

One-Dimensional Hydrodynamic/Sediment Transport Model for Stream Networks

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Notice

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Abstract

This technical report describes a new sediment transport model and the supporting post-processor, and sampling procedures for sediments in streams. Specifically, the following items are described herein:

- EFDC1D - This is a new one-dimensional hydrodynamic and sediment transport model that can be applied to stream networks. The model code and two sample data sets are included on the distribution CD. The User Manual is published as a separate report (Hamrick 2001). EFDC1D can simulate bi-directional unsteady flows and has the ability to accommodate unsteady inflows and outflows associated with upstream inflows, lateral inflows and withdrawals, groundwater-surface water interaction, evaporation and direct rainfall. The model also includes representation of hydraulic structures such as dams and culverts. For sediment transport, the model includes settling, deposition and resuspension of multiple size classes of cohesive and noncohesive sediments. The bed is represented by multiple layers of mixed sediment classes. A bed consolidation model is implemented to predict time variations of bed depth, void ratio, bulk density and shear strength. The sediment bed representation is dynamically coupled to the cross-sectional area representation to account for area changes due to deposition and resuspension.
- GenScn - The interactive computer program *GENeration and analysis of model simulation SCeNarios* (GenScn) was modified to read in one of the output files from EFDC1D, namely the “dump1d.out” file. This file contains simulated time series of parameters such as water surface elevation, temperature, salinity, discharge, cross-sectional area and wetted perimeter, concentrations of suspended cohesive and non-cohesive sediment, and average bed shear stress at each computational cell. Time series plots of these parameters can be generated for any computational cell. The modified version of GenScn is also included on the distribution CD.
- Another task in this project was to link the EFDC1D hydrodynamic and sediment transport model with HSPF (Bicknell *et al.* 1997) to provide a more valid flow/sediment transport modeling tool for development of TMDLs in watersheds that experience significant nonpoint source impacts. While complete integration of EFDC1D with HSPF is feasible, it is a task that requires: 1) additional study to determine the advisability and method of integration, 2) additional 1-D model code testing and refinement, and 3) more resources than were available in this effort. As such, a linkage program was developed to reformat the output of HSPF for subsequent input to the stand-alone EFDC1D model. This linkage program is also included on the distribution CD.
- To perform sediment transport modeling, a comprehensive set of hydrologic, hydraulic, and sediment data must be collected/measured in the water body to be modeled. A generic field study work plan, including sampling procedures, is given as an example of the type of field study that should be performed to collect these data.

Foreword

The National Exposure Research Laboratory's Ecosystems Research Division (ERD) in Athens, Georgia, conducts research on organic and inorganic chemicals, greenhouse gas biogeochemical cycles, and land use perturbations that create direct and indirect, chemical and non-chemical stresses, exposures, and potential risks to humans and ecosystems. ERD develops, tests, applies and provides technical support for exposure and ecosystem response models used for assessing and managing risks to humans and ecosystems, within a watershed / regional context.

The Regulatory Support Branch (RSB) conducts applied research and development, and provides technical support and assistance to customer Program and Regional Offices, States, Municipalities, and Tribes. As an outreach for ERD research on the occurrence, movement, transformation, impact, and control of environmental contaminants, RSB develops management and engineering tools to help environmental resource managers achieve environmental goals through comprehensive watershed management. Exposure models are distributed and supported via the EPA Center for Exposure Assessment Modeling (CEAM).

The development and release of EFDC1D and the supporting programs described herein is in support of the Agency's Total Maximum Daily Load (TMDL) program as required by the Clean Water Act. EFDC1D is a state-of-the-science one-dimensional hydrodynamic and sediment transport model that can be used to model sediment impacted streams and rivers for determination of sediment TMDLs. The development of EFDC1D was funded by EPA's Office of Research and Development (ORD), but resulted from a cooperative effort between ORD and the Office of Water's Office of Science and Technology.

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I. Introduction

I.A Background

Excessive loads of nutrients, sediments and pathogens are being transported by overland drainage and riverine flow to many lakes, reservoirs and estuaries. The Clean Water Act of 1987 (CWA) requires the EPA to develop, revise and review effluent limitations and standards for a technology based industrial point source water pollution control program under Section §304(m). Additionally, for water bodies, e.g., streams, rivers, lakes, reservoirs and estuaries, that have been classified by State Environmental Regulatory Agencies as impaired, Section §303(d) of the CWA requires the States to develop Total Maximum Daily Loads (TMDLs) for the contaminant(s) of concern (COC) considering point sources, nonpoint sources, and a margin of safety for uncertainty. The goal of TMDL analysis is to provide a defensible, scientific approach that the States can use to establish water quality based controls for impaired waters. The main goal of sediment TMDL analysis is to protect designated or existing uses of natural resource systems in watersheds by:

- a. Characterizing properly functioning watershed processes that influence the erosion, transport and storage of sediment;
- b. Evaluating the degree to which the current and expected future functioning of these processes is impaired. The impairment usually results from the transport of excessive sediment loads to water bodies (e.g., streams, lakes) within the watershed. The excess sediment loads are usually generated by changes in watershed processes that result from both natural (e.g., wildfires) and anthropogenic (e.g., logging, agriculture) causes; and
- c. Identifying land and water management restoration actions that should be implemented to restore the proper functionality of the impacted watershed processes.

The Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) was developed to aid States in the targeting and assessing water body segments which fail to meet water quality standards. In addition, BASINS also helps in TMDL development by providing nonpoint and water quality modeling tools. These tools make it possible to predict the effect of allocating allowable pollutant loads among point and nonpoint sources with the goal of meeting water quality standards. BASINS is suitable for many other applications beyond developing TMDLs. Its wide variety of data layers, modeling tools, its ability to query the underlying databases, and its capability to display the results on a map gives it broad applicability for watershed management or community-based environmental protection. Since BASINS is built on ArcView, an industry standard GIS platform, users can also incorporate their own data to the system so that BASINS will more accurately represent local conditions.

BASINS is a suite of interrelated components developed to perform watershed and water quality analysis. These components are grouped into five categories: (1) national databases; (2) assessment tools (TARGET, ASSESS, and Data Mining) for evaluating water quality and point

source loadings at a variety of scales; (3) utilities including local data import, land-use and DEM reclassification, watershed delineation, and management of water quality observation data; (4) watershed and water quality models including NPSM (HSPF), TOXIRROUTE, and QUAL2E; and (5) post processing output tools for interpreting model results. The databases and assessment tools in BASINS are directly integrated within an ArcView GIS environment.

The Nonpoint Source Model (NPSM) in BASINS is HSPF (The Hydrological Simulation Program - FORTRAN). HSPF is a set of computer codes that can simulate the hydrologic, and associated water quality for both conventional and toxic organic pollutants, processes on pervious and impervious land surfaces, and in streams and well-mixed impoundments. HSPF incorporates watershed-scale ARM and NPS (nonpoint source) models into a basin-scale analysis framework that includes fate and transport in one-dimensional stream channels. It is a comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in the modeled watershed. HSPF simulates the transport, deposition and scour of three inorganic sediment types (sand, silt, and clay) in streams and well-mixed reservoirs. In addition, HSPF simulates the transport of a single organic chemical and transformation products of that chemical. Flow and sediment transport related assumptions/limitations included in HSPF are the following:

1. Scour or deposition of inorganic sediment does not affect the hydraulic properties of the channel.
2. Sand, silt, and clay deposit in different areas of the bed; consequently, the deposition or scour of each material is not linked to the other fractions (i.e., "armoring" is not modeled).
3. Longitudinal movement of bed sediments is not modeled.
4. The rates of deposition and scour of cohesive sediments (clay and silt) are calculated using the expressions given by Krone (1962) and Partheniades (1962), respectively.
5. The settling velocity, critical shear stress for deposition, critical shear stress for scour, and erodibility coefficient for each fraction of cohesive sediment that is modeled have to be specified by the user.
6. Bed structure (i.e., variation of bed density and bed shear strength) with depth below the water-bed interface is not modeled.
7. Primary consolidation of cohesive sediment beds is not represented.
8. Flow is assumed to be unidirectional in the modeled stream/river reaches. Thus, tidal (oscillatory) flow cannot be simulated.
9. User has to supply the evaporation rate time series as opposed to having this calculated internally.
10. Outflow from each stream reach (and thus the average velocity), and the advection of suspended/dissolved constituents, is determined using the kinematic wave routing method as opposed to solution of the governing equations (i.e., conservation of mass and conservation of linear momentum).
11. There is a fixed relation between depth (at the deepest point in the reach), surface area,

- and volume. Thus, the shape of the stream's cross-section in a reach is not explicitly taken into account in routing the flow and determining the transport of sediment through that reach, and the shape of a reach does not influence the flow in the upstream reach.
12. Water density is not a function of water temperature, salinity, or suspended sediment concentration.
 13. The bed shear velocity and shear stress is calculated using the assumption that the slope of the energy grade line is equal to the reach (i.e., bed) slope, and thus, that steady, uniform flow occurs in the reach.
 14. Longitudinal dispersion of transported constituents is not represented.

I.B Project Objectives

The goal of this project is to upgrade the flow and sediment transport routines in HSPF. The existing sediment transport and flow routines in HSPF are simple routing modules, and as such, are limited to steady, uni-direction flows. The specific objectives of this research project designed to accomplish the stated goal are listed below and then described in Section I.C.

1. Develop a new stand-alone one-dimensional (1-D) hydrodynamic and sediment transport model.
2. Describe the sampling procedures for collecting the sediment transport data necessary to perform sediment transport modeling in streams/rivers.

I.C Technical Approach

The proposed methodology to accomplish the objectives given in the previous section is described in this section. The methodology is presented as the following two tasks.

1. Develop a new stand-alone 1-D hydrodynamic and sediment transport model - The new stand-alone model will provide for more accurate simulations of the flow in a stream/riverine network as well as the transport and fate of both in-stream sediments and sediments entering the water body being modeled from nonpoint and point sources. This task, which is being performed via a Work Assignment with Aqua Terra Consultants, Inc., will be accomplished by developing a new stand-alone 1-D unsteady hydrodynamic and sediment transport model. The new model will be tested by the EPA Work Assignment Manager (WAM), Dr. Earl J. Hayter. The components involved in this task are listed below.

Element 1 - Develop and test a stand-alone 1-D model which simulates the flow of water and transport of sediments.

The 1-D model will solve the governing 1-D (cross-sectionally averaged) equations for conservation of mass of water and sediment and linear momentum. Thus, it will be capable of simulating both uni-directional and oscillating (i.e., tidal) flows. Nonpoint and point sources and sinks of water and sediment (including groundwater, precipitation and

evaporation) will be included in the appropriate equations. The 1-D model will be capable of representing a network of streams/channels. In general, a network will be composed of any number of stream reaches, and multiple junctions of these reaches that represent bifurcations and confluences. Boundary conditions for the equations of motion will consist of stage and/or discharge hydrographs, while those for the conservation of sediment mass equation will be total sediment load hydrographs or a user specified sediment flux. Processes/features to be included in the 1-D model are:

- a. Precipitation and evaporation.
- b. Efflux and influx of groundwater to and from the stream reaches, respectively.
- c. Specification and representation in the flow and sediment transport routines of the average cross-sectional shape in each 1-D cell.
- d. The calculated change in bottom elevation (due to scour or deposition) for each cell is taken into account by the hydrodynamic model during the next time-step. Thus, scour and deposition in any cell will affect the hydraulic properties in that cell during subsequent time-steps.
- e. Specification of a representative (or average) bed composition (e.g., grain size distribution, armoring) in each cell.
- f. Water density calculated as a function of water temperature, salinity, and suspended sediment concentration.
- g. Primary consolidation of cohesive sediment (clay and silt) bed should be simulated in each cell using a finite-strain consolidation module. A user-specified flag would indicate whether or not to invoke this module.
- h. In the sediment transport module, longitudinal dispersion of suspended sediment should be simulated. The user should specify whether to use a constant value of the longitudinal dispersion coefficient or a semi-empirical model to calculate the value as a function of local flow properties.
- i. Use state-of-the-art equations for calculating the rates of erosion and deposition and the settling velocity of cohesive sediments. Coagulation and flocculation of suspended cohesive sediments should be explicitly represented in the sediment transport routine.

The stand-alone 1-D model will be thoroughly tested using existing field data from a stream/river system selected by the Contractor and approved by WAM. The field data will be provided by the Contractor to the WAM. A documentation report describing the new model and the testing performed on the model will be produced.

Element 2 - Develop a post-processing program for visualization of the simulated flows and changes in the stream bed resulting from deposition and/or scour of sediments.

Output from the new 1-D model needs to be readable by a post-processing program that graphically displays the spatial and temporal changes in flows and stream bed morphology. The post-processing program must run on a PC running Windows 95, 98, or NT operating systems. In addition, stage, discharge, and total sediment transport load

hydrographs must be generated and displayed at user selected locations in the stream network being modeled. The program must be able to produce color copies of all visualization products.

Element 3 - Report on the recommended approach for incorporation of the new 1-D hydrodynamic and sediment transport model into HSPF.

A report that describes the recommended approach for incorporation of the new 1-D model into HSPF will be produced. The report will document the primary issues and their resolution, and a detailed design/structure of the incorporation.

2. Describe the sampling procedures for collecting the sediment transport data necessary to perform sediment transport modeling in streams/streams - To perform sediment transport modeling in surface waters, a comprehensive set of hydrologic, hydraulic, and sediment data must be collected/measured in the water body (e.g., stream network, river, lake, reservoir, estuary) to be modeled. A generic field study work plan (including sampling procedures) is described as an example of the type of field study that should be performed to collect the necessary data to perform sediment transport modeling. This generic work plan is specific to an inland river/stream network. Thus, some modifications would have to be made to the plan if the surface water body to be modeled was a reservoir, lake, tidal river, or estuary.

II. One-dimensional Hydrodynamic and Sediment Transport Modeling System

II.A. EFDC1D

Hamrick (2001) describes the theoretical and computational aspects of EFDC1D (Environmental Fluid Dynamics Code - One-Dimensional), a box or control volume based one-dimensional hydrodynamic and sediment-contaminant transport model. This document serves as the User Manual for the EFDC1D model. The model is implemented in a stand-alone version and also externally linked to HSPF (Hydrologic Simulation Package: Fortran). The following material was extracted from Hamrick (2001).

Features included in EFDC1D include the following:

1. Box or reach based spatial data structure, compatible with existing HSPF data structure, for representing one-dimensional channel networks.
2. Utilization of water surface elevation dependent descriptions of channel cross-section area, surface width, wetted perimeter and buoyancy centroid, including representation of overbank regions.
3. Bi-directional unsteady flow and the ability to accommodate unsteady inflows and outflows associated with upstream inflows, lateral inflows and withdrawals, groundwater-surface water interaction, evaporation and direct rainfall. The model includes representation of hydraulic structures such as dams and culverts. Downstream boundary conditions include rating curves and time varying water surface elevation.
4. The model includes a generic one-dimensional transport solver for salinity, temperature and multiple sediment and contaminant classes. Longitudinal dispersive transport is represented. Sources and sinks will be represented consistent with continuity constraints.
5. Buoyancy effects due to salinity and temperature are dynamically coupled with the hydrodynamic component using an equation of state. Temperature transport includes a predictive surface heat exchange formulation representing the effects of solar radiation, long wave back radiation, and latent and sensible heat transfer.
6. For sediment transport, the model includes settling, deposition and resuspension of multiple size classes of cohesive and noncohesive sediments. The bed is represented by multiple layers of mixed sediment classes. A bed consolidation model is implemented to predict time variations of bed depth, void ratio, bulk density and shear strength. The sediment bed representation is dynamically coupled to the cross-sectional area representation to account for area changes due to deposition and resuspension.

7. The overall approach taken in developing the flow and sediment transport model was to minimize code development by the utilization of existing process subroutines from the multi-dimensional EFDC (Environmental Fluid Dynamic Code) model (Hamrick 1992; Hamrick 1996; Hamrick and Wu 1997).

Process routines from the EFDC model are utilized to satisfy the following requirements:

1. A fully dynamic one-dimensional solver for the momentum and continuity equations with channel cross-section area, surface width, wetted perimeter and buoyancy centroid as functions of the water surface elevation.
1. Time varying upstream inflows, and lateral inflows and withdrawals including corresponding sediment loads.
2. Hydraulic control structures and rating curve boundary conditions.
3. Time varying downstream boundary conditions for water surface elevation, salinity, temperature and sediment concentration.
4. A generic one-dimensional transport solver utilizing a monotone, positive definite scheme which minimizes numerical diffusion
5. A fully predictive surface heat exchange formulation which includes evaporation.
6. An equation of state relating density to salinity and temperature.
7. A multiple class sediment processes module that incorporates a wide variety of parameterization for settling, deposition and resuspension of cohesive and noncohesive sediments.
8. A multiple layer bed module that includes a bed consolidation solver and parameterizations relating void ratio, bulk and dry density, and shear strength.

Utilizing the above existing routines, code development focused on the main driver program, input and output routines for the stand alone version of the model, interface routines for the HSPF embedded version of the model, and a new hydrodynamic solver optimized for one-dimensional channel network applications. The user manual (Hamrick 2001) describes the theoretical and computational formulations of the governing hydrodynamic and transport equations, and model input and output files. Before attempting to use EFDC1D, the user manual should be read.

II.B GenScn

The interactive computer program *GENeration and analysis of model simulation SCeNarios* (GenScn) was developed by Aqua Terra Consultants, Inc. “to create simulation scenarios, analyze results of the scenarios, and compare scenarios (Kittle *et al.* 1998). As a part of this Work Assignment, GenScn was modified to read in one of the output files from EFDC1D, namely the “dump1d.out” file. This is an ASCII file that contains time series of the following parameters (in SI units) for each computational cell:

- L1D - Cell index number from cellnet.inp
- L - EFDC1D single count computational index
- I - EFDC1D I double count computational index
- J - EFDC1D J double count computational index
- X - cell center east coordinate from cellnet.inp
- Y - cell center north coordinate from cellnet.inp
- BEL - cell bottom elevation
- DEP - cell depth relative to lowest point in cross-section
- AREA - cell cross-section area
- WPER - cell wetted perimeter
- BSRF - cell water surface width normal to flow direction
- VEL - velocity (negative indicates downstream direction)
- Q - discharge (negative indicates downstream direction)
- SAL - cell salinity
- TEM - cell temperature
- SED - concentration of cohesive sediment (1st class if multiple classes)
multiple classes)
- SND1 - concentration of 1st class of noncohesive sediment
- SND2 - concentration of 2nd class of noncohesive sediment
- SEDB - bed mass per unit area of 1st class of cohesive sediment
- SNDB1 - bed mass per unit area of 1st class of noncohesive
sediment
- SNDB2 - bed mass per unit area of 2nd class of noncohesive
sediment
- TAUBED - bed shear stress

A copy of the dump1d.out file from the Brandywine Creek simulation is included on the distribution CD. Instructions to install and use the modified version of GenScn to view the time series in the dump1d.out file are included in Appendix B. The two installation files for GenScn are also included on the CD.

Figure 1 shows the Brandywine Creek watershed, located in the Christina River Basin of Delaware and Pennsylvania. Figure 2 shows the GenScn generated schematic of the Brandywine Creek network. The downstream end of the main stem, i.e., Brandywine Creek, is located in the upper right-hand portion of this figure. The main stem, segment 1, corresponds to the lower portion of the creek extending upstream to a dam just below the confluence of the East and West

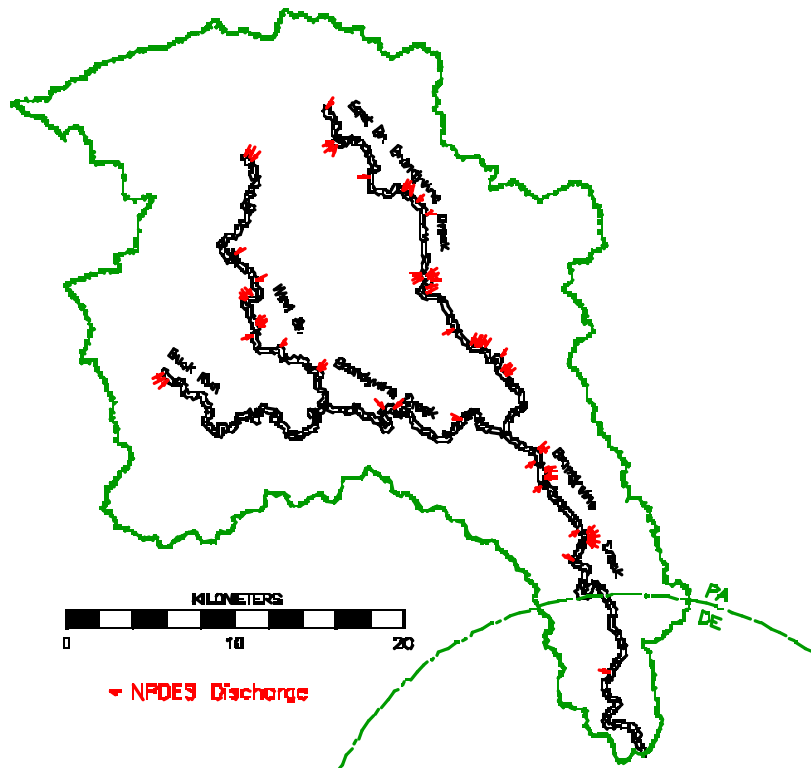


Figure 1. Brandywine Creek and Tributaries (Hamrick 2001)

Branches. Segment 2, corresponding to the East Branch, connects to segment 1 by a control structure. The lower portion of the West branch, segment 3, joins the East Branch segment 2, by a free flowing connection. Segment 3 extends upstream along the West Branch to a dam just below the confluence with Buck Run. Segment 4 is along the West Branch to a dam just beyond the confluence with Buck Run. Buck Run, segment 5, joins segment 4 by a free flowing connection. Segments 6, 7 and 8 represent the remaining portion of West Branch and are separated by dams.



Figure 2. GenScn Generated Schematic of the modeled Brandywine Creek Network

Figures 3 and 4 below show the time series generated by GenScn for Q and TAUBED at cell number 25 in the Brandywine Creek network. Similar time series plots can be generated for the other parameters listed above.

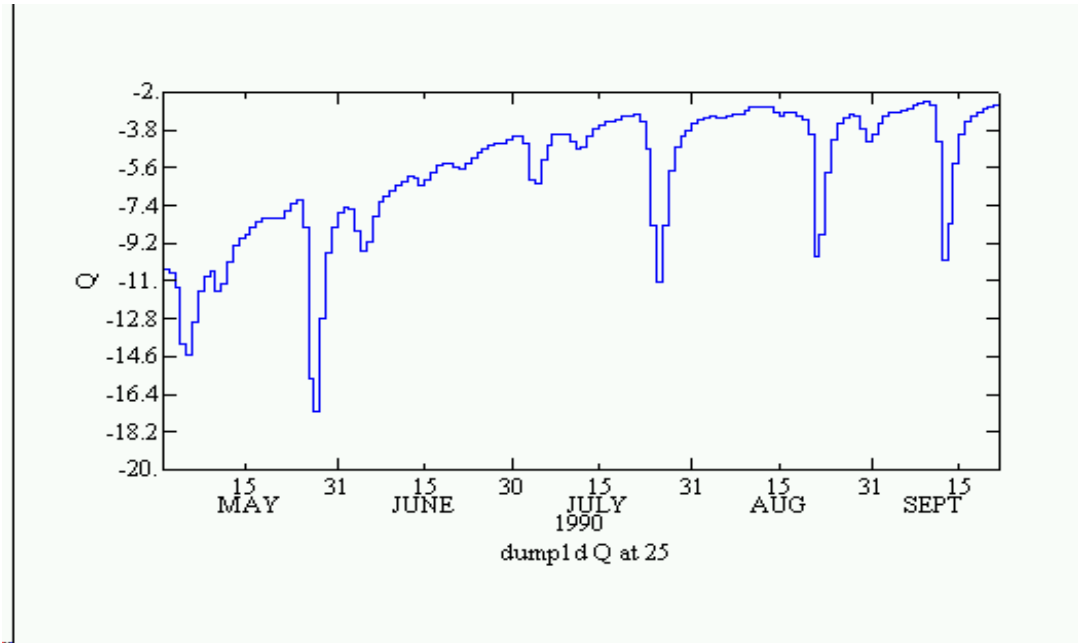


Figure 3. Discharge (Q) time series at Cell 25 in the Brandywine Creek Network

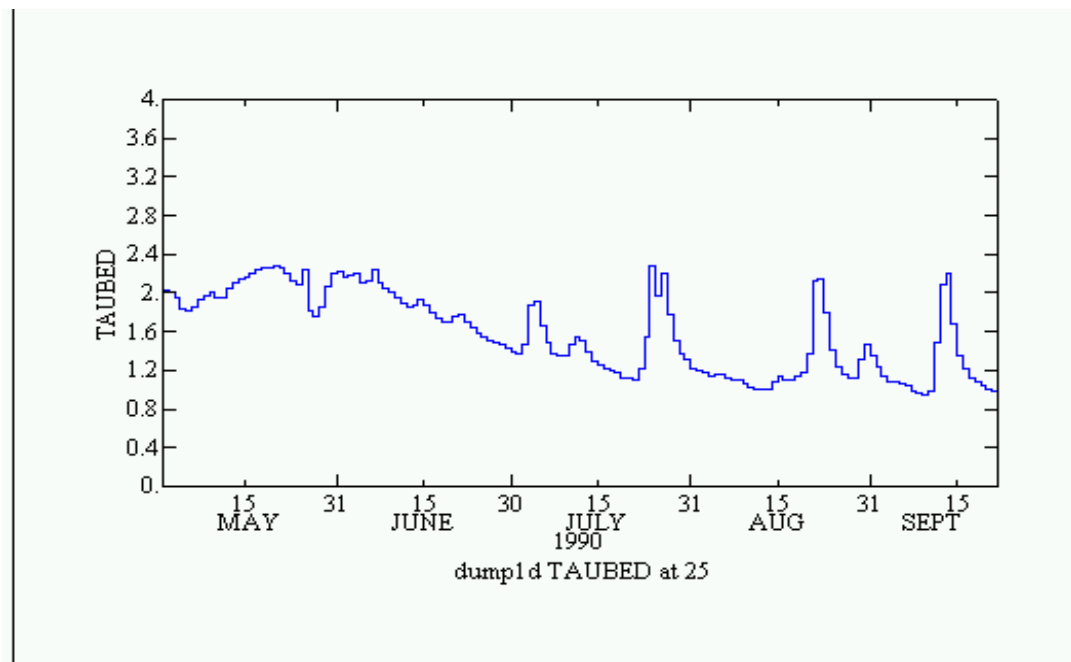


Figure 4. Bed Shear Stress (TAUBED) time series at Cell 25 in the Brandywine Creek Network

II.C Report on Linkage of EFDC1D to HSPF

The purpose of this task was to report on the recommended approach for incorporation of the new 1-D hydrodynamic and sediment transport model into HSPF (Bicknell *et al.* 1997). The ultimate goal of this effort (that is beyond the scope of this study) is to provide a more valid flow/sediment transport modeling tool for development of TMDLs in watersheds that experience significant nonpoint source impacts. While integration of the 1-D model that was developed in this study with HSPF is feasible, it is a task that requires: 1) additional study to determine the advisability and method of integration, 2) additional 1-D model code testing and refinement, and 3) more resources than were available in this effort. The first requirement, i.e., determination of the advisability and method of incorporation is briefly addressed below. The remaining portions of this section describe the currently available methodology for linkage of the two models using a bridge or linkage program to reformat the output of HSPF for subsequent input to the stand-alone 1-D flow and sediment transport model.

II.C.1 Issues Related to Code Integration of HSPF and EFDC1D

Analysis of the two models indicated three major problems with complete integration within a single program. These problems relate to the fundamental simulation schemes and architectures (including source code standards) and their I/O management methods.

The architecture of HSPF is an important factor in the issue of code integration. The program imposes a strict upstream-to-downstream direction on movement of mass. Also, it simulates each component of the watershed (moving downstream) for a portion of the run time span, and saves the interim results in memory until the next portion of the run span. This makes it problematic to interact directly with a module that permits material to move upstream, and which effectively solves the entire physical system simultaneously. "Full" integration would require HSPF to complete its run; save the results for all watershed components over its simulation time span; invoke the EFDC1D module and provide the results to EFDC1D during its subsequent simulation. It is not feasible to integrate the two models more completely than this - given the fundamental architectures and simulation schemes of the two programs - without a complete reworking of HSPF.

A second issue relates to the time series management schemes of the two programs, which are fundamentally different. HSPF includes relatively complex, comprehensive, and well-isolated modules for handling input, internal transfer, and output of time series data. EFDC1D utilizes simple time series management, and the time series I/O functions are widely distributed throughout the code. Modifying an HSPF-integrated EFDC1D to utilize the HSPF time series modules would require major reworking of EFDC1D, with changes throughout the code.

A similar difficulty occurs with inputs other than time series. EFDC1D has a large number of input options/parameters, but its input processing routines utilize relatively simple software techniques. While general incorporation of new inputs into the HSPF data structures is straightforward, the complexity of EFDC1D's options, and the large amount of required stream characterization data and the spatial interface with the HSPF watershed would necessitate

development of a logically complex input routine and several new sophisticated input formats and data structures. The alternative, i.e., direct incorporation/adaptation of EFDC1D's input structures/formats into HSPF would not be possible within the HSPF code guidelines. While this strict adherence to the original HSPF structure, methodology, and standards slightly limits its flexibility, it has been very useful in the long-term maintenance, viability, and usability of the system. Similarly, our experience indicates that major changes to a complex code such as EFDC1D would make it less amenable to maintenance/error correction and future enhancement by its original developer. In summary, full integration is a difficult task under the constraints of the existing structures and methods of the two models.

II.C.2 Linkage of HSPF and EFDC1D using MKINP1D

The program MKINP1D was written to transform HSPF time series output files and write the corresponding input files for EFDC1D. It is based on Tetra Tech's existing linkage program MKINP, which links HSPF with the full 3-D version of EFDC, and much of the feel and format of that program has been preserved. This document assumes that the user is familiar with the usage, input formats, and terminology of both models.

Although EFDC1D is intended primarily to handle flow and sediment, the linkage program is also capable of passing heat and a generic toxic chemical (normally simulated in HSPF with the GQUAL module in the stream and the PQUAL/IQUAL or PEST modules on the land surface). These two constituents are modeled by the portions of the original EFDC code that remain active in EFDC1D. Salinity and shellfish larvae can also be modeled by EFDC and EFDC1D, but since they are not generally represented in HSPF, they were omitted from consideration by MKINP1D.

The approach used in MKINP1D is the following. MKINP1D reads flow volumes and constituent loadings that have been generated by HSPF, transforms them to the flow rates and constituent concentrations needed by EFDC1D, and produces EFDC1D input files containing time series of loadings to the specified cells. The HSPF time series output is in "PLTGEN" format, which is a simple column-dependent text file with one time step per line at a constant interval, and one or more columns containing results from the run. Figure 5 shows this methodology in the form of a flowchart.

Each PLTGEN file can be applied to one or more EFDC1D cells. If applied to multiple cells, the loads from the file are divided equally among all target cells. Normally, RCHRES (stream) output is applied to a single EFDC1D cell at an upstream boundary, while diffuse inputs from PERLND and IMPLND are divided equally among a set of cells along a stream.

A PLTGEN file may contain only the loadings from a single HSPF reach or land segment, or it may contain aggregate loading from several land segments or reaches that

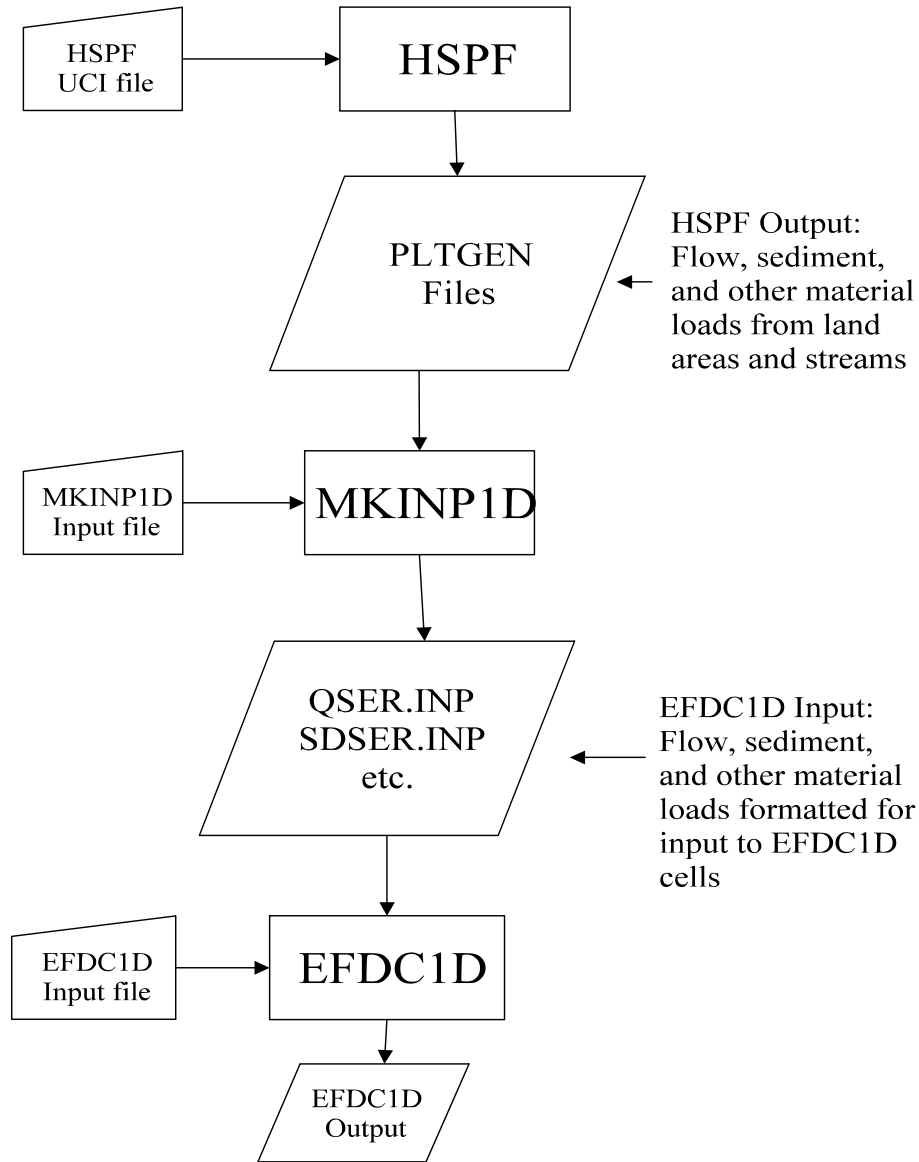


Figure 5. Flow Diagram of HSPF - EFDC1D Linkage

contribute to the same cell or group of cells. For instance, if two small tributaries are represented as reaches in HSPF, and they both flow into the same EFDC1D cell, then you may generate a single PLTGEN file that contains the total loadings from the two streams.

Likewise, you may have a set of several PERLND and IMPLND segments that represent the different land use types in an area that provides diffuse inputs to a group of EFDC1D cells that make up a portion of a river. In this case, you can sum up the loadings from all of these land uses, with each segment's loadings weighted by its respective area, and produce a single PLTGEN file that accounts for them all.

MKINP1D allows the loadings in any given file to be divided among up to 20 EFDC1D cells, and a total of 300 cells can be targeted from all PLTGEN files. The total number of PLTGEN files that can be processed is 100.

HSPF Setup

The HSPF run should be set up to provide output of the desired constituents:

Table 1. HSPF Outputs Needed for EFDC1D

Quantity	Units	PERLND*	IMPLND*	RCHRES
Flow	acre-feet or Mm ³	PERO	SURO	ROVOL
Sediment	tons or tonnes	SOSED	SOSLD	ROSED(1-3)
Heat	BTU or kcal	POHT	SOHT	ROHEAT
Toxic	lb or kg	POQUAL/POPEST	SOQUAL	TROQUAL

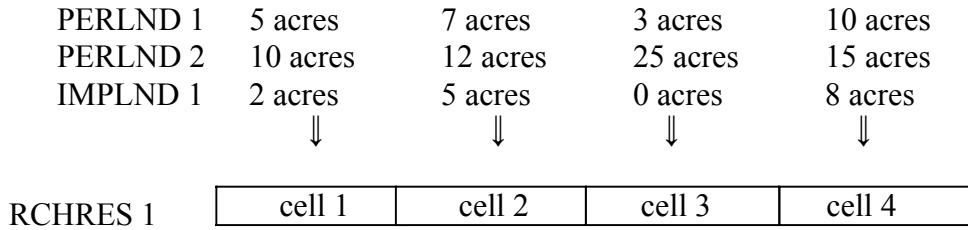
The PERLND and IMPLND variables are multiplied by the area and converted to the appropriate units using standard HSPF time series linkages. This step is normally done using the SCHEMATIC and MASS-LINK blocks (see below).

PERLND and IMPLND do not distinguish sediment particle sizes; therefore, the sediment loadings from these operations (SOSED and SOSLD, respectively) are divided into sand, silt, and clay using constant fractions, which are specified in the MKINP1D input file. RCHRES accounts for the transport of these three sizes automatically, so HSPF can provide separate loadings for these.

However, EFDC1D divides sediment sizes somewhat differently from the RCHRES module of HSPF. The HSPF sand, silt, and clay fractions must be mapped to EFDC1D's "noncohesive", "cohesive-1" and "cohesive-2". This is done by an additional set of factors in the MKINP1D input file.

Example HSPF Input Setup

Figure 6. Example Basin Diagram



In this example, a single stream is being modeled. The upstream portion is being represented by HSPF RCHRES # 1, while the downstream end is modeled using four EFDC1D cells. The drainage basin is conceptually divided among three land use types (two pervious and one impervious), with varying amounts of each tributary to each cell. The upstream RCHRES would have additional land areas that drain to it, but those loadings are accounted for in the output from that reach, so it is not included separately.

The relevant portion of the SCHEMATIC block in the HSPF input file might contain the following:

Figure 7. Sample SCHEMATIC Block Input

```

SCHEMATIC
<-Source->          <--Area-->          <-Target->  <ML->  ***
<Name>   #          <-factor-->          <Name>   #    #    ***
RCHRES   1          PLTGEN          1          3
          5.         PLTGEN          2          1
PERLND   1          10.         PLTGEN          2          1
PERLND   2          2.         PLTGEN          2          2
IMPLND   1          7.         PLTGEN          3          1
          12.         PLTGEN          3          1
PERLND   1          5.         PLTGEN          3          2
PERLND   2
IMPLND   1
          etc.
END SCHEMATIC

```

If flow, sediment, and heat are being modeled, then the HSPF MASS-LINK block would contain:

Figure 8. Sample MASS-LINK Block Input

```

MASS-LINK
  MASS-LINK      1
<Srce>      <-Grp> <-Member-><--Mult-->      <Targ>      <-Grp> <-Member-> ***
<Name>      <Name> <Name> # #<-factor->      <Name>      <Name> <Name> # # ***
PERLND      PWATER PERO      0.0833333      PLTGEN      INPUT MEAN 1
PERLND      SEDMNT SOSED      PLTGEN      INPUT MEAN 2
PERLND      PWTGAS POHT      PLTGEN      INPUT MEAN 3
  END MASS-LINK  1
  MASS-LINK      2
<Srce>      <-Grp> <-Member-><--Mult-->      <Targ>      <-Grp> <-Member-> ***
<Name>      <Name> <Name> # #<-factor->      <Name>      <Name> <Name> # # ***
IMPLND      IWATER SURO      0.0833333      PLTGEN      INPUT MEAN 1
IMPLND      SOLIDS SOSED      PLTGEN      INPUT MEAN 2
IMPLND      IWTGAS SOHT      PLTGEN      INPUT MEAN 3
  END MASS-LINK  2
  MASS-LINK      3
<Srce>      <-Grp> <-Member-><--Mult-->      <Targ>      <-Grp> <-Member-> ***
<Name>      <Name> <Name> # #<-factor->      <Name>      <Name> <Name> # # ***
RCHRES      ROFLOW ROVOL      PLTGEN      INPUT MEAN 1
RCHRES      ROFLOW ROSED 1      PLTGEN      INPUT MEAN 2
RCHRES      ROFLOW ROSED 2      PLTGEN      INPUT MEAN 3
RCHRES      ROFLOW ROSED 3      PLTGEN      INPUT MEAN 4
PERLND      ROFLOW ROHEAT      PLTGEN      INPUT MEAN 5
  END MASS-LINK  3
END MASS-LINK

```

When the HSPF run is made, the PLTGEN operations will correctly write out the time series for use by MKINP1D. The beginning of the first PLTGEN file might contain the following:

Figure 9. Sample PLTGEN File Output

```

SIMU HSPF FILE FOR DRIVING SEPARATE PLOT PROGRAM
SIMU Time interval: 1440 mins          Last month in printout year: 12
SIMU No. of curves plotted: Point-valued: 0 Mean-valued: 5 Total 5
SIMU Label flag: 0                    Pivl: 24 Idelt: 60
SIMU Plot title:
SIMU Y-axis label:
SIMU Scale info: Ymin: 0.0000          Threshold:-0.10000E+31
SIMU Ymax: 150.00
SIMU Time: 20.000 intervals/inch
SIMU Data for each curve (Point-valued first, then mean-valued):
SIMU Label LINTYP INTEQ COLCOD TRAN TRANCOD
SIMU TRIB REACH FLOW 0 7 1 AVER 2
SIMU TRIB REACH SAND 0 7 1 AVER 2
SIMU TRIB REACH SILT 0 7 1 AVER 2
SIMU TRIB REACH CLAY 0 7 1 AVER 2
SIMU TRIB REACH HEAT 0 7 1 AVER 2
SIMU
SIMU
SIMU
SIMU
SIMU Time series (pt-valued, then mean-valued):
SIMU
SIMU Date/time Values
SIMU
SIMU 1995 12 31 24 0-1.0000000E+30-1.0000000E+30-1.0000000E+30-1.0000000E+30
SIMU 1996 1 1 24 0 1.4474289E-02 0.260718 9.5694907E-02 0.1248719

```

The file continues with one line for each time step at the desired interval, which may be the same as the time step of the HSPF simulation or a multiple of the time step. The first 25 lines are a default header generated by HSPF; it is not used by MKINP1D. The first line of numbers (line 26) contains dummy values for the time step prior to the start of the run; it is also ignored.

MKINP1D Input File

EFDC1D requires the input of a separate text file for each constituent modeled; these files have specific names, and the data are stored in different units and formats than HSPF can generate on its own. In order for MKINP1D to create these files, a separate input file (MKINP1D.INP) is needed. The following figure shows this input file for running the bridge program for the sample basin that was discussed in the previous section. It is a simple text file with six sections of input values. Each section consists of a header of comment lines followed by one or more lines of input to be read by the program. The comment lines begin with a “C” in the first column, and the last comment line of each header is also marked by the section number (e.g., the last comment before section 2 begins with “C2”). In the following, each of the sections is followed by a brief description of its contents.

Figure 10. Sample MKINP1D.INP File

```

C-----
C

```

```

C River name = Text title of run
C Note       = Additional information
C
C1 Title (20 Ch)          Note
  'Test HSPF to EFDC1D'   'Flow, sediment, and heat'

```

The titles in Section 1 are for the user's documentation purposes only. They appear at the top of the output files being passed to EFDC1D, such as QSER.INP.

```

C-----
C nhead      = head lines of HSPF input file to be skipped (usually 26)
C sdate      = Start date to extract time series data
C edate      = End date to extract time series data
C nfile      = total input HSPF files: max 100
C units      = unit system of HSPF time series data (1=English, 2= Metric)
C tdelt      = number of minutes per time step of HSPF data (60=hourly, etc.)
C
C2 nhead     sdate          edate          nfile  units  tdelt
    26      1996 01 01 00 00  1996 12 31 24 00    5      1  1440

```

Section 2 contains global information about the linkage. This is an one-year run that reads HSPF output from five PLTGEN files at a daily time step and in English units. The first 26 lines (the default header plus the line of dummy values) are skipped in each PLTGEN file.

```

C-----
C ID         = index number of PLTGEN-format file
C FNAME      = HSPF PLTGEN-format filename
C optype     = 1= total sed only   2=sand/silt/clay
C flo        = column in PLTGEN that is flow (ac-ft or Mm3)
C sed1-3     = columns in PLTGEN that are sediment: (ton or tonne)
C             op=1: sed1=total   sed2=not used sed3=not used
C             op=2: sed1=sand    sed2=silt    sed3=clay
C heat       = column in PLTGEN that is heat input (BTU or kcal)
C tox        = column in PLTGEN that is tox substance input (lb or kg)
C
C3 ID FNAME          op flo sed1 sed2 sed3 heat  tox
    1 "trib_flo.plt"  2  1  2  3  4  5  0
    2 "cell_1_d.plt"  1  1  2  0  0  3  0
    3 "cell_2_d.plt"  1  1  2  0  0  3  0
    4 "cell_3_d.plt"  1  1  2  0  0  3  0
    5 "cell_4_d.plt"  1  1  2  0  0  3  0

```

Section 3 is a list of the PLTGEN filenames, along with a set of flags for each file. The first flag, OPTYPE, tells MKINP1D whether to expect the PLTGEN file to contain only a single time series for sediment (such as generated by PERLND and IMPLND) or to have separate sand, silt, and clay time series. There must be NFILE (Section 2) lines present in this section.

The remaining flags indicate which column, if any, contains each of the possible constituents. PLTGEN column numbers may range from 1 to 20. In this example, all of the files have the flow as the first time series column. The tributary inflow to cell 1 has separate entries for sand, silt, and clay (columns 2-4), and the heat load is in column 5; the diffuse inputs from PERLND and IMPLND

areas to cells 1-4 have a single sediment time series in column 2, with heat in column 3. As we saw in the sample MASS-LINK block above, toxics are not being modeled.

Figure 10. Sample MKINP1D.INP File (completed)

```

C-----
C ID      = index number of file
C ntar    = number of target EFDC1D cells using same HSPF file (divided equally)
C          maximum 20
C i1,...  = EFDC1D cell number for each target cell (see cellnet.inp)
C
C4 ID ntar  i1  i2  i3  i4  i5  i6  i7  i8  i9  i10 . . .
    1    1    1
    2    1    1
    3    1    2
    4    1    3
    5    1    4
  
```

The lines in section 4 connect the PLTGEN file output to the appropriate cells. The “i” values are the index numbers assigned to the EFDC1D cells in the CELLNET.INP file. There must be NFILE lines present.

```

C-----C
C Sediment/Solid Distribution
C
C5 ID  Sand    Silt    Clay
C
    1  0.3     0.3     0.4
    2  0.3     0.3     0.4
    3  0.3     0.3     0.4
    4  0.3     0.3     0.4
    5  0.3     0.3     0.4
  
```

These fractions divide the total sediment outflow time series (when present) into sand, silt, and clay particle sizes. The program will attempt to read NFILE lines, one for each PLTGEN file, even though files that already contain separate sand, silt, and clay time series (OPTYPE=2 in Section 3) do not use them.

```

C-----C
C Mapping HSPF to EFDC1D sediment fractions
C
C
C
C HSPF EFDC1D
C
C6----- Noncohesive Cohesive-I Cohesive-II -----C
"Sand" 1.0 0.0 0.0
"Silt" 0.5 0.0 0.5
"Clay" 0.0 1.0 0.0

```

Section 6 contains the factors that map from HSPF sediment fractions to EFDC1D sediment types.

MKINP1D Output Files

MKINP1D reads its input file, then reads the HSPF PLTGEN files as instructed in order to produce time series files with the required formats and filenames for EFDC1D. The units are automatically converted from HSPF output units to the proper units for the receiving model.

Each file contains a full time series for each target EFDC1D cell, one after another. The pointers for these target cells must be placed in the CELLNET.INP file so that EFDC1D can associate each time series with the correct cell.

The flow is always output. For each of the water quality constituents, a file is produced whenever at least one of the files has a nonzero column flag for that constituent in section 3 of MKINP1D.INP. Any time series for a target cell that receives no load of a given constituent is simply filled with zeroes.

Table 2. EFDC1D Input files

Constituent	Filename	Units
Flow	QSER.INP	cms
Cohesive sediment (2 fractions)	SDSER.INP	mg/l
Noncohesive sediment	SNSER.INP	mg/l
Temperature	TSER.INP	C
Toxic substance	TXSER.INP	mg/l

Conclusion

MKINP1D should aid the modeler in linking flow and water quality loads generated by HSPF to EFDC1D, whether they are generated from the land surface or from upstream tributaries above the bounds of the EFDC1D cell network.

III. Sampling Procedures for Sediments

To perform sediment transport modeling in surface waters, a comprehensive set of hydrologic, hydraulic, and sediment data must be collected/measured in the water body (e.g., stream network, river, lake, reservoir, estuary) to be modeled. In this section, a field study work plan for the South Fork Broad River (SFBR) watershed in Georgia is given as an example of the type of field study that should be performed to collect the necessary data to perform sediment transport modeling. This work plan is specific to an inland river/stream network. Thus, some modifications would have to be made to the plan if the surface water body to be modeled was a reservoir, lake, tidal river, or estuary.

III.A Field Work Plan

The field data collection plan that was developed by the Office of Research and Development's National Exposure Research Laboratory - Ecosystems Research Division (ERD) for the SFBR watershed (see Figure 11) consists of spatially intensive rain-event sampling in one of the sub-watersheds (Biger Creek basin) of the SFBR, to be performed by EPA Region IV, and less spatially intensive rain-event sampling to be performed by ERD over the balance of the basin. Specifics of the field work plan are described in the 14 tasks given below. A subsequent report will describe this particular field study in detail, and will include sampling protocols and a description of the database developed for this study.

1. A Class A meteorological (Met) station was installed by ERD in the city of Comer, Georgia (see Figure 11). The nearest existing Met station is in Athens, which is not in the SFBR watershed. The Met station measures the following meteorological data required by HSPF (to be used for simulating the nonpoint sediment loads in the SFBR watershed): precipitation rate, solar radiation, relative humidity, temperature, wind speed/direction, barometric pressure, and evaporation rate.
2. Tipping bucket rain gages were installed at seven other locations throughout the SFBR watershed to provide basin-wide spatial coverage of rain fall quantities.
3. Stage-discharge rating curves are being developed by the State of Georgia Water Resources Division of the U.S. Geological Survey (USGS) using USGS Standard Operation Procedures (SOPs) (Stamey 1999) at the following rain-event sampling stations (see Figure 11):

South Fork of the Broad River

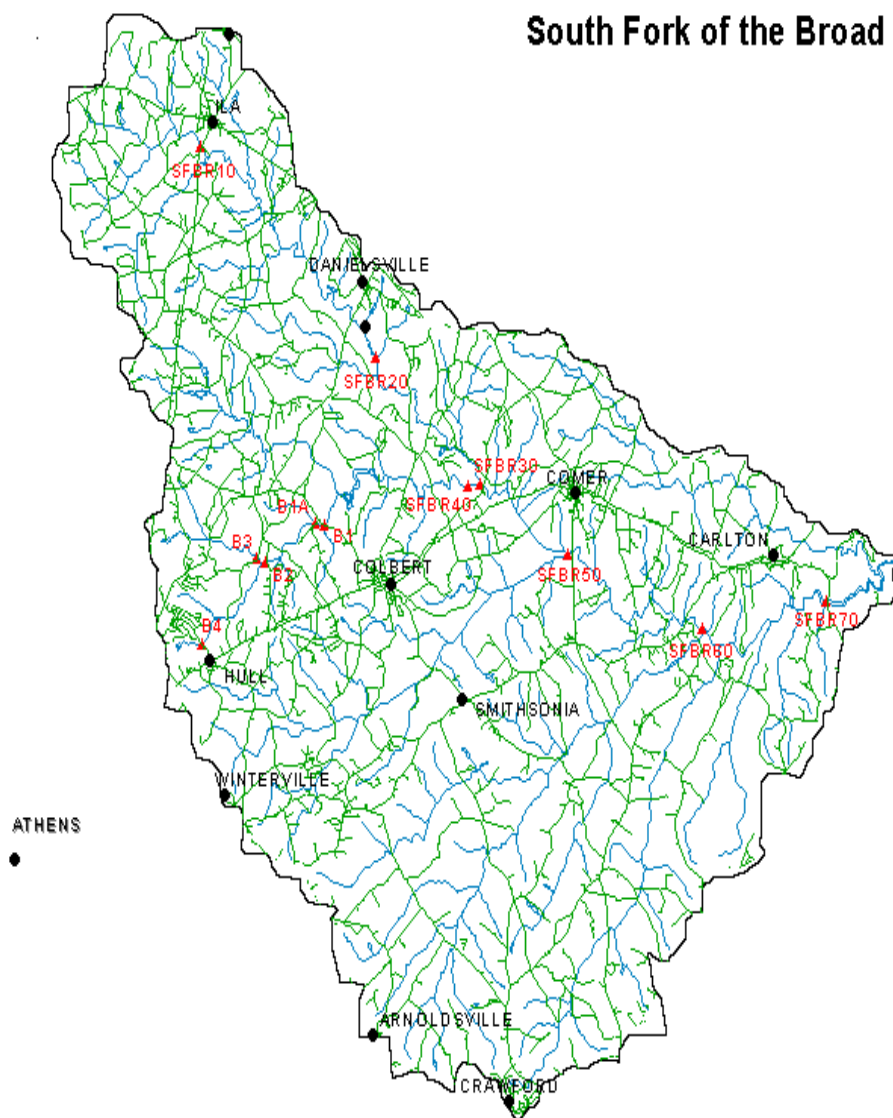


Figure 11. South Fork Broad River Watershed showing the locations of the sampling stations.

SFBR70 - Sandy Cross Road bridge over the SFBR near the town of Carlton, GA. A Bank-Operated Cableway system, to be used to collect depth-integrated and bedload samples at several lateral stations across the SFBR, is to be installed at this station in Fall 2001. This station is the outlet of the portion of the SFBR basin that is being monitored by ERD and Region 4.

SFBR60- Big Clouds Creek, approximately 250 m upstream of the confluence of the SFBR and Big Clouds Creek. A Bank-Operated Cableway system was installed at this station in 2000. This system is used to collect depth-integrated and bedload samples at five lateral stations across Big Clouds Creek.

SFBR50 - Highway 22 bridge over the SFBR, immediately downstream of the confluence of Beaverdam Creek and the SFBR. **NOTE - THIS SAMPLING STATION WAS DROPPED DUE TO FY 2000 BUDGET CUTS.**

SFBR40 - Highway 172 bridge over the SFBR, immediately downstream of the confluence of the SFBR and Brush Creek. A Bank-Operated Cableway system was installed at this station in 2000. This system is used to collect depth-integrated and bedload samples at five lateral stations across the SFBR.

SFBR30 - At the wood bridge over Brush Creek on McCarty-Dodd Road. A crane truck is used to collect depth-integrated and bedload samples at three lateral stations across Brush Creek.

SFBR20 - Approximately 100 m downstream of the three box culverts under Highway 29, located immediately downstream of the confluence of the north and south branches of Double Branch Creek. Depth-integrated and bedload samples are collected by a person wading the creek and using hand-held samplers.

SFBR10 - Old steel bridge over the SFBR, located approximately 40 m downstream of the bridge on Old Ila Road. A crane truck is used to collect depth-integrated and bedload samples at five lateral stations across the SFBR. This is the upstream most monitoring station.

Stations B1, B1A, B2, B3 and B4 on Biger Creek, which is a tributary of Brush Creek. Region 4 has been monitoring these stations, and has developed stage-discharge rating curves for each station.

At the outlet of the Region 4 designated reference watershed (Lightwood Log Creek). This station is being monitored by Region 4.

The rating curves are being determined by installing staff gages at these stations and then measuring the discharges corresponding to at least ten different stages (Stamey 1999).

4. The USGS set up a real-time stream gaging station at the Sandy Cross Road bridge (SFBR70). This will provide a continuous stage/discharge hydrograph at the outlet of the basin.
5. Rain-event sampling is being performed at the identified sampling stations. Rain-event sampling consists of measuring bedload, suspended load, and nutrient concentrations once every one to two hours during both the rising and falling stages of the runoff hydrograph. Established USGS SOPs for suspended load and bedload measurements (Edwards and Glysson 1998) are being used at these sampling stations. The suspended load will be determined by filtering water samples to be collected using a depth-

integrated sampler (DH-48 and DH-59) and a single-point automatic sampler (ISCO model 6700 portable sampler). A six-inch Helley Smith bedload sampler is being used to measure the bedload at three locations across the SFBR or tributary (at approximately 25%, 50% and 75% of the width from the right bank, facing downstream) at stations SFBR20 and SFBR30, while at sampling stations SFBR10, SFBR40, SFBR60 and SFBR70, the bedload is being measured at five locations across the SFBR or tributary. A 25-lb hand-held bedload sampler is being used at SFBR20, while a 167-lb cable-suspended bedload sampler is being used at the other stations. A depth-integrated sampler is being used to collect a sample at the same three or five locations at each sampling station. A DH-48 hand-held sampler is being used at SFBR20, whereas a DH-59 rope/cable suspended sampler is being used. General information about performing rain-event sediment sampling is given in Section III.B.

6. A YSI multi-probe 6920 was installed at each sampling station to measure stage, conductivity, temperature, dissolved oxygen, pH, turbidity, and oxidation-reduction potential (ORP) once every 15 minutes.
7. A second ISCO sampler was installed at each sampling station. The samples collected by this sampler will be analyzed using standard U.S. EPA methods (US EPA 1997) to determine concentrations of ammonia, nitrate, orthophosphate, and total phosphorus.
8. In addition to these samples/measurements, at least two depth-integrated water samples of sufficient quantity to perform grain size analysis (i.e., sieve and hydrometer analysis) should be collected, one on the rising stage and the other on the falling stage, at each station. Bedload size distribution needs to be measured as well during the rising limb of the runoff hydrograph. Rosgen (1996) describes a method to estimate the size distribution of bedload that is transported during a bankfull event.
9. Cross-sectional surveys of the SFBR and the identified tributaries will be performed at approximately 0.10 mile intervals using the stratified random approach, starting at the downstream-most sampling station at the Sandy Cross Road bridge (SFBR70). The major tributaries are the following creeks: Brush, Big Clouds, and the Double Branch (up to the confluence of the South and North Forks). The surveys in these tributaries will start at the confluence with the SFBR and proceed upstream to the sampling stations. The surveys should be performed using a total station, a survey grade GPS unit and other required surveying equipment, and extend out onto both floodplains to a distance at which the elevation is +5 ft that of the banks.
10. The following channel characteristics will be observed/measured at each surveyed cross-section: stream width, depth and maximum depth from previous runoff events, channel planform (i.e., straight, bend), profile (i.e., riffle, pool, run), flow type (i.e., rapid, slow), features (i.e., point bars, shoals, chutes, snags, debris), and bed form features (i.e., ripples, sand bars, armoring).

11. Stream bank erosion potential will be evaluated at the surveyed cross-sections using bank pins, as described by Rosgen (1996). In addition, bank height and slope will be measured, and the bank status (i.e., protected with vegetation, eroding, stable), bank material (i.e., clay, silt, sand, exposed roots), and vegetation type and percent cover will be noted.
12. Channel stability will be monitored at selected surveyed cross-sections. Specifically, this includes evaluating vertical or bed stability, lateral stability, and changes in bed material size distribution. The methods described by Rosgen (1996) should be used to perform this monitoring.
13. Particle size distributions of channel bed materials at five lateral positions at each surveyed cross-section are being determined using sieve and hydrometer analysis. Sediment cores will be collected at each cross-section at the following five locations: 1) thalweg, 2) one-half the distance from the thalweg to the right bank (looking downstream), 3) one-half the distance from the thalweg to the left bank, 4) right bank, and 5) left bank. The locations of the second and third cores will vary somewhat depending on the river morphology.
14. River reach assessment should be performed at selected surveyed cross-sections. In general, river reach assessment should include channel planform (e.g., bar morphology), riparian vegetation, channel evolution model status (Schumm *et al.* 1986), bank properties, and bank and backslope erosion processes. Overall geomorphic condition and aquatic habitat should be assessed with a stream reach inventory model (Pfankuch 1975) and the habitat assessment form (Plafkin *et al.* 1989) or an appropriate habitat assessment model.

III.B Rain-event Sediment Sampling Procedures

The procedures described in this section relate to the fifth task (i.e., rain-event sampling) given in the previous section. Detailed information related to the measurement methods for sediment sampling using the depth-integrated samplers and the bedload samplers are given elsewhere (Edwards and Glysson 1998; Pruitt *et al.* 1999). Generic procedures for performing rain-event sediment sampling using the referenced sediment samplers and measurement methods are described in this section.

The following data need to be collected at each sampling station:

- Continuous stage (i.e., water surface elevation) and temperature record over the duration of the runoff event. These data can be collected using, e.g., a YSI multi-probe 6920.
- Rainfall rate and amount using, e.g., a tipping bucket rain gage.

- Depth-integrated samples and bedload samples need to be collected at the relative lateral positions described in the previous section over the duration of the runoff hydrograph. These samples should be collected once every one-to-two hours, ideally starting before the water starts rising in the river due to runoff. These measurements will enable determination of the total sediment load hydrograph.

In order to calculate the discharge hydrograph during the runoff event using the measured stage hydrograph, a stage-discharge rating curve needs to be determined at each sampling station using the method described by Carter and Davidian (1968). In addition, a cross-sectional survey (as described in task 9 in the previous section) of the stream/river at each sampling station needs to be performed.

Appendix A

Contents on Distributed CD

Folders

Contents

Brandywine Creek	Input files for EFDC1D simulation of the Brandywine Creek stream network
HSPF Linkage	Files, including executable and input files, to run the Mkinp1d program
LA River	Input files for EFDC1D simulation of the Los Angeles River

Files

Contents

EFDC.CMN	ASCII file containing common blocks for the EFDC1D model.
EFDC.PAR	ASCII file containing parameter statements for the EFDC1D model.
EFDC1D.F	ASCII file containing the EFDC1D FORTRAN program.
EFDCmapInstall	Binary file that installs the EFDCmap utility.
GenScn_WDMUtil_WinHSPF_2.0.5	Binary file that installs the modified version of GenScn.

Appendix B

Instructions for Installing and Using EFDC1D Visualization Software (GenScn)

1. Install the GenScn 2.0.5 package:
 - a. Copy the GenScn_WDMUtil_WinHSPF_2.0.5.exe file from the distribution CD to a hard drive on your computer.
 - b. Double click on this file inside Windows Explore.

2. Install the EFDCMap utility:
 - a. Copy the EFDCmapInstall.exe file from the distribution CD to a hard drive on your computer.
 - b. Double click on this file inside Windows Explore.

3. Run EFDCMap utility
Open dump1d.out file
Write shape file (use name: brandy)
When asked if you want to add to map file or create a new one, select "Yes"
(use name: brandy.map)
Exit

4. Run GenScn
maximize window
File > New Project
 For the map file, click "Select", and choose brandy.map
 Change "File Type" to EFDC in drop-down menu
 Click Add from File
 Browse/Select and then Open dump1d.out file
 Click OK at bottom
File > Save Project As
 Enter a project name (e.g., brandy)
Exit (unless going on to step 5)

5. Run GenScn (if not already open)
Maximize window
Open Project Browse/Select brandy(.sta)
Map > Change to List (if map is not in list form)
Select Constituent/Location/Scenario
 (scenario = dump1d file name)
 (constituent = parameter name(s) from dump1d file)
 (location = node number(s))
You can choose more than one of each category if desired
The "OBSERVED" scenario is normally empty for this type of project
 unless added separately

Click + key in Time Series window

Select/click on time series of interest in Time Series window

Click on Generate Graphs in Analysis window (or Analysis > Graph)

The Generate Graphs button looks like 5 vertical red bars on a bar chart

Etc. (refer to GenScn documentation for details of using GenScn features for analysis of data)

Note: you can ignore steps 2 and 3 and the parts of 4 related to the Map if you want to just open the dump1d.out file and plot various parameters without access to the "visual" map of the stream.

REFERENCES

- Bicknell, B.R., J.C. Imhoff, J.L. Kittle Jr., A.S. Donigan Jr., and R.C. Johanson. 1997. Hydrological Simulation Program - FORTRAN, User's Manual for Release 11: EPA/600/R-97/080. U.S. Environmental Protection Agency, National Exposure Research Laboratory, Athens, GA.
- Carter, R.W., and J. Davidian. 1968. "General procedure for gaging streams," U.S. Geological Survey, Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 3, Applications of Hydraulics, Chapter A6 (TWRI 3-A6), 13 pp.
- Edwards, T.K., and G.D. Glysson. 1998. "Field Methods for Measurement of Fluvial Sediment," U.S. Geological Survey, Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 3, Applications of Hydraulics, Chapter C2 (TWRI 3-C2), 89 pp.
- Hamrick, J. M., 1992. "A three-dimensional environmental fluid dynamics computer code: Theoretical and computational aspects," The College of William and Mary, Virginia Institute of Marine Science, Special Report 317, 63 pp.
- Hamrick, J. M. 1996. "Users manual for the environmental fluid dynamic computer code," The College of William and Mary, Virginia Institute of Marine Science, Special Report 328, 224 pp.
- Hamrick, J. M. 2001. "EFDC1D – A One Dimensional Hydrodynamic and Sediment Transport Model for River and Stream Networks, Model Theory and Users Guide," Technical Report, U.S. EPA National Exposure Research Laboratory, Athens, GA and U.S. EPA Office of Science and Technology, Washington, DC.
- Hamrick, J. M., and T. S. Wu, 1997. "Computational design and optimization of the EFDC/HEM3D surface water hydrodynamic and eutrophication models," Next Generation Environmental Models and Computational Methods. G. Delich and M. F. Wheeler, Eds., Society of Industrial and Applied Mathematics, Philadelphia, 143-156.
- Harrelson, C.C., C.L. Rawlins and J.P. Potyondy. 1994. "Stream channel reference sites: An illustrated guide to field technique," United States Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. General Technical Report RM-245.
- Kittle, J.L., Jr., A.M. Lumb, Hummel, P.R., Duda, P.B., and Gray, M.H. 1998. "A Tool for the Generation and Analysis of Model Simulation Scenarios for Watersheds (GenScn)," U.S. Geological Survey Water-Resources Investigations Report 98-4134.
- Leopold, L.B. 1994. A View of the River, Harvard University Press.

Pruitt, B.A., L.C. McGrath, M.G. Bowden, A.W. Carroll, M.C. Flexner, and W.F. Simpson. 1999. "Field and Laboratory Standard Operation Procedures, Quality Assurance Plan, and Safety Control Plan for Conducting Sediment and Nutrient Total Maximum Daily Loads," U.S. Environmental Protection Agency, Region 4.

Rosgen, D.L. 1996. Applied River Morphology, Wildland Hydrology, Pagosa Springs, Colorado.

Stamey, T.C. 1999. "Surface Water Quality-Assurance Plan," U.S. Geological Survey, Georgia District," Open-File Report 99-71, Atlanta, Georgia.

U.S. Environmental Protection Agency. 1997. "Region 4 Analytical Support Branch SOP and QA Manual," SEDS, EPA, Region IV, Athens, GA.