Final Report

Literature Search

Chattahoochee-Flint
Regional Development Center

Franklin, Georgia

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CHATTAHOOCHEE - FLINT STUDY

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EXECUTIVE SUMMARY

The Chattahoochee-Flint Regional Development Center (CFRDC) requested a literature search to document the development of a state-of-the-practice approach to the design of cost-effective, comprehensive erosion prevention and sediment control systems that may be reasonably expected to meet a water quality performance specification. The literature evaluation was to consider computer modeling widely available to design professionals and regulators. In addition, efforts were made to locate newly available materials that could direct and shape further computer modeling and public information phases of the project. Specific goals of this effort were to search all reasonably available data sources using applicable topic areas and to locate relevant data sources and performance information that closely relate to the Chattahoochee Basin.

The Woolpert team used a multifaceted approach to accomplish the goals and objectives identified for the literature review. Electronic databases, university libraries, and personal libraries were used to locate available information in a timely manner. To take advantage of these databases, the Woolpert team, in conjunction with CFRDC personnel, developed a list of key words and combinations of key words. These keywords were used in keyword and subject searches to generate "hits" in electronic data bases. In addition, the Woolpert team used internal and external sources of its personnel to locate unpublished information through networking, Internet, professional memberships, and current research.

As information was found, it was screened for relevancy to project needs and potential application to the Chattahoochee Basin. A meeting between Woolpert team members (Spearman, Holbrook, Hayes, and Barfield) with representatives of CFRDC was held on February 27, 1998 to refine the goals and objectives. At this meeting, the CFRDC representatives clearly emphasized that they were particularly interested in identifying the capabilities of available models and innovative practices that might be applicable to control erosion and sediment from construction in the Chattahoochee Basin. They requested this information with a rapid turnaround because of its timeliness relative to other ongoing efforts. Commonly used structures and methods were of little interest unless they made a connection between sediment concentration and turbidity or dealt with topics like efficiency and cost effectiveness. Thus, the Woolpert team placed considerable emphasis on searching the literature for potentially appropriate models and their capabilities. A draft report on model findings was submitted March 17, 1998. The most significant aspect of this report was the three tier screening processes which delineated the features of numerous models. This screening led to tables that are also included in this report.

In order to accomplish the other objectives of the literature search, the Academic ASAP database and the Monthly Catalog of Government Publications database were initially searched using keywords and subjects that were previously submitted to the Committee.

This initial search of Academic ASAP developed a reference listing containing approximately 6000 articles as found in Volume I. These are based on keywords and keyword combinations as shown in Volume I. The keywords were also used in a subject search of Academic ASAP with results shown in Volume II. Similarly, the search of the Monthly Catalog of Government Publications database led to the listing shown in Volume III. This large listing of articles was filtered by reading through each title and publication listing to determine the most relevant articles. This led to the references that are shown in the Appendix. The Appendix lists some 300 literature references that were considered to be somewhat relevant to the effort but were not necessarily deemed to be as closely aligned to the project as the cited references. They are arranged in the Appendix by year since this is the manner in which the search took place and because many of the references involve several keywords. Abstracts for these 300 articles were evaluated and further filtered for relevance to the Chattahoochee-Flint Project and more extensive review. This summary of the most relevant articles is contained in the following sections of this report. The digital version of this section can easily be searched for keywords or phrases using a browser or word processor.

Volume IV contains approximately 300 abstracts for these potentially useful articles. No attempt was made to group them by topic since most articles would fit under several topics. They are available in digital form and can easily be searched for keywords or phrases using a browser or word processor. Full documentation of the source is also provided so that these publications can be easily located. Copyright limitations prevent the inclusion of complete manuscripts for all articles.

LITERATURE SEARCH: CHATTAHOOCHEE - FLINT STUDY

Countless articles have been written describing the impacts and sources of erosion and sediment. Historically, emphasis on erosion control began in the agricultural areas because the loss of topsoil was seen as an economic loss. More recently, methods of estimating soil loss and sediment yield have been applied to other activities such as timber harvesting, mining, and urban construction. In many cases, this work has included developing relationships for a wider range in conditions or as a result of specific actions that are necessary to conduct the activity. Limited emphasis has been placed on relating the cost of on-site erosion prevention and sediment control to off-site water quality. The following information summarizes recent literature that appears to relate in-stream turbidity with on-site erosion prevention and sediment control. Another consideration is providing cost-effective prevention and controls. This is also addressed.

In order to accomplish the objectives of the literature search, the Academic ASAP database and the Monthly Catalog of Government Publications database were initially searched using keywords and subjects that were previously submitted to the Committee. A listing of these keywords is shown in Table 1. This initial search developed a reference listing for approximately 6000 articles. This large listing was filtered by going through the title and publication for the most relevant articles. This led to the references that are shown in the Appendix. The Appendix contains some 300 literature references that were considered to be somewhat relevant to the effort but were not necessarily deemed to be closely aligned to the project as the cited references. Abstracts for these 300 articles were evaluated and further filtered for relevance to the Chattahoochee-Flint Project and more extensive review. The following sections summarize the most relevant of these articles. For further information concerning the process, references, abstracts, or availability of full publications, please contact Woolpert.

A subsequent section deals specifically with the screening of available models relative to their features that relate to this study. The results shown in the model matrices are based on information gleaned from numerous published or unpublished articles and experience of the Woolpert Team.

MODELING

A particularly useful publication was published by the Department of Environmental Conservation and the Soil and Water Conservation Committee as NYS (1994). This publication compares a variety of models with respect to their ability to predict pollutant loading. Unfortunately, many of the models presented do not include sediment movement as a component. The erosion and sediment related models are presented in the later section dealing with model screening. Numerous mathematical models to predict capability for soil and water erosion under global change have been developed (Nearing et al., 1996). One of these models is the Erosion-Productivity Impact Calculator (EPIC) model which was originally developed to assess the effect of soil erosion on soil productivity. The model has been expanded and refined to allow simulation of many processes important in agricultural management. EPIC is a continuous simulation model that can be used to determine the effects of management on agricultural production and soil and water resources. Drainage areas considered by EPIC are generally field-sized, up to 100 ha with weather, soils, and management systems assumed to be homogeneous. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient cycling, pesticide fate, plant growth, soil temperature, tillage, economics, and plant environment control. Another model, Water Erosion Prediction Project (WEPP), is a new generation of soil erosion prediction technology for use in soil and water conservation planning and assessment. WEPP is physically-based on rill and interrill erosion processes and sediment transport mechanics. It does not use principles, parameters, or logic from the USLE for predicting erosion. Since it is mostly process-based, the model is well suited for studying effects of environmental system changes on hydrologic and erosion processes. WEPP is a continuous simulation model and works primarily on a daily time step in terms of updating system parameters that define the surface conditions. The WEPP model includes eight major components: climate, infiltration, water balance, plant growth and residue decomposition, tillage and consolidation, surface runoff, erosion, and winter processes. The erosion part uses a steady-state sediment continuity equation to calculate net values of detachment or deposition rates along the hillslope profile and in watershed channels. The erosion process is divided into channel, rill, and interrill portions where interrill areas serve to direct sediment to the rills, or small channel flows. Hillslopes direct sediment to watershed channels. Within rills and channels the sediment may be carried downslope or deposited. Scour by rill and channel flow is calculated when flow shear exceeds critical shear of the soil and when sediment load is less than calculated sediment capacity.

The Water Erosion Prediction Project (WEPP) model was developed to replace the Universal Soil Loss Equation (Laflen, 1997). Since the USLE has been used worldwide for years, its replacement as a tested technology required years of extensive research on soil erodibility. WEPP will serve as a tool in helping managers choose the best way to produce on and protect a specific farm based on its soil, topography and climate.

WEPP is a computer simulation model of soil erosion and sediment transport that was the result of a research program that was initiated by the agricultural Research Service and Natural Resource Conservation Service in 1985 (Laflen et al., 1997). The WEPP model provides daily predictions of soil erosion based on environmental parameters. The computer model can be utilized for the development of soil erosion practices, watershed rating or classification and forest management.

The ability to predict sediment yield from catchments for studies of reservoir sedimentation, morphologic modeling, and soil-conservation planning was considered by Kothyari et al. (1994). They recognized that although records on sediment yield are generally not available, sediment yield can be predicted from other commonly available hydrologic data in the literature. Their study compared some of these methods for their accuracy using carefully collected data from experimental catchments. They found that existing methods do not adequately account for the process of sediment delivery; these methods produce less accurate prediction of sediment yield. As a result, they proposed a new method based on the routing of surface erosion through time-area segments. This method was found to estimate sediment yield more accurately than those it was compared with. The proposed method has a more sound basis for further use in distributed models.

A relatively original point of view was introduced by Menendez (1997) in order to classify sedimentation phenomena according to spatial scale. Three categories are identified: large-, medium-, and short-scale models. The distinction is made between the hydrodynamic adaptation length and the study scale. This allows determination of the right mathematical model for each particular case. The main features of the models involved and of the associated numerical methods are briefly described.

Although most soil erosion studies are confined to short time frames and small plot scales, Kirkby et al. (1996) expanded soil erosion studies to increase the understanding of the relationship between global climatic change and soil erosion. Scientists have developed dynamic systems strategies to integrate spatial variations between small and large scale erosion studies into a new soil erosion monitoring and experimentation model.

A non-point source pollution management model, ANSWERS-2000, was developed by Bouraoui and Dillaha (1996) to simulate long-term average annual runoff and sediment yield from agricultural watersheds. The model is based on the event-based ANSWERS model and is intended for use without calibration. The Green-Ampt infiltration equation was incorporated into ANSWERS-2000 to improve estimates of infiltration. An evapotranspiration submodel was added to permit long-term, continuous simulation. The model was validated without calibration using data from field-sized watersheds in Watkinsville, Ga. Additional validation with limited calibration was done on the Owl Run watershed in Virginia. Model predictions of cumulative sediment yield were within 12% and 68% of observed values. Predicted cumulative runoff volumes ranged from 3% to 35% of observed values. Predictions of sediment yield and runoff volume for individual storms were less accurate, but generally within 200% of observed.

A basin-scale model was developed by Cooper and Bottcher (1993) to simulate long-term average losses of water, sediment, and nutrients from large rural watersheds. In addition to simulating diffuse sources using the Chemicals, Runoff, and Erosion from

Agricultural Management Systems (CREAMS) model, the model incorporates point sources, nitrogen leaching from septic tanks, riparian and stream channel attenuation processes, and routing algorithms. Predictions of long-term average sediment and nutrient losses were generally within 30% of those estimated from data gathered at the basin outlet.

A model was developed to simulate suspended transport of fine-grained sediment, both cohesive and noncohesive, in the Pawtuxet River, Rhode Island (Ziegler Bradley Nisbet, 1994). The model utilizes results of extensive laboratory and field studies to specify parameters governing deposition and resuspension processes. The SEDZL modeling framework, which accurately and realistically simulates cohesive resuspension and deposition, including the effects of flocculation, has been modified to include simulation of noncohesive suspended transport. Field studies were conducted during the spring of 1992 to collect bathymetric, stage-height, suspended-solids, and sediment-bed data. The hydrodynamic and sediment transport models were calibrated and validated during a 33-day period, which included two high-flow events, each of which approximately correspond to the annual flood. Successful calibration indicated that the model has potential as a predictive tool.

A method for determining data required to reduce model-prediction uncertainty using first-order reliability analysis was developed (Melching and Yoon, 1996). They demonstrated the uncertainties in simulation of stream water quality for the Passaic River, NJ, with the QUAL2E model. Results may suggest that water-quality modelers and planners do similar reliability analyses for more efficient sampling programs.

Arnolds et al., (1995) discussed the use of simulation models to evaluate the impact of changes in land use and agricultural management on streamflow and sediment yields from watersheds and river basins. Current agricultural-management models are limited by spatial scale, and river-basin models do not simulate land use and management adequately to evaluate management strategies. A model called ROTO (routing outputs to the outlet) was developed to estimate water and sediment yield on large basins (several thousand square miles). ROTO is a continuous model operating on a daily time step that accepts inputs from continuous-time, soil-water balance models. Components for water and sediment movement in channels and reservoirs are developed within a comprehensive basin-scale agricultural management model. The model was validated on three different spatial scales: the small watershed, watershed, and river basin.

An in-place pollutant export model (IPX) was used by Velleux et al. (1996) as a screening-level model for estimating contaminant export from tributaries with contaminated sediments to receiving water bodies. IPX is a modified version of the USEPA's WASP4 modeling framework. IPX synthesizes sediment transport processes for sediment aging, decreased sediment resuspendability, and resuspension of deposited sediments as a function of water velocity, into an expanded WASP4 contaminant transport framework. These process descriptions are needed to accurately simulate contaminant transport and substantially improve the framework for application to tributary systems subject to significant deposition and resuspension events. The potential for applying IPX is broad; water quality impairments attributable to contaminated sediments are widespread due to discharges from industry, agriculture, and mining and ore processing.

CE-QUAL-ICM is a three-dimensional, time-variable, eutrophication model that uses 22 variables that include physical properties; multiple forms of algae, carbon, nitrogen, phosphorus, and silica; and dissolved oxygen (Cerco and Cole, 1993). Application in the Chesapeake Bay indicates the model successfully simulates water-column and sediment processes that affect water quality. Phenomena simulated include formation of the spring algal bloom subsequent to the annual peak in nutrient runoff, onset and breakup of summer anoxia, and coupling of organic particle deposition with sediment-water nutrient and oxygen fluxes.

A highly urbanized watershed near Boston was used by Solo-Gabriele and Perkins (1997) to evaluate whether streamflow can be separated into three separate components: quick storm flow, slow storm flow, and long-term baseflow. Quick storm flows were thought to activate highly sources of sediment from outside the river and result in large increases in concentrations during storm events. Slow storm flows and long-term base flows result in low and relatively constant suspended sediment concentrations. Net concentration of dissolved and particulate metals observed in the river is a result of mixing the components. Differences between subbasins can be addressed by stream flow.

Runoff and sediment yield for 30 runoff events on three experimental watersheds were calculated using the agricultural non-point-source pollution(AGNPS), areal non-point-source watershed environmental response simulation(ANSWERS), and chemicals runoff and erosion from agricultural management systems (CREAMS) runoff-erosion models by Wu et al. (1993). Results compared with measured runoff and sediment yield show reasonable to poor agreement for runoffs. The average ratios of computed to measured sediment yields for the various storms and watersheds show a large scatter. ANSWERS provides the most consistent results for estimates of runoff and sediment yield. All three models tend to underestimate sediment yield for large storms.

MODELING PRINCIPLES

Walker (1994) published a study on effectiveness of various management practices in small rural lakes and streams at the watershed scale. Statistical techniques were used to test for changes in water-quality data from watersheds where best management practices (BMPs) were implemented. Reductions in data variability due to climate and seasonality were compared through the use of regression methods. He also discussed the merits of using storm-mass-transport data to improve the ability to detect BMP effects on stream-water quality. In all cases, the use of regressions improved the ability to detect trends.

Wu et al. (1996) monitored three urban wet detention ponds in the Piedmont of North Carolina to investigate long-term pollutant removal as a function of surface to area ratios. Eleven storm events were monitored over a sampling period of 13 months. Urban runoff originating from the study area was characterized by event-mean concentrations for total suspended solids (135 mg/L), total Kjeldahl nitrogen (0.88 mg/L), total iron (6.11 mg/L), and total zinc (66ug/L). Observed event-mean concentrations were generally lower than national values reported by the Nationwide Urban Runoff Program. Particle sizes of sediment discharged in runoff were found to be much finer than the national averages due to the predominant clayey soils in the region. This study demonstrated that surface to area ratio can be a useful predictor of wet pond performance. Utilizing 1-2% of watershed area for development of wet detention ponds at strategic locations could reduce pollutant loadings to meet targeted requirements of water quality improvement.

The varying velocities of flood waves and stream flow can be a major consideration relating stream discharge to suspended sediment concentrations according to Marcus (1989). Flood waves move downstream faster than the flow velocity, thus leaving original flood waters and their entrained sediments lagging increasingly farther behind with increasing distance downstream. This process can be modeled by routing the changes in discharge at the flood-wave celerity, while routing the sediments at the flow velocity. Testing of this model using data previously collected indicated that differences in flood-wave and flow velocity explain a large portion of the downstream variations in the relation of discharge to concentration through time. The routing model results suggests that one explanation of seasonal and storm-period variations in sediment rating curves may be seasonal changes in the distance to sediment sources.

Tsihrintzis (1995) stated that the primary function of a drainage culvert - to convey the design flow effectively - is often greatly impaired or lost due to deposited sediments. The effect of sediments on the total head loss within the culvert may be significant. A case study is presented that describes the performance of a roadway drainage culvert designed for clear-water flow conditions in an alluvial stream carrying sediments. The actual capacity of the culvert was approximately only 20% of the presumed design capacity, as a result of sediment deposition not accounted for in the design. The case study reviews design errors and demonstrates the necessity of sediment-transport calculations when designing roadway drainage culverts in ephemeral alluvial streams. Ignoring sediment transport may have adverse effects, including significant road and adjacent-property flooding as well as continuous and costly maintenance problems. He concludes that it is more economical to undertake a complete sediment-transport study before design than to deal with continuous maintenance later.

Changes of sediment-yield rates from disturbed earth systems were considered by Schumm and Rea (1995) through time as they reflect evolutionary changes within a landscape. When a drainage basin is disturbed significantly by base-level, climatic, or tectonic change, sediment yields increase dramatically, but with no further disturbance they decline rapidly. These sediment-yield changes have been documented at all scales, from small experimental studies, to incised channels, to the Colorado River basin, and to the Himalaya Mountains. Thus, the shape of the sediment-yield curve can be used to estimate future sediment yields and to interpret past tectonic events.

A simple design aid is presented by Akan and Antoun (1994) for quickly sizing flood-control detention basins and outlet structures. The design objective is to control post development flood volume rather than peak discharge. Alternatively, the method can control downstream channel erosion caused by post development flows. The detention basins considered have a single outlet. The design aid is based on predetermined solutions to the reservoir-routing equation. To evaluate the channel-erosion tendencies, a generic bed-load formula is employed. All equations are written in dimensionless form, and solutions are obtained in terms of a set of governing dimensionless parameters. Results are generalized using hydrologic similarity and presented in chart form. These charts can be used to determine required stage-storage relationship for a detention basin and the size of the outlet structure.

Garbrecht et al. (1995) discussed a new sediment transport capacity algorithm for measuring large scale propagation and redistribution of sediments in channel networks. The method uses four established sediment transport equations to calculate transport capacity. The equal mobility characteristics of sediment mixtures is considered by modified critical shear stress. They showed that the algorithm generates consistent results for a wide range of flow and sediment characteristics.

GEOGRAPHICAL INFORMATION SYSTEMS AND MODELING

Uses of Geographical Information Systems to simplify data input have been considered recently. A computer algorithm to calculate USLE and RUSLE LS-factors over a two-dimensional landscape is presented by Desmet and Govers (1996). When compared to a manual input, both methods yield broadly similar results in terms of relative erosion risk mapping. There appear to be important differences in absolute values although both methods yield similar slope values. Use of the manual method leads to underestimation of erosion risk because of the effect of flow convergence. The computer procedure has the obvious advantage that it can easily be linked to GIS software. A comparison with soil data showed a reasonably good agreement between predicted erosion risk and intensity of soil truncation in the test area. Another method that integrates geographic information systems and databases was developed by Mellerowicz et al. (1994) to aid in soil and water conservation planning. A map of polygons with combinations of Universal Soil Loss Equation factors was formed through integration of soil, climate and land use information. Manipulation of factors allowed evaluation of different scenarios that may occur in the watershed.

Garbrecht (1994) combined the geographic information system Arc/Info with the Agricultural Nonpoint Source Pollution Model (AGNPS) and proved that the sensitivity of water and sedimentation yield relates to size of the AGNPS grid. Delivery ratio, stream length and sediment yield were highly dependent on grid size. In-depth analysis of the input data and model results shows many inconsistencies that could affect findings and conclusions for a given application.

A geographic information system (GIS) interfaced with a geomorphic-basedhydrologic and sediment transport model by Mashriqui and Cruise (1997) uses the "grouped response unit" concept whereby land classes are identified within homogeneous regions and used as hydrologic and sediment response units. The computational units are defined on the basis of homogeneity of topography and soil characteristics using frequency histograms of relevant parameters as objective criteria. The model is then applied to each land class within the computation units. The GIS/model interface is accomplished on an interactivebasis in order to allow the user to have some decision-making authority. The methodology is demonstrated in detail and six years of runoff and sediment data are simulated.

URBAN DEVELOPMENT AND SEDIMENT CONTROL

Stream channel erosion has long been suspected as the major contributor to long-term sediment yield from urbanizing watersheds (Trimble, 1997). For San Diego Creek in southern California, measurements indicated that stream channel erosion furnished 105 megagrams per year of sediment, about two-thirds of the total sediment yield. Channel erosion can be a major source of sediment yield from urbanizing areas, and channel stabilization should be a priority in managing sediment yield.

Lange et al. (1996) suggest that the most effective efforts to control construction sediment usually focus on preventing the contaminants from ever reaching the storm drainage system. By far the most significant urban storm water contaminant is sediment. Construction activities are the chief culprit in increased sediment by providing areas where natural vegetative cover has been removed and bare soil is subject to the full erosive force of rainfall and runoff. The most cost effective technologies must be used.

Raghuwanshi et al. (1994) produced a model for an instantaneous-unit sediment graph (IUSG) based on attenuation and translation functions of mobilized sediment developed and applied to a Chaukhutia watershed (452.25 km^2). An IUSG is a sediment graph resulting from one cm of mobilized sediment generated uniformly over the basin area during the effective rainfall of infinitesimally small duration. The catchment representative IUSG was converted into a unit sediment graph and convolved with mobilized sediment for generation and prediction of sediment graphs. The predicted sediment graphs showed good agreement with observed values except for lower peak sediment rates. Changes in hydrologic regime of the catchment due to adoption of conservation measures are mainly reflected by the attenuation of crest segments and peak sediment flowrates of IUSGs for the successive years.

PARTICLE SIZE AND SETTLING

Particle settling has long been recognized as an important aspect of water and wastewater treatment processes. Johnson et al. (1996) suggested that microbial aggregates generated by these processes are fractal and therefore, have different settling velocities. An investigation of the settling velocities of impermeable spherical aggregates generated from dyed latex micro spheres in standard paddle mixers shows that fractal aggregates settle about four to eight times faster than velocities predicted using an impermeable sphere model, also known as Stoke's law.

Meyer and Harmon (1992) recognized that sediment size characteristics, distribution and density should be considered in erosion assessments because they all affect sediment transport and deposition. Soil samples from 22 areas in Mississippi, Iowa and Alabama were studied for sediment characteristics. Researchers simulated rainstorms and collected data on erosion rate and sediment size. The data gathered were used to construct a model of soil and nutrient losses from agricultural lands.

A new and simplified formula for predicting the settling velocity of natural sediment particles was developed by Cheng (1997). His formula proposed a relationship between particle Reynolds number and a dimensionless particle parameter. It is applicable to a wide range of Reynolds numbers from the Stokes flow to the turbulent regime. The proposed formula has the highest degree of prediction accuracy when compared with other published formulas.

Water quality, metals concentration, and particle size distributions were characterized in urban runoff by Characklis and Wiesner (1997). Concentrations of particle number, organic carbon, suspended solids, iron, and zinc increased during storms. Data from two storms followed throughout their duration show individual materials eluting at different stages during storms. These measurements also indicated potential relationships between the zinc/organic carbon and iron/macrocolloidpairs. Elevated contaminant concentrations

and increased flowsduring storms created loadings equal to weeks or months of background flow. Data showed no evidence of the "first flush" which has been observed in many smaller watersheds. Results may have implications for the design of large-scale storm-water management strategies.
Loss of sediments and nutrients from land surfaces to surface water supplies continues to be an important source of nonpoint source pollution according to Wall et al. (1996). The close relationship between loadings of suspended solids and total phosphorus has been reported in many studies. Wall et al.'s study sought to develop an empirical relationship between phosphorus and suspended solid loadings in the Canadian Great Lakes basin. Annual loadings of suspended solids and total phosphorus were collected from agricultural surface water quality studies carried out in Ontario. Various study factors such as plot, field, and watershed sizes, as well as methods, loadings, and references, were documentedand annual loading values were plotted as the ratio of annual phosphorus/suspended solids loading versus the unit area suspended solids loading. The developed equation showed an exponential enrichment relationship of the phosphorus to suspended solids ratio with the unit area suspended solids loading, regardless of drainage area size. The equation enables a reasonable prediction of phosphorus loads for known sediment loadings.

Wu et al. (1993) used traditional techniques such as sieving, sedimentation and static and dynamic light scattering to estimate soil particle-size distributions across a broad range, from 5-cm to 20-nm radius. A power law N-alpha-r (super -v), with the exponent v = 2.8 plus or minus 0.1, was observed in cases where the number of particles, N, per unit volume was present in a radius which was greater than r. Normally, more than twenty to fifty years of length scales were observed.

The matching of parameterized models with particle-sizedistribution was used to compare the jaky model, the standard lognormal model, two improvised lognormal models and the bimodal lognormal model, and examine them with mass-size data of 71 texturally varied New Zealand soils (Buchan et al., 1993). The standard lognormal model gave a worse fit to data for 23 soils, than the jaky model did for several soils. An improvised lognormal model, ORL and the bimodalmodel matched the data the best.

Analytical techniques applied to the definition of a particle are reviewed by Barth and Sun (1993). They involved the utilization of scattering techniques, size exclusion/hydrodynamic chromatography, field-flow fractionation electrozone sensing, sedimentation/centrifugation, sieving and other methods such as ultrasonics. They also compared the techniques in terms of particle shape and particle size standards.
Haster and James (1994) presented a mathematical model representing washoff of sediments from small urban watersheds during storm events. The model simulates the contribution of sediments from each of the different land surfaces present within an urban watershed. They reasoned that different land surfaces contribute sediments differently, and that a better estimate of the total sediment load could be determined by representing

each of the major land surfaces independently. The model was developed and tested using water-quality data from four small urban watersheds in Houston and Austin, Tex., and by using data from bare-soil erosion plot studies. Performance of the model compared the simulated results with observed results during storm events that were analyzed. Given the appropriate parameters, the model provides reasonable estimates of the observed sediment yield from each of the different land surfaces studied. Therate at which sediments are washed off the impervious area of a watershed is shown to correlate with the length of time since rainfall has last occurred.

A study by Durnford and King (1993) consisted of rainfall-runoff events produced with a large rainfall simulator. Three test plots were 2.44 m wide, with lengths of 6.1 m, 13.72 m, and 24.38 m, and a slope of 2%. The soil on the plots was loamy sand. Rainfall intensities of 44 mm/h, 79 mm/h, and 160 mm/h were run for 1 h for each test. Samples of the runoff were analyzed for sediment particle-size distribution. Conclusions about the processes governing the erosion rates were that transport capacity tended to limit erosion rate of larger particles and supply limited the erosion rate of smaller particles. Data demonstrated that evaluating a single detachment or transport rate and assuming it to be constant for a season, or even a storm, may not always produce accurate results. Variations of these rates, due to armoring, must be taken into consideration.

Daniels and Gilliam (1996) found that vegetated filter strips help reduce non-point source pollution from agricultural areas. Even though such vegetation is an accepted and highly promoted practice, little quantitative data exist on its effectiveness under fieldconditions. The objective of this research was to determine the amount of nutrients and sediment removed by natural and planted filters. This was achieved by collecting and analyzing runoff at field edges and at various locations in vegetated buffers. Total weight of sediment and nutrients in runoff from North Carolina agricultural fields showed that the grass and riparian filter strips studied reduced runoff load by 50 to 80%. Total sediment decrease through the filters was about 80% for both grass and riparian vegetation.

TURBIDITY

Turbidity can be effectively used as an indicator of total phosphorus and suspended solids concentrations in streams (Grayson et al., 1996). Data collected from a 5000 square km catchment revealed the utility of the turbidity parameter in continuous measurement of containment loads. Field turbidity measurements largely overcome the disadvantages of conventional common flow based methods. However, they believe attitudinal changes must precede the induction of site specific estimations as a routine feature of monitoring containment loads.

Siano (1993) developed a simple method to correct for primary light scattered forward to the detector in turbidity measurements of Rayleigh scatters. The relative measurement error is shown to be independent of turbidity and specific absorbance, unlike the error calculated by use of a more involved model. In addition, although both methods consider absorbing components in the sample, only the simple method can be used when absorbing components and/or scattering components of any size are present in the blank.

Present knowledge regarding associations between sediment and riverine aquatic habitat is summarized in ASCE (1992). This article reports that engineering approaches can be used to evaluate and predict aquatic-habitat conditions, but as the grain size distribution of the bedload approaches that of the bed material, the number of benthic species declines. Sediments provide cover and spawning sites for fish and habitat for fish and food organisms. Sediment also serves as an indirect indicator of habitat quality. Major environmental issues associated with sediment transport in rivers include transport of organic sediments, sediment-water-quality interactions, deposition of sediments finer than gravel on and within coarser deposits, and filling of low-velocity areas contiguous to major river channels. It is noted that most stream organisms can withstand short-term exposure to elevated levels of suspended sediment, but chronic exposure is more detrimental.

Turbidity results from suspended material including clay and other sediment, algae, organic matter, and bacteria. The term is used to define the degree to which light is scattered and absorbed instead of passing through a water sample. Various studies have either measured turbidity at specific times and locations or have tried to relate turbidity to other contaminants. In this section, primary focus is on relating turbidity to suspended solids.

Turbidity relationships with fish survivability has been studied by various researchers. A study by Barnes, et al. (1996) analyzed existing fish and sediment data by comparing suspended sediment as measured by turbidity (NTU) with fish characteristics. They concluded that in the Piedmont, native fishes could be protected if random monthly samples of turbidity never exceed 100 NTU or less than 20 percent of samples exceed 25 NTU.

A field and modeling study by Sturm and Kirby (1991) evaluated the design criteria and best management practices for controlling sediment from construction sites. They utilized field data from landfill sites with sediment basins and compared TSS and NTU relationships. Rainfall, watershed hydrology and size, soil properties and conservation measures, and the sediment basin design were all found to impact whether desired turbidity limits were exceeded. A significant conclusion was the importance of applying soil conservation practices to prevent sediment from reaching the sediment basin.

A separate study by the Gwinnett County Department of Public Utilities (1993) conducted sampling at three sites with varying degrees of erosion control for approximately four months. Considerable variations in the NTU versus TSS measurements were observed. For example at site 3 on Agust 27, Bottle 1 had a turbidity of 1230 NTU and TSS of 150 mg/l while Bottle 1 on September 21 had a turbidity of 78 NTU and TSS of 492 mg/l. Again, this shows that while an one-to-one relationship between turbidity and TSS can be assumed, there is tremendous variability between samples and the direct relationship may be an inverse relationship for specific samples.

The Georgia Board of Regents' Scientific Panel (1995) discussed the relationship between turbidity and suspended solids. They recognized that while a relationship can often be established between turbudity (NTU) and total suspended solids (TSS), the relationship can vary over a wide range as a function of location, time, stream energy, and sediment composition. They particularly noted that TSS and NTU levels may differ substantially and significantly. They concluded that, in the absence of better information about specific watersheds, a 1:1 relationship be assumed. Such a relationship was plotted for 1991 U.S. Geological Survey data for Georgia for suspended solids levels up to about 150 mg/l. Variation in the turbidity level was often one order of magnitude at a specific TSS level. It should be noted also that 150 mg/l is a relatively low TSS level compared to what frequently has been detected from construction sites.

A fact sheet by the Big Creek Project Technical Advisory Committee (1996) also considered the relationship between NTU and TSS. Measured values were compared at different stream levels. They indicated that statistical comparison of turbidity and total suspended solids shows a nearly one-to-one relationship using a logarithmic plot of the measurements. Measured values reached as high as 7000 mg/l with typical values between 300-800 NTU. Very few samples were less than 80 NTU.

A study of silvicultural practices (Green and Rasmussen, 1996) desribed efforts to relate turbidity in streams to BMP usage. Monitoring stations located up and down stream of forest practices were used to quantify the magnitude of turbidity changes. They concluded that while forest harvesting operations caused no significant long-term increase in average turbidities, turbidities can be affected by practices at individual sites. This was particularly evident for perennial streams under high flow in erodible soils of the Piedmont. Emphasis in this study was on long-term effects and not on direct affects during harvesting when there is increased potential for high erosion rates.

COST EFFECTIVENESS

Walker et al. (1993) studied average cost efficiency technique for quality control of water that is degraded by sediments in irrigation return flows and applied marginal analysis that considers change in cost per unit in sediment reduction. A cost efficiency frontier is used for acquiring alternative levels of sediment control. They found that preventive methods for controlling erosion are not as cost effective as practices that clean up runoff.

The long-run cost of erosion to a farmer is incorporated in a damage function which is applied to evaluate conservation tillage in a model by Walker and Young (1986). The model was evaluated for four alternative rates of technological change affecting wheat yields and for the mean discount rate of each group under the four rates of technological change. Higher anticipated rates of multiplicative technological progress increase future damage from erosion, accelerate projected adoption of conservation tillage and encourage conservation of topsoil. Results such as these have policy implications for the control of erosion.

Epp and Hamlett (1996) evaluated changes in field costs and revenues with seven conservation best management practices (BMP) and two nutrient management programs (NMP) for three sites in the Susquehanna River Basin in Pennsylvania. Field layouts, rotation selection, BMP design, and CREAMS modeling of sediment and nutrient losses were reported. BMP implementation costs, field operation costs, and crop revenues were calculated with each BMP as well as the baseline condition representing present practices. The BMP/NMP combinations are compared for cost-effectiveness in reducing sediment, nitrogen, and phosphorus losses. Nonstructural BMPs (no-till, contour, contour with waterways, strip crop with waterways, filter strips) produced less reduction in net field income than did structural BMPs (terraces with waterways, parallel tile outlet terraces, sediment basins).

A nonpoint pollution control model to check monitoring problems in cases of dispersed pollution is proposed by Miljkovic (1995). The model acknowledges the inter-connection between policy makers, economic influences, and aims to promote environmental quality. A tax or subsidy incentive is used to attract polluting firms to an optimal abatement level, which preserves industries' incentives while providing government with additional income. Details of decision making processes by the government regulator and agent,a suspected polluter, are discussed

SCREENING FOR NEEDED MODEL CAPABILITIES

Screening of the models was accomplished using a three-level screening process. Level I screening was a simple determination of whether or not the model addresses stormwater, sediment, and sediment size distribution. Level II screening was used on those models that passed the first level to determine if the sediment modeling procedure was sufficiently detailed to allow the appropriate prediction of sediment yield and impact of erosion prevention and sediment control. Finally, Level III screening was simply a comparison of the capabilities of the four models that passed the first two levels of screening. Based on the comparisons in Level III, recommendations are made on a model to be used.

LEVEL I SCREENING - GENERAL STORMWATER, SEDIMENT, AND SEDIMENT SIZE

Stormwater prediction - Turbidity results from erosive forces of rainfall and stormwater runoff, hence the need to predict stormwater discharge.

Sediment prediction - Turbidity is related to sediment concentration, hence the need to predict sediment production. It is important to recognize that some models (i.e., RUSLE) require the user to estimate a delivery ratio in order to estimate sediment yield. This is a significant disadvantage and is difficult to handle from a user viewpoint. Such models are not included in the Level II Screening.

Sediment size distribution - the performance of all sediment control measures is related to size distribution, hence the need to predict size distribution.

LEVEL II SCREENING - GENERAL SEDIMENT COMPUTATION REQUIREMENTS

Sediment yield/delivery ratio - Mere computation of erosion is not sufficient to estimate turbidity in a stream or reservoir. The quantity of sediment delivered to the channel must be calculated, which requires either a delivery ratio or computation of transport capacity. Some of the models use delivery ratio as input. However, delivery ratios are complex functions of parameters such as velocity, sediment size, transport capacity, etc., thus estimation is not simple.   In order to have a reliable estimation procedure that is semi-independent of modeler expertise, a reliable procedure for estimating sediment yield should be included as part of the model computational procedure, not as an input parameter.

Erosion prevention (on-site) - The first line of defense for controlling erosion and turbidity is on-site control. Once suspended, sediment is difficult to remove, particularly the finer particle sizes. On-site controls protect soil from the erosive power of rainfall and flowing water. Techniques for evaluating the impact of on-site controls are thus necessary.

Erosion control (off-site)

- Retention/detention/ponds - The most commonly used technique for controlling sediment off-site is some form of impoundment. These structures retain sediment for a period to allow particles to settle from the flow. The trapping efficiency varies widely, depending on outflow structure, surface area, and settling velocities. Accurate evaluation of the impact of impoundments is essential to developing proper control techniques.

- Small controls - Small controls are widely used as part of sediment control plans. Their effectiveness depends on the type of structure, porosity (slurry flow rate), and location (overland flow or channel flow control). A model to evaluate the impact of these structures is important.

LEVEL III SCREENING - SPECIFIC PREDICTION TECHNOLOGY REQUIREMENTS

Type simulation

- Single storm - Most design is based on single event predictions, hence the need to predict single events.

- Multiple storm - In addition to single storm events, it is sometimes advantageous to predict turbidity over a period of days to months. When that information is needed, routines will need to be developed to utilize the single event models to develop such predictions.

Predict sediment discharge

- Rill and interrill - Erosion from rills and interrill areas can be the primary source of sediment in construction areas when exposed areas have not been stabilized, thus models should have rill and interrill prediction capability.

- Concentrated flow - Flow in concentrated channels is a common occurrence on construction sites. It occurs when flow moves to convergence zones, prior to entering a defined stream. Such flows can be major sediment sources. In stabilized (vegetated) watersheds, channelized flow can be the primary source of sediment, thus it is important to have this computational capability built into the model.

- Predict turbidity - The project is focused on turbidity as the measure of impact of urbanization on stream water quality. The model selected must be capable of predicting parameters that can be used to estimate turbidity, or must be modified to predict turbidity itself.

Hydraulic computations

- Variable time step to allow for small storage/large discharge - Flow controls such as culverts and inlets on urbanized watersheds will frequently create small impoundments and trap the coarser sediments. In these controls, outflow rates are typically nearly as large as the inflow rate and the storage volume is small, giving rise to unstable hydraulic routing predictions unless computational step size is extremely small. Such small step sizes are impractical for all calculations, hence results from fixed time step models frequently show outflow rates exceeding inflow rates, a physical impossibility. Thus, accurate estimation of the impact of these small controls is difficult to estimate unless the model being used has a variable time step. These variable time steps are employed when computed flow rates start changing rapidly.

- Continuous functions for stage discharge and area - Frequently, stage-discharge and stage-area information is utilized at discrete stage points and linear interpolation is utilized for values in between. Where discharge values change abruptly as flow transitions from one type of outlet to another (i.e., weir flow control to open channel flow control), serious errors can result in routing computation. This problem can be overcome by using continuous functions for stage-discharge and stage-area.

- Drop inlet - A commonly used outlet control device.

- Perforated risers - A commonly used outlet control device.

- Perforated risers with rock fill wrapping - An outlet control device which is sometimes used to prevent large sediment particles from clogging dewatering devices.

- Culvert outlets - A common flow control device.

- Open channel spillways - with control section - A frequently used emergency spillway type which can also be used as a principal spillway.
- Open channel spillways - without control section - A frequently used emergency spillway type which can also be used as a principal spillway.

Evaluate impact of small controls

- Rock fill checkdam - A commonly used small control, typically employed in ditches during construction.

- Filter fence - One of the most commonly used control techniques in overland flow control.

- Straw bales - A commonly used control technique in overland flow control.

- Inlet filters - A technique commonly used to protect storm sewer inlets during construction.

Evaluate impact of on-site controls (erosion prevention)

- Mulch (varying types) - A commonly used protection mechanism.

- Vegetated cover - A commonly used method of stabilizing bare soil, both temporary as well as permanent.

- Timing of establishment of vegetation - Timing of vegetal establishment is critical to erosion control.

- Geotextile blankets and netting - Frequently used in place of natural mulch or to hold mulch in place.

- Channel bank stabilization - Finding increasing use in stabilizing concentrated flow areas and channelized flow.

- Grade control structures - Used in channelized flow to prevent channel erosion.

Account for instream flow above and below discharge point - Based on current regulations, it will be necessary to output values that will allow computation of the impact of discharge on the turbidity of the receiving stream, showing how the turbidity downstream is changed from the turbidity upstream.

History of use on urban watersheds - Many erosion and sediment models have been developed primarily for evaluating agricultural and silvicultural operations. These models may not be readily adaptable to urban conditions, due to the nature of the difference in drainage structures.

Economic analysis capability - As one of the final products of this project, an analysis of the cost of the EP and SC systems must be made in order to select the system which has least total cost to the developer and society in general while meeting the turbidity standards under design conditions. Thus, the output of the model must be in a form such that these computations can be readily made.

SALIENT POINTS ABOUT PREDICTION CAPABILITIES NOT CURRENTLY AVAILABLE IN ANY MODEL

Turbidity

Since turbidity has been identified by the RFP as the critical parameter for this project relating sediment to ecological impacts, it is important that turbidity predictions be modeled as accurately as possible. No current model includes turbidity as an output parameter, but the models that have been suggested as alternatives all predict sediment concentrations and sediment size distributions as output information. It has been suggested that turbidity can be related by simple regression relations to TSS, particularly for the finer portion. In a study of individual soil series, Rogers and Blalock (1991) indicate that for an individual soil horizon, 88-99% of the variability in turbidity can be explained by the TSS. For samples of more than one horizon, 81-91% of the variability in turbidity can be explained with mean errors varying between 22-32% for these composite analyses. Data further suggest that turbidity in NTU's can be estimated using a power function of the form, $NTU = aTSS^b$, where a and b are regression coefficients and TSS is total suspended solids in mg/l. Considerable variation was observed between both the field and laboratory values of "a and b," i.e., regression coefficients for "a" ranged from 1.84-107. This suggests that simple linear regression is not generally desirable, particularly for watersheds with multiple soil series where primary source areas may vary from storm to storm because of construction scheduling, etc.

The bottom line on this is that accurate computation of turbidity from suspended solids will require a more physically based relationship that accounts for the optical properties of sediment as well as the quantity of sediment.

Economics

An optimal analysis of the cost of the EP and SC systems must be made in order to select the system which has least total cost to the developer and society in general while meeting the turbidity standards under design conditions. Thus, the output of the model must be in a form such that these computations can be readily made. These may require some modification of the currently available model outputs.

RECOMMENDATIONS

After considering the characteristics of all the models surveyed, the following conclusions were reached about their overall capabilities:

1. SEDIMOT III is the most current model in terms of computational capability, stability of predictions, utilization of appropriate prediction technology for erosion prevention and sediment control, and variety of control technologies which can be evaluated. It is consistent with many of the routines employed by the latest and most sophisticated watershed hydrology and sedimentology model known as WEPP, but does not employ the rectangular hydrograph and sedimentgraph simplifications utilized in WEPP for ease of computation. It employs the much improved WEPP hydraulic routines for outlet structures and hydraulic routing but maintains the needed complexity of CSTRS utilized in SEDIMOT II and SEDCAD. A channel erosion routine has been employed utilizing a modification of the WEPP technology that can be utilized to predict concentrated flow erosion, a major component of sediment yield in many watersheds experiencing construction activity. Finally, it employs a more physically-based sedimentation procedure for small controls that were not available when SEDIMOT II and SEDCAD were developed. The major drawback to SEDIMOT III is the lack of a user-friendly interface. A Windows 95-based interface is currently being developed with version 1.0 nearing completion. If SEDIMOT III is utilized for this project, evaluation and modification of the interface will need to be a part of the activity. Modifications will need to be made to the model to predict turbidity and economics. Model inputs are very similar to SEDIMOT II and SEDCAD+ which have been widely applied to urban watersheds undergoing construction. Thus users should not have difficulty generating the inputs. The model was used to develop the Design Aids utilized in South Carolina.

2. SEDCAD+, V3 has the best developed user interface currently available. The current DOS version allows the user to utilize a number of peripheral devices such as digitizers, plotters, and printers. Routines have been included to allow the user to more easily input slopes, areas, slope lengths, volumes, etc. Utilities are available to design stable channels and outlet protection. The computational procedures in the model are essentially those of SEDIMOT II, with their inherent limitations, including fixed time steps, discrete stage area and stage discharge inputs, and limited built-in capability for evaluation of small controls. Evaluation of concentrated flow erosion is not a possibility for the model. In addition, the calculation of sediment deposition between structures is based on the MUSLE routine, which is not widely accepted. The model will need to be modified to predict turbidity and evaluate economics. The model has been widely used for urban watersheds undergoing construction.

3. SEDIMOT II has the same basic problems that are present in SEDCAD. In addition, it has a user interface that is acceptable, but not as sophisticated as SEDCAD. If used on this project, it will need to be modified to predict turbidity and to evaluate economics. The model has been widely used for urban watersheds undergoing construction.

4. WEPP is the model developed to replace the Universal Soil Loss Equation and watershed hydrology and sedimentology models used by the NRCS. The model is a very sophisticated continuous simulation model that can evaluate hillslope erosion and route sediment through to reservoirs and sediment control structures. The hydraulic routines are state of the art as are the hydrologic procedures. Since the model uses continuous simulation, simplification of the hydraulic and sediment routing procedures were made to facilitate computational speed including the assumption of rectangular hydrographs and sedimentgraphs. Sediment routing procedures were simplified as well to a single reactor model. The procedures are primarily focused on agricultural production operations and require an extensive database for input. The user interface is somewhat cumbersome. The model could be utilized for urban watersheds but there is no experience in its use for this purpose. It would need to be evaluated for urban areas and modified to predict turbidity and to evaluate economics.

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MATRIX I - HYDROLOGY, SEDIMENTOLOGY, SIZE DISTRIBUTION

ACRONYM	*NAME*	*HYDR*	*SED YIELD*	*SED SIZE*	*SOURCE*
AGNPS	Agricultural Non-Point Source Pollution Model	Y	Y	Y	1
ANSWERS	Aerial Non-Point Source Watershed Environmental Response Simulation	Y	Y	Y	2
Auto-QI	Automated Q-IIL Urban Drainage Area Simulator	Y	Y	?	3
BASIN	Basin Scale Nutrient Delivery Model	Y	N	N	4
CREAMS/GLEAMS	Chemicals and Runoff in Agricultural Management Systems	Y	Y	Y	5
DR3M	Distributed Routing Rainfall Runoff Model	Y	N	N	6
DR3M-QUAL	Distributed Routing Rainfall Runoff Model-Quality	Y	?	?	7
FESHM	Finite Element Sediment Hydrology Model	Y	Y	Y	8
FESWMS-2DH	Finite Element Surface Water Modeling System - 2D Horizontal Hydraulics	Y	N	N	9
FHWA	Federal Highway Administration Model	Y	N	N	10
GWLF	Generalized Watershed Loading Functions	Y	Y	?	11
HEC1	Flood Hydrograph Model	Y	N	N	12
HEC5Q	Simulation of Flood Control & Conservation Systems	N	N	N	13
HSPF	Hydrological Simulation - FORTRAN	Y	Y	Y	14
NPSMAP	Nonpoint Source Model for Analysis and Planning	Y	N	N	15
P8-UCM	Urban Catchment Model	Y	N	N	16
QUAL2E	Enhanced Stream Water Quality Model	N	N	N	17
RUSLE	Revised Universal Soil Loss Equation	N	Y	N	18
SEDCAD+, V3	Civil Software Version of SEDIMOT II	Y	Y	Y	19
SEDIMOTII	Sedimentology by Distributed Modeling Techniques - Version II	Y	Y	Y	20
SEDIMOTIII	Sedimentology by Distributed Modeling Techniques - Version III	Y	Y	Y	21
SIMPLE (STORM)	Nonpoint Source Simulation Model	Y	Y	Y	22
SIMPTM	Simplified Particle Transport Model	Y	Y	Y	23
SLAMM	Source Loading and Management Model	Y	Y	?	24
SLOSS-PHOSH	Sediment and Phosphorus Prediction	N	Y	?	25
STORM	Storage, Treatment, Overflow, Runoff Model	Y	Y	?	26
SWMM	Stormwater Management Model	Y	Y	?	27
SWRRBWQ	Simulation for Water Resources in Rural Basins	Y	Y	Y	28
TR55	Urban Hydrology (NRCS)	Y	N	N	29
TR55 W SED (PROP)	Urban Hydrology with Sediment (Proposed)	Y	Y	Y	30
WASP5	Water Quality Analysis Simulation Progra	N	N	N	31
WEPP (WSHED)	Water Erosion Prediction Project Model (Watershed Version)	Y	Y	Y	32
WMM	Watershed Management Model	Y	N	N	33
WQRRS	Water Quality for River Reservoir Systems	N	N	N	34

MATRIX II - SECOND SCREENING LEVEL

TYPE OF EROSION/SEDIMENT PREDICTION

ACRONYM	*NAME*	*Deliv Ratio/ Sed Yld*	*Erosion Prevent Eval*	*Sediment Control Evaluation*	
				Reservoir/ Pond	*Small Controls*
AGNPS	Agricultural Non-Point Source Pollution Model	Y	Y	N	N
ANSWERS - 2000	Aerial Non-Point Source Watershed Environmental Response Simulation	Y	Y	N	N
Auto-QI	Automated Q-IILLUDAS	N	N	N	N
CREAMS/GLEAMS	Chemicals and Runoff in Agricultural Management Systems	Y	Y	N	N
DR3M-QUAL	Distributed Routing Rainfall Runoff Model-Quality	*	*	*	*
FESHM	Finite Element Sediment Hydrology Model	Y	Y	N	N
GWLF	Generalized Watershed Loading Functions	N	Y	N	N
HSPF	Hydrological Simulation Program-FORTRAN	Y	N	N	N
SEDCAD +,V3	Civil Software Version of SEDIMOT II	Y	Y	Y	N/Y
SEDIMOTII	Sedimentology by Distributed Modeling Techniques - Version II	Y	Y	Y	N/Y
SEDIMOTIII	Sedimentology by Distributed Modeling Techniques - Version III	Y	Y	Y	Y
SIMPLE (STORM)	Nonpoint Source Simulation Model	Y	Y	N	N
SIMPTM	Simplified Particle Transport Model	Y	?	N	N
SLAMM	Source Loading and Management Model	N	N	N	N
STORM	Storage, Treatment, Overflow, Runoff Model	N	N	Y	N
SWMM	Stormwater Management Model	N	N	N	N
SWRRBWQ	Simulation for Water Resources in Rural Basins	Y	Y	Y	N
TR55 W SED (PROP)	Urban Hydrology with Sediment (Proposed)	N	N	Y	Y
WEPP (WSHED)	Water Erosion Prediction Project Model (Watershed Version)	Y	Y	Y	Y

*****Additional data being sought from USGS.

MATRIX III - FINAL MODEL CHARACTERISTICS

MODEL CHARACTERISTICS NEEDED	***SEDCAD+ V3***	***SEDIMOT II***	***SEDIMOT III***	***WEPP (WSHD)***
Type Simulation				
• Single storm	Y	Y	Y	?
• Multiple storm	Y	N	N	Y
Predict sediment discharge				
• Rill and interrill	Y	Y	Y	Y
• Concentrated flow	N	N	Y	Y
• Predict sediment size distribution	Y	Y	Y	Y
• Predict turbidity	N	N	N	N
Hydraulic computations				
• Variable time step to allow for small storage/large discharge	N	N	Y	Y
• Continuous functions for stage discharge & area	N	N	Y	Y
• Drop inlet	Y	Y	Y	Y
• Slotted risers	Y	N	Y	Y
• Slotted risers with rock fill wrapping	N	N	N	N
• Culverts outlets	Y**	N	Y	Y
• Open channel spillways - with control section	Y**	Y	Y	Y
• Open channel spillways - Without control section	Y**	Y	Y	Y
Evaluate impact of small controls				
• Rock fill checkdam	Y*	Y*	Y	Y
• Filter fence	N	N	Y	Y
• Straw bales	N	N	Y	Y
• Inlet filters	N	N	N	N
Evaluate impact of on site controls (erosion prevention)				
• Mulch (varying types)	Y	Y	Y	Y
• Vegetated cover	Y	Y	Y	Y
• Timing of establishment of vegetation	N	N	N	Y
• Geotextile blankets	Y	Y	Y	Y
• Channel bank stabilization	N	N	Y	Y
• Grade control structures	N	N	N	N
Account for instream flow above and below discharge point	N	N	N	N
History of use on urban watersheds	Y	Y	Y	N
Economic analysis capability	N	N	N	N

* Algorithms are not physically based or verifed. At time of model development, they were the only ones available. More recent physically based models are available.
** The stability and accuracy of these procedures remain in question. Further information is needed.

Table 1. List of Search Keywords for Chattahoochee-Flint Literature Search.

- Aquatic Macroinvertebrates
  - Sediment
  - Water quality
  - Turbidity
  - Siltation

- Best Management Practice
- Erosion
  - control
  - controls
  - prediction
  - models
  - mathematical models
  - modeling
  - prevention
  - regulations
  - costs
  - on-site control
- Fish
  - Turbidity
  - Reproduction impacts
  - Siltation
  - Sediment
  - Habitat degradation
  - Water quality
- Chattahoochee
- Piedmont
  - geography
  - physiography
  - soils
  - water quality
  - hydrology
  - sediment concentration
  - rivers
  - watersheds
  - basins
  - hydrologic soil groups
  - curve numbers
  - runoff
  - flooding
- Pollution
  - NPS
  - site
- Sedimentation
  - controls
  - small controls
  - reservoirs
  - detention reservoirs
  - check dams
  - filter fence
  - porous structures
  - vegetative filters
  - yield
  - trapping efficiency
  - size
  - size distribution
- Soil Erosion
- Soil Loss
- Sediment
  - control
  - controls
  - small controls
  - reservoirs
  - detention reservoirs
  - check dams
  - filter fence
  - porous structures
  - vegetative filters
  - yield
  - trapping efficiency
  - size
  - size distribution
  - sediment graph
  - systems
  - models
  - mathematical models
  - transport
  - deposition
  - modeling
  - concentration
  - properties
  - prediction
  - stream
  - regulations
  - off-site controls
- Site characterization
- Turbidity
  - instruments
  - measurements
  - standards
  - sediment concentration
  - theory
- Water quality
  - in-stream
  - performance
  - standards
- Urban
  - pollution
  - runoff
  - nonpoint source
  - construction and pollution
  - modeling
  - development and pollution