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Hydrodynamic Modeling for Ex-Situ Testing

Final Report
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16. Abstract

The primary objective of the project is to provide a review of the current state of practice regarding hydrodynamic models and modeling for ex-situ testing applications. From a selection of graphics, simulations and numerical modules available, the study will provide ease of use, parameter requirements, applicability, functionality, capabilities and output results to aid in the selection process and make a recommendation based on ex-situ testing analysis needs, possible trends and response indicators.

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FORWARD: This report presents a summary of a literature review of a number of existing and available hydrodynamic models and modeling references. The review was conducted in support of a separate study by CAIT on an alternative ex-situ method for measurement of erosion rates in riverine and estuarine environments.

1. Background on Ex-Situ System

The current state of practice in modeling of sediment and contaminant transport and fate rely heavily on measuring sediment erosion as a function of depth with shear stress as a parameter by means of Sedflume. The data from Sedfluem testing is an important component of hydrodynamic models used to estimate the maximum bottom shear stress encountered during flood events in river and estuarine environments. Comparison of estimated bottom shear stresses with measured critical shear stresses are normally an indicator of whether surface sediments will erode under flood, or non-storm conditions.

The purpose of the Sedflume as described by Borrowman, et al., 2005 is to " measure the variability of erosion rates with depth of relatively undisturbed core samples extracted from a site. Erosion rate variation with depth measured in the Sedflume is important in quantifying sediment stability and movement. Sedflume measurements are generally considered the best method to quantify these erosion processes and their variation with depth. "

A major shortcoming of Sedflume method for predicting erosion rate as a function of sediment depth is that it does not fully simulate the conditions that lead to sediment incipient motion. Most sediment-laden flows are characterized by irregular velocity fluctuations indicating turbulence. Under turbulent flow conditions with sediments consisting of fine grained soils with grain size less than 0.25 mm, the plane bed surface. is considered hydraulically smooth. This indicates that the flow becomes laminar in a layer of thickness □ □adjacent to bed surface (Figure 1).

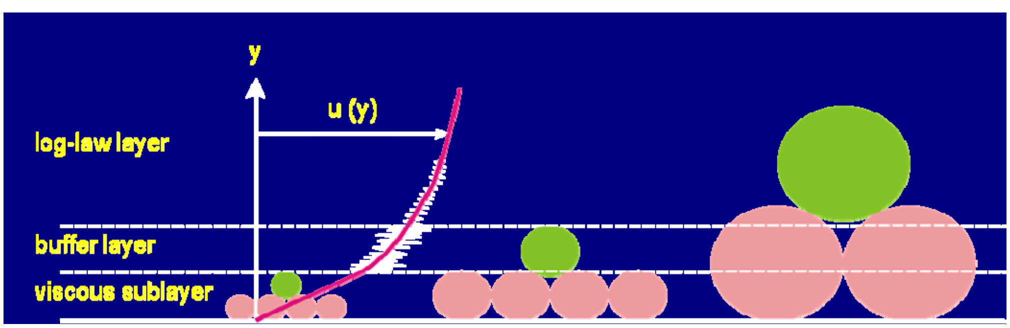

Figure 1. Flow Velocity Profile and Modeling of Incipient Motion

The steady turbulent flow profile extends from viscous laminar sub-layer □ to a buffer layer and then extends to turbulent zone (log-law layer). In general, turbulent flows are considered hydraulically smooth as long as the height of the boundary roughness characterized by the sediment size remains much smaller than the laminar (viscous) sub-layer thickness (Julien 2002). This is the case in river beds with silty-san or silty- clay characteristics such as those in the NY/NJ estuarine systems.

The fluid flow around sediment particles exerts forces that tend to initiate particle motion. Threshold conditions occur when the hudrodynamic moment of forces acting on soil particles balance the resisting moment of force and hence particle at “incipient” motion. The ratio of hydrodynamic forces to the submerged weight and cohesion of fine sediments which corresponds to the initiation of motion depends on whether laminar or turbulent flow conditions prevail around the particles. It is therefore important for sedflume type modeling of incipient motion on river beds, the distinction between laminar sublayer, buffer layer and turbulent zone are clearly recognized and modeled.

In order to realistically model and simulate the transition in flow profiles on a river bed, a new approach, Ex-Situ Erosion Testing Method (ESETM) has been developed by the hydraulic laboratory at Turner Fairbank Highway Research Center at FHWA that accurately simulates the flow conditions leading to incipient motion of river bed sediments. In comparison with the sedflume approach ESETM:

1. Accounts for laminar sublayer which is important for sediment incipient motion, ESETM can perfectly generate viscous sublayer in laminar flow condition to control shear stress acting on sediment samples (Figures 2 and 3).
2. Simulates turbulent fluctuation of pressure effect on the sediment incipient motion by the vertical periodic alternating pressure, which can couple with laminar flow condition to realize actual turbulent flow condition (Figures 2 and 3).

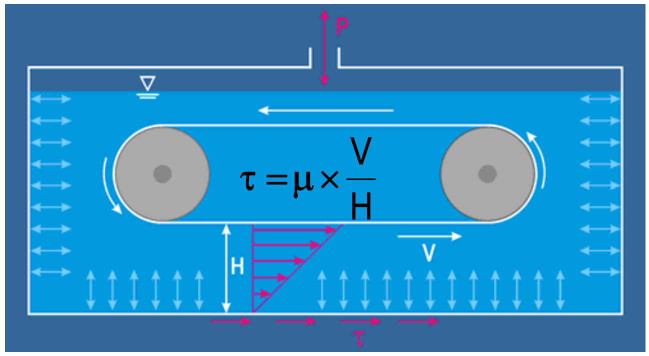

Figure 2. Realistic Simulation of Flow profile

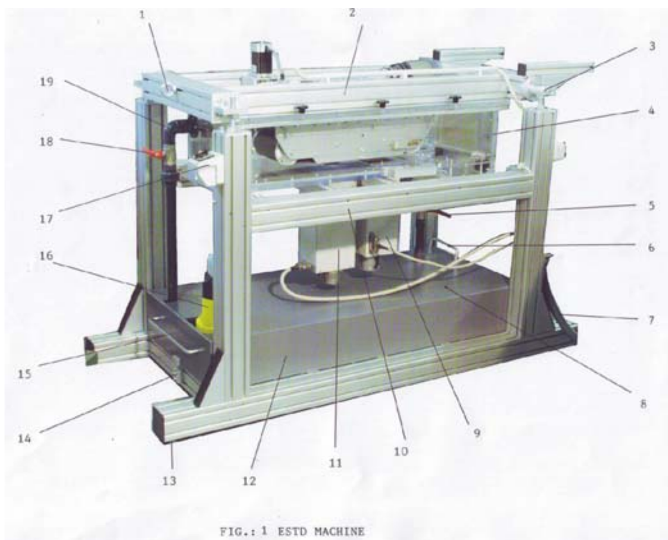

Figure 3. A working model of ESETM by FHWA, TFHRC

The Sediment Management Laboratory at CAIT has undertaken a study to evluate ESETM capability for evaluation of sediments characteristics of those in the NY/NJ waterway systems. The objective of the were two-fold:

- Test and evaluate the ESETM technology for determination of accurate sediment erosion parameters such as critical shear stress used in hydrodynamic modeling of estuarine systems. and Determine the viability of in-situ treatment methods by comparing the critical shear stresses and corresponding velocity profiles between treated and untreated specimens and hence determine preliminary design guidelines for all types of in-situ treatment strategies prior to any full-scale field trial. This is particularly important as the NY/NJ Harbor sediments have been shown to be contaminated with a number of contaminants, including dioxin/furans, DDT, PCBs, pesticides, mercury and heavy metals. The contamination is widespread, but is also concentrated in several "hot spots," that are usually centered on areas of ongoing or historical industrial activity. Because this part of the estuary is highly dynamic, there is some concern regarding the potential release of these contaminated sediments during storm events, or during dredging activities. If the sediments are disturbed during storm events or dredging operations, sediments and sediment-bound contaminants could be dispersed. The potential for sediment release is exacerbated by high liquid content and fine grained matrices. Techniques designed to alter these characteristics could potentially limit contaminant dispersion. Moreover, The use of ESETM is the first step in evaluating the utility of in-situ treatment and the feasibility of in-situ stabilization of highly contaminated river sediments, which is the objevtive of another parallel study at CAIT.

2. Objective of the study

The main objective of this study is to identify and describe some of the current and existing hydrodynamic models and their capabilities. Any improvement in measurement of erosion rates using ex-situ systems is anticipated to enable hydrodynamic mdoes to better estinate the volume of sedument tarnsport in estuarine an riverine environments. A brief overview of the models reviewed are presentd herein.

3. Review of Hydrodynamic Models

Hydrodynamics is the motion study of water. The hydrodynamic model is a tool which helps describing the movement of water. In past physical laboratory models were used for modeling water movement in order to gain knowledge on water movements. With technological development and advent of computer systems, the numerical models with advanced computational power become the major source of modeling. These numerical models were specifically used for water movement studies in rivers, lakes, bays, etc.

An important step in performing a hydraulic modeling study is determining the relevant flow parameters and the type of model needed to obtain this information. In some cases a one dimensional model is sufficient to estimate the parameter of interest like determining the area of inundation in flood plain analysis. But the selection of the appropriate model is not always so simple. Factors such as the complexity of domain, level of accuracy and cost can affect the selection. More advance algorithms and techniques caused the use of two and three dimensional hydrodynamic models which has become prevalent and essential tool for the study of water bodies these days. These models can be used for studies where local parameters of flow and their distribution in space and time is important. In proceeding section three major source of these models will be discussed. The Surface-water modeling system by Aquaveo Company, the models created by Environmental Protection Agency and United States Geological Survey models will be discussed in subsequent sections.

3.1. Surface-water Modeling System (SMS) (Developed by Aquaveo LLC.)

Aquaveo began as a part of the Engineering Computer Graphics Laboratory at Brigham Young University in 1985. In 1998 the lab name changed to the Environmental Modeling Research Laboratory (EMRL). In April, 2007, the main software development team at EMRL entered private enterprise as Aquaveo, LLC and continued developing modeling software specializing in ground water, watershed, and surface water modeling (SMS) which is very widely used.

Surface-water modeling system is a family of programs for modeling and simulating the surface water movement on rivers, estuaries, lakes, bays and coasts. It is designed to facilitate the operation of numerical models which was developed for governing equations of water movements. It has graphical interface which allows users to fully visualize and analyze the data and have better understanding of changes in different conditions.

It has different modules and models based on the specific application and can analyze in one, 2 and 3 dimensions. The basis of these models is based on solving the governing equation of motion of fluids, but the complexity of the system of interest (river, bay, etc.) prevents using analytical methods therefore the solution is by using finite difference, finite element or finite volume techniques. There are two different approaches in hydrodynamics models, the first approach is structured grid approach which uses finite difference method to solve governing equation and the other approach is unstructured grid approach which uses finite element or finite volume method.

The application of these models is very useful to wide range of problems, provided the model shows sufficient accuracy. The accuracy of the model can be checked by comparing the model results with actual field observation.

Models are applicable for steady and unsteady type of flow and can result the velocity of flow, discharge and water surface elevations. Other models are also available and can be used for other applications such as sediment transportation, wave energy generation, salinity intrusion studies and contamination migrations.
The ability to models in 1, 2 or 3 dimensions varies between models and mostly is based on the geometry of the problem. Some of the models have the capability to

enable the user to graphically build, view and edit the model. In this case the user can enter the necessary parameters through interactive and user friendly graphical interfaces.

Based on the level of complexity of the problem finite difference or finite element schemes are used to solve the governing equation of water movement. Surface water modeling system is a family of powerful tools that can graphically model the problem based on user-defined models, digital maps and elevation models. The graphical interface and its ability to 3D modeling provide users with better view and understanding of the domain and input parameters. It helps to create models more accurately by correctly assigning the required parameters to specific domains.

The 3D display of the results which can help user generating different type of plots is another advantage of the SMS models over other models. Contour and color-shaded plots can be used to graphically represent the discharge, velocity and water elevations in shallow surface water modeling. Bed elevations, scour and contamination migration can be pin pointed in any location at any time with time history plots too. Type of flow such as steady and transient flows and their effect on the results such as flow velocity or water elevation can be animated like viewing a movie which can allow the user to observe and study the change of different parameters in their analysis of interest.

Some models like structured grid models, uses finite difference solution which has limited flexibility in terms of complicated domains, but it is fast and straightforward because it has efficient algorithms for solution. On the other hand unstructured grid models is very flexible in modeling the complex studies because they can change the resolution of model in required areas but they are time consuming and prone to numerical errors.

SMS has different parts including modules, general models, coastal models and riverine/estuarine models. Modules are 1D Grid, 1D River, Cartesian Grid, Curvilinear Grid, GIS, Map, Mesh, Particle, Raster and Scatter. General models include numerical programs such as FVCOM, Generic Mesh, PTM, and TUFLOW-FV. Costal models are ADCIRC, BOUSS-2D, CGWAVE, CMS-FLOW, CMS-WAVE, GENCADE, STWAVE and WAM. Riverine/Estuarine models are ADH, FESWMS, HYDRO AS-2D, RIVERFLO-2D, RMA2, RMA4, SRH-2D, STEERING and TUFLOW.

Based on the type of design, the application of above mentioned models can be for Hydraulic design some of the models are for hydraulic design like:

- ADCIRC (Advanced Circulation Model) (Luettich & Westernik, 2012) - coastal circulation and flooding model based on finite element hydrodynamic model used for inlets, rivers and floodplains.
  This is a series of programs designed for solving time dependent, two or three dimensional transport problems based on finite element method. Using finite

element method of analysis enables the user to utilize unstructured grid network for complex domains. This program can be used for flooding predictions, tide and wind driven circulation, and material disposal studies and dredging feasibilities.

- CMS-FLOW (Coastal Modeling System) (USACE, 2006) - is a hydrodynamic model intended for local applications, primarily at inlets, the nearshore, and bays
  This program is a component of coastal modeling system. The solution is based on finite-volume method and can be used for two dimensional problems such as sediment transport, salinity transport and hydrodynamics of surface water under different hydraulic conditions. It is incorporated into SMS software and can be used together with CMS-WAVE. The CMS-WAVE is one of the principal programs in coastal modeling system which calculates the wave action in nearshore domains. CMS-FLOW has the ability to interactively work with CMS-WAVE and user can modify the boundary conditions, grid network, run the analysis and visualize the results.

- FESWMS (The Finite Element Surface Water Modeling System) (Froehlich, 1995) – It is a two dimensional finite element based model which can compute the direction of flow and water surface elevation in a horizontal plane. Also has the ability to model hydraulic structures commonly used by hydraulic engineers.
  It is a set of programs that simulates two dimensional surface water flows such as shallow rivers, flood plains and coastal seas. It can analyze steady or unsteady flow problems in flow control structures and allows the user to include structures such as culverts and weirs. It is capable of analyzing roadway embankments, drop-inlet spillways and bridge crossings where complicated hydraulic conditions exist.

While some of them are wave models which are useful for harbor design like:

- CGWAVE (Demirbilek, 1998) - It is a general purpose two dimensional numerical model for simulating and predicting the wave's transformation and properties in coastal regions. The output of this program can be wave velocity, heights, and pressures. The program is based on finite element method and can be used for complex domains which the grid size can vary throughout the domain based on wavelength. Therefore it is well suited for wave simulations in harbors and regions with difficult boundaries. It can simulate wave refraction, diffraction, combination of refraction and diffraction in both short and long waves in nearshore applications.

- BOUSS-2D (Boussinesq based model) (Demirbilek, 1993) – Numerical model for simulating the propagation and transformation of waves in coastal regions.
  This is a program for wave estimation in navigation design, channel sedimentation and harbors based on time-domain solution of Boussinesq-type equation. It is a comprehensive model based on finite difference method for simulation of propagation and transformation of both periodic and non-periodic waves in both unidirectional and multidirectional sea states. It can calculate wave heights, mean direction of currents, and mean water levels.

And some of them are for wave generation and transformation:

- CMS-WAVE (Coastal Modeling System-WAVE) (Lin, Demirbilek, Mase, Zheng, & Yamada, 2008) – Two dimensional model for calculation of wave and other nearshore processes
- STWAVE (Steady State spectral WAVE) (Smith, Resio, & Zundel, 1999) – This is a steady state finite difference model for nearshore wind-wave growth and propagation. It can be used for refraction, shoaling, wave interactions in nearshore regions, and breaking wave angles and energy due to sediment transportation. It can include all types of flows such as subcritical, trans-critical and supercritical and also steady state and unsteady flows can be simulated.

It also has the capability to use generic model which based on the user's need, it can be configured to accommodate the specific types of data such as:

- SRH-2D (Sedimentation and River Hydraulics) (Lai, 2012) – Two dimensional (2D) hydraulic, sediment, temperature, and vegetation model for river systems. It is a very flexible numerical model with a flexible mesh for better solution accuracy. It can be used for calculation of flow velocities, water surface elevations, and water depth in in-stream structures.
- RIVERFLO-2D (Garcia, 2009) – It is a two dimensional (2D) finite element model for flood hydraulics, current and sediment transport simulation in rivers. It uses triangular flexible meshes with refinement and is very stable handling dry and wet river beds, subcritical and supercritical flows in rivers. It can be used for complex river environments since it has a flexible mesh and provides a quick and high resolution flood hydraulics in rivers.
- HYDRO AS-2D (Nujic, 2001) – This program is a two dimensional (2D) finite volume model for current, pollutant, and sediment transport simulation. It is based on numerical solution of a two dimensional current equations with finite volume discretization. It can be used for river flooding analysis, flood-wave

propagation, sediment erosion and depositions studies and pollutant dispersion in waterways. It can calculate the water surface elevation, water depth, and flow velocity. It is very user friendly and well suited for subcritical or supercritical flows and the transition between these two states.

- TUFLOW-FV (Syme, 2011) – This is two and three dimensional flexible mesh, finite volume model for flood, tide and water quality simulation software. The model is suitable for solving wide range of hydrodynamic problems such as hydrodynamic of open channels, rivers, estuaries, coasts, and oceans. The flexible mesh enables user to consider seamless boundary fitting along complex domains and analyze it efficiently and accurately with numerical scheme employed.
- TABS (USACE, 1985) – It is a family of multidimensional numerical models (GFGEN, RMA2, RMA4, RMA10 and SED2D) for modeling hydrodynamic, sediment and constituent transport processes in rivers, reservoirs and estuaries. It can simulate the wetting and drying of shallow areas caused by discharge fluctuations in rivers or tidal fluctuations in estuaries.

    - GFGEN (Geometry File Generator) – it is a pre-processor for changing the geometry file while checking the data and prepare it for SMS application
    - RMA2 - One and Two dimensional finite element hydrodynamic model for simulating water levels, horizontal velocity component for subcritical flow in two dimensional flow fields. It can be used for calculation of water levels and flow distribution at bridges having one or two openings, river junctions, into and out of off-channel hydropower plants and pumping plant channels and general hydrodynamics of water in rivers and water bodies. It operates under the hydrostatic assumptions which means the vertical component of acceleration is negligible and it is not good for near field problems where vertical acceleration is of primary interest.
    - RMA4 – One and Two dimensional finite element water quality transport model for simulation of constituent concentration either dissolved or neutrally buoyant within the water. It assumes the depth distribution of constituents to be uniform. It is meant to analyze the advection-diffusion of pollutants in the environment. It can be used for investigating the physical processes of migration and mixing of substances in rivers, bays and reservoirs and the effectiveness of remedial control measures. It is capable of simulating salinity distribution, identify critical areas of pollutants spread and monitor water quality within the domain.

  - RMA10 – One, Two or Three dimensional finite element hydrodynamic model for simulation of steady or dynamic state sediment transport and salinity.
  - SED-2D – Two dimensional numerical model for cohesive and non cohesive sediment deposition, erosion and transport
- TUFLOW (Syme, 2011) – Is a one and two dimensional (1D/2D) Finite difference model that simulates hydrodynamic behavior in rivers and flood plains. It can be used for rivers, coastal regions and flood plains or any other two dimensional water bodies which have complex flow patterns.
- PTM (Particle Tracking Model) (MacDonald & Davies, 2012) – It is particle tracking model for transport process of sediments and contaminants in large domains. It can simulate sediment movement of multiple sediment types in a flow field. It can predict the fate of sediments in dredging operations and can be used in dredged material management.

The SMS program has different modules in order to help users manipulate their models and create it based on different data sets. Map, mesh, Cartesian grid, boundary fitted grid, scatter point and 1D hydraulics are the modules incorporated into the program.

Map module allows users to use GIS, CAD data, IMAGE data to manipulate and enhance the visual aspect of their models as well as accurately modeling it. GIS and CAD data can be used to help assigning parameters and boundary conditions and can greatly reduce the required time for creating a model. Observation points and cross sections can be set up into the model to help comparing the output data with data collected in the field and verifying the models.

Mesh tool can aid constructing the two dimensional finite element meshes of rivers, bays or any other water bodies that can be modeled in two dimensions. The editing tool can be useful to refine and handle complex spots in modeling the domain. The result at each node of the mesh can be used to generate different type of plots based on the time history and also can be used to generate dynamic animations.

Cartesian grid module can be used to build two dimensional Cartesian finite difference model which is basically creating cells aligned with x/y coordinate systems. This feature can help to create grid network very fast and filling them with data easily. Therefore creating a numerical model in this way is very easy and the analysis is less time consuming. There are two models in the SMS which uses this module,

The Wave Energy Model (STWAVE)

Hydrodynamics Circulation for Coastal Zones(M2D)

The module alike the other modules has the ability to display the outputs in contour, fringe and vector plots and can create animations for better display of the results.

Boundary fitted grid module unlike the Cartesian module which uses rectilinear coordinate system, uses 2D or 3D boundary fitted grids which can better model the curves and difficult domain geometries. The grid network has rows and columns of cells and the cells can have any quadrilateral shape which helps in manipulating the model.

Scatter point module is one of the great advantages of this program. It interpolates the data from scattered data point to meshes and grids. The interpolation is based on three methods, i.e. linear, natural neighbor and inverse distance weighted method. It also has the ability to edit and view the data points. It can be used for initial conditions and verifying the model too.

1D hydraulic module is used to create and modify different type of cross sections for one dimensional hydraulic analysis. Using topographic data, extraction of cross sections, filtering the data for efficiency are some the aspects of this module.

3.2. EPA Models

As discussed earlier, the type and level of complexity of the problem are the two major factors affecting selection of the numerical model. The SMS is a comprehensive and advanced software system available for surface water simulation. There are several other numerical models developed by private or government entities for simulation of surface water hydrodynamics. Environmental Protection Agency (EPA) is one of the major contributors in developing numerical models for water bodies' hydrodynamics. From EPA point of view the following surface water models were developed to quantify movement of water in water bodies.

- EFDC: The Environmental Fluid Dynamics Code (EFDC) (Wool, 2002)

  It is capable of modeling hydrodynamic, sediment-contaminant, and eutrophication. It has been used to many water bodies for assessment and management purposes. EFDC is a comprehensive hydrodynamic model that can be used to simulate water bodies in one, two, and three dimensions. It has been used for over two decades globally and is a technically defensible hydrodynamic model. It can use different types of coordinate systems to represent the physical characteristics of water-body. According to EPA "It solves three-dimensional, vertically hydrostatic, free surface, turbulent averaged equations of motion for a variable-density fluid. Dynamically-coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity and temperature are also solved. The EFDC model allows for drying and wetting in shallow areas by a mass conservation scheme." It is one of the popular and powerful tools for hydrodynamic modeling which can be used for lakes, bays, rivers and etc.

- HSCTM2D: The Hydrodynamic, Sediment, and Contaminant Transport Model (Roy Burke III, 2005)

  HSCTM2D is a two dimensional finite element modeling system of surface water flow which can simulate short term and long term scour, sedimentation rates, contaminant transport in water-bodies. It consists of two modules, one for hydrodynamic modeling (HYDRO2D) and the other for sediment and contaminant transport modeling (CS2D).

3.3. United States Geological Survey Models

According to United States Geological Survey (USGS) managing water use in water-bodies requires understanding of hydrodynamics and transport properties of that type of water-body. Qualitative and quantitative evaluation of any water system can be computed via numerical simulation models. These model needs to be capable of accounting the factors affecting the temporal and spatial parameters of flow. Simulation models needs to account for hydraulic fluctuations, wind effects, geometric configurations, type of flow, physical parameters of domain and etc. There are several mathematical/numerical models for modeling the surface water movement which will be described shortly herein.

- ANNIE (Flynn et al., 2002) Version 4.1, Interactive Hydrologic Analyses and Data Management

Annie interactively helps users to list, plot and retrieve data for Hydrologic models and analyses. It can update parametric, spatial and time-series data for different hydrologic models. Data are stored in a shared file format in order to be accessible by different programs and eliminates the reformatting the data file for different application. The type of file is Watershed Data Management (WDM) which shares the platform with other programs and is developed by U.S Geological Survey (USGS) and Environmental Protection Agency (EPA). This program is widely used in watershed modeling projects and time-series data managements.

- BRANCH (Schaffranek et al., 1997) Version 4.3, Branch-Network Dynamic Flow Model

This program is used I simulation of steady and unsteady flow in single and network of branches (Open-channel reach). Time varying water levels, velocity of flow, discharge and volumes can be computed at any location within the network. It is applicable to wide range of complicated cross sections of channels and can be used in assessment of flow and transport in upland rivers and coastal networks. Surface and ground water interactions can be simulated in three dimensions, finite difference scheme by combining Branch and ground water flow module (MODFLOW) of USGS, referred to as MODBRANCH.

- BSDMS (Landers et al., 1996) Version 2.1, Bridge Scour Data Management System

This program has been developed for analysis of bridge scour. It can interactively display and analyze the associated data with local pier scour, local abutment scour, contraction scour and long term measurements. It can compare the analysis data with selected published scour equations and can accommodate site, flood events and geometry data.

- CRT (Henson et al., 2013) Version 1.1.1, Cascade Routing Tool to Define and Visualize Flow Paths for Grid-Based Watershed Models

This computer application is the combination of groundwater and surface water flow model (GSFLOW) and the precipitation-runoff modeling system (PRMS). It uses grid based model domain and can generate shallow subsurface flow paths as output.

- FEQ (Franz et al., 2009) Version 10.60, Full Equations Model

It is a one dimensional unsteady flow simulator for open channels. The program is designed based on the stream system to provide maximum applicability. It can consider different type of water structures like culverts and weirs and also can simulate a wide range of stream configurations.

- FESWMS-2DH (Froehlich D. C., 1995) Version 1.10.DG1, Finite-element surface-water modeling system for two-dimensional flow in the horizontal plane

This is a two dimensional depth-integrated surface water flow program which can be used for any surface water bodies like rivers, coastal seas and estuaries where the flow can be determined in two dimensions. It has different modules for input, flow model, output and graphics conversion which can be used to analyze flow of surface water where complicated hydraulic conditions exist like at bridge crossings.

- FourPt (DeLong, Thompson, & Lee, 1997) Version 95.01, An unsteady, one-dimensional, open-channel flow model

This is a one dimensional, open channel, unsteady flow program. It is a numerical model which can use different pre-defined and user defined governing equations. It can model different and complex flow conditions and geometries.

- GSFLOW (Markstrom et al., 2013) Version 1.1.6, Coupled Groundwater and Surface-water FLOW

This model is based on the USGS Precipitation-Runoff Modeling System (PRMS) and Modular Groundwater Flow Model (MODFLOW-2005). This program can simultaneously simulate flow across the land surface in saturated and unsaturated subsurface material. Climatic data such as temperature, solar radiation and precipitation, boundary conditions and groundwater stresses caused by withdrawals can be introduced to the program. It can consider different climate variability as well as change in land-use and can consider wide range of watershed areas with different time periods.

- WSPRO (Shearman, 1997) Version V060188, Water-Surface Profile Computation model

This program can be used for one dimensional steady state flow and can analyze open channels, flow through bridges, culverts, and embankment overflows. This program is designed by Federal Highway Administration (FHWA). The purpose of designing this program was to provide users with a highly flexible tool for analyses of different bridge openings. One of the advantages of this program is its user-friendliness and its applicability in water-surface profile analyses, flood plain mapping, and flood insurance studies.

Surface water movement, sediment transport, pollutant migration, water levels, salinity studies and management of riverine and estuarine requires the knowledge of flow parameters, wave and wind effects and in general hydrodynamics of that specific water-body. Several numerical models are available which are based on the type of problem, type of solution algorithm and type of flow. Models can simulate one, two or three dimensional problems, with finite difference or finite element solution algorithm, and can consider steady or transient type of flow. The complexity of the problem, level of accuracy and required time can affect the type of model. In general finite difference models are very stable and fast but very strict on meshing network but on the other hand finite element models are very flexible with meshing the domain but are more prone to errors. Therefore mathematical/numerical models can help to have better understanding of hydrodynamics of water bodies and can be useful in risk management

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