the Transition to Performance" documents estimated annual costs of sedimentation and who bears the loss. The property-value loss from ' degraded streams and ponds' ($100 million) and 'ecological damage: reduced or extirpated species' (greater than $50 million) categories listed in Table 1 of the above-referenced report accounted for the vast majority of off-site costs associated with adverse impacts of sediment. The focus of this discussion will therefore be on the fluvial system, that is, the stream itself, organisms that call it their home and property owners and recreationists who view and use it as well as citizens and businesses that use water downstream.

What potentially would adversely impact fish and aquatic invertebrates? Sediment, of course! In numerous applied research studies, sediment was shown to affect both the bottom habitat (used for food and spawning) and fish and aquatic invertebrates. The answer, to the question of impact, is not as simple as saying "sediment, of course". The coarser sized sediment, sand-sized particles, which settles out in quiescent reaches of a stream and is deposited in ponds and lakes, is easily and cheaply removed by even the most basic functioning sediment control system.

How are fish and aquatic invertebrates affected by sediment? The level of adverse impact is directly related to the combination of sediment concentration and duration of exposure. The frequency of exposure to either a high concentration for a short duration and/or medium sediment concentration for longer periods exacerbates the problem. Therefore reducing the exposure to frequent inundation of high or medium sediment concentration, and reducing the duration of occurrence significantly helps maintain a strong and diverse fish and invertebrate population.

We rarely see the big storms, obviously because such storms occur infrequently. Then why design an erosion protection and sediment control program to protect the fluvial system from a rare occurrence? Also consider that depending upon the size and staging of a development, the length of time for exposed soils may last for only a few months to a year. The probability of having a 25-year storm event in any given year is about four percent. Furthermore, when a large storm event occurs, the stream has substantially more dilution and transport capacity for the added sediment load.

The question still remains - what size storm should be regulated in the design of erosion prevention and sediment control system design? The answer lies in how to balance (1) how often a storm of a given size occurs, (2) the level of treatment that is expected from an erosion prevention and sediment control system and (3) and the on-site and off-site cost of the treatment system. If we specify that a very high level of sediment treatment is required for a 10-year storm, it is evident from the analysis presented in Figures 1-3 through 1-5 in the Cost and Performance of Alternative Erosion Prevention and Sediment Control Systems section of the Executive Summary, and the more extensive analysis in Chapter 9, that control measures will be quite extensive and costly considering on-site costs.

The premise here is that we do an excellent job in designing a system that removes a very high percentage of sediment for the most frequently occurring storms throughout a 1- or 2-year period. To accomplish this, the entire volume of runoff needs to be substantially retained and then slowly released. A riparian zone with level spreader, sand filter or some other innovative treatment system is required to further reduce effluent sediment concentration. Preferably the control system will discharge to multiple locations, thereby significantly reducing runoff volume and peak flow. The retention, slow release and treatment of the entire storm are needed to meet regulations that require a low level of effluent concentration to maintain higher water quality in the waters of the state. The requirement to retain the entire runoff volume is the main factor that drives up the cost for larger storm events.

Consider Figure 1-6 that shows the annual number of storm events at 0.2-inch rainfall increments. The obvious conclusion, that all of us already know, is that most rainfall events are small. A very high level of treatment for storms smaller than the 3- to 4-inch size effectively treats the vast majority of storms that are likely to occur throughout the year. Effectively accomplishing this would result in very low contribution of sediment to the fluvial system from construction-sites for the majority of storms. Additionally these same erosion prevention and sediment control systems are effective in reducing a significant amount of sediment from larger storm events as well.

Being successful at implementing such a regulatory framework would result in effectively accomplishing the multifaceted goals of (1) providing a stable fluvial system, (2) providing an excellent habitat for fish and aquatic invertebrates, and (3) providing downstream home owners and individual and business stream users with an aesthetically pleasing visual environment. All of this can be accomplished at a cost that balances the needs of developers and downstream owners alike. The cost and performance charts shown in Chapter 9 provide initial guidance in formulating legislative and regulatory policies.

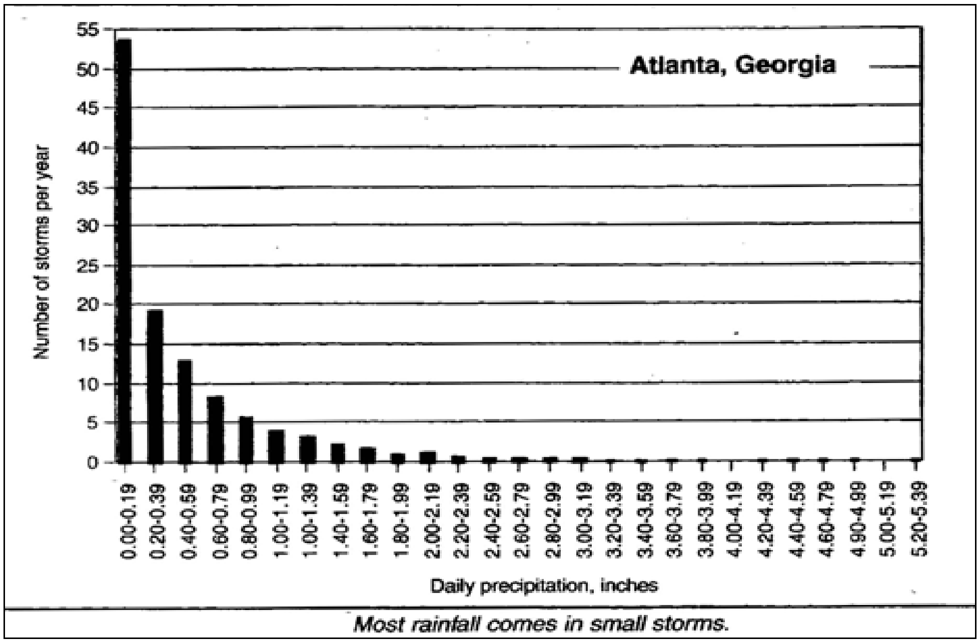


Figure 9 Frequency of storm event sizes in the Atlanta area.

Future Efforts

The multiple objectives of this project have been meet. However, the nagging question of "Is the problem solved?" remains. Certainly, for the first time, a quantitative computer modeling tool is now available for designing erosion and sedimentation control systems in the same way that design professionals currently design storm water control systems on a routine basis. The performance of alternative erosion prevention and sediment control systems has been successfully demonstrated and extended through application to commercial, residential and highways. It is evident that a system of appropriately designed and implemented controls can achieve excellent water quality. From the cost and performance assessment it is seen that the marginal cost of a system, that performs, is quite reasonable. For some construction sites by using innovated controls and approaches to designing erosion prevention and sediment control systems the cost can actually decrease, and performance increase, generating not only better water quality but creating a true win-win resolution.

The development of storm water permits by EPD with real regulatory "teeth" provides incentives for acceptance of the new methodology offered by Dirt 2. Whether the new methodology will come to be routine remains to be seen, so one of the most important follow-up efforts is to encourage its use among design professionals. One of the ways to accomplish this would be to offer 3 to 4 day continuing education courses on the new computer methodology in the Atlanta metro area. In addition, the word needs to be disseminated to policy and decision makers which is a goal that other parts of the Dirt II effort are intended to accomplish. Finally, there are technical limitations to the methodology developed, and these are delineated in this final report, but it should no longer be acceptable to offer excuses for not evaluating the expected performance of erosion and sedimentation control designs.

Future research and applications are foreseen for the development of sediment TMDLs in Georgia and for the possible revision of current erosion and sediment control regulations. One aspect of the sediment TMDL problem is to measure the existing sediment load in the stream, and the other is to assess the nonpoint source contributions to the total sediment load. The computer modeling technology that has been developed can be adapted to quantify the contributions of construction sites to the total sediment load. In addition, as outlined in this executive summary, the combination of storm water regulations and sediment and erosion control regulations into a single law may be highly desirable because of the close relationship between the two. At the same time, however, the design storm of interest may be different in the two cases, and future regulations should address this issue.

Additional work is needed in developing effective monitoring plans for measuring the sediment discharge from construction sites. The new storm water permit requires samples that are really only isolated grab samples that do not give the full picture of the unsteadiness of storm water events. In addition, it is not just peak concentration, or turbidity, of sediment that matters to the biological integrity of the stream, but also total event and seasonal storm water and sediment load that contribute to destruction of aquatic habitat. Future work should focus on developing receiving stream water quality standards that account for both sediment concentration and load, and that establish the critical duration of storm water events that are most harmful to fish and aquatic invertebrates.

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