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National Management Measures to Control Nonpoint Source Pollution from Hydromodification

Chapter 8: Modeling Information

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Assessment and Watershed Protection Division
Office of Water
U.S. Environmental Protection Agency

Chapter 8: Modeling Information

Physical and chemical effects of hydraulic and hydrologic changes to streams, rivers, or other surface water systems can often be estimated with models and past experience (expert judgment). Several different models are available that can simulate many of the complex physical, chemical, and biological interactions that occur when hydraulic changes are imposed on surface water systems. Additionally, models can sometimes be used to determine a combination of practices to mitigate the unavoidable effects that occur even when a project is properly planned. Models, however, cannot be used independently of expert judgment gained through past experience. When properly applied models are used in conjunction with expert judgment, the effects of hydromodification activities (both potential and existing projects) can be evaluated and many undesirable effects prevented or eliminated. Models combined with expert judgment can also be used to evaluate existing hydromodification activities as part of operation and maintenance programs to identify possible opportunities to reduce or eliminate water quality impacts.

In the U.S. Army Corps of Engineers' (USACE's) report, *Review of Watershed Water Quality Models*[1] (Deliman et al., 1999), the authors compare and evaluate existing hydrologic and watershed water quality models, make recommendations for base model(s) for predicting nonpoint source (NPS) pollution, and identify areas for model improvement. The authors review commonly used and well validated models used in urban or nonurban settings. Users of the models can use the report to obtain basic model information and to review how well the models simulate NPS pollution and where the authors think improvements could be made. This information might be useful to readers who are trying to select the best model for analyzing how to reduce NPS pollution in their watersheds (Deliman et al., 1999).

Tables 8.1 and 8.2 below provided example of models and assessment approaches that could be used to determine the effects of hydromodification activities.

[1] http://el.erdc.usace.army.mil/elpubs/pdf/trw99-1.pdf

Available Models and Assessment Approaches

Table 8.1 lists some of the models available for studying the effects of channelization and channel modification activities, as well as models to analyze watershed runoff and to assess BMPs and low impact development to reduce impacts (of hydromodification activities.) The table also provides a quick description of each model and the dimension in which it models, as well as source and contact information.

Table 8.1 Models Applicable to Hydromodification Activities

Model	Dimension	Description	Model Resources
Channelization and Channel Modification Models			
BRANCH	1	The Branch-Network Dynamic Flow Model is used to simulate steady state flow in a single open channel reach or throughout a system of branches connected in a dendritic or looped pattern. The model is typically applied to assess flow and transport in upland rivers where flows are highly regulated or backwater effects are evident, or in coastal networks of open channels where flow and transport are governed by the interaction of freshwater inflows, tidal action, and meteorological conditions. (Last updated: 1997)	http://water.usgs.gov/cgi-bin/man_wrdapp?branch
CE-QUAL-RIV1	1	CE-QUAL-RIV1 is a one-dimensional (cross-sectionally averaged) hydrodynamic and water quality model, meaning that the model resolves longitudinal variations in hydraulic and quality characteristics and is applicable where lateral and vertical variations are small. CE-QUAL-RIV1 consists of two parts, a hydrodynamic code (RIV1H) and a water quality code (RIV1Q). The hydrodynamic code is applied first to predict water transport and its results are written to a file, which is then read by the quality model. It can be used to predict one-dimensional hydraulic and water quality variations in streams and rivers with highly unsteady flows, although it can also be used for prediction under steady flow conditions.	http://www.wes.army.mil/el/elmodels/riv1info.html

Model	Dimension	Description	Model Resources
CE-QUAL-W2	2	CE-QUAL-W2 is a two-dimensional, laterally averaged, finite difference hydrodynamic and water quality model for rivers, reservoirs, and estuaries. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. Branched networks can be modeled. The model accommodates variable grid spacing (segment lengths and layer thicknesses) so that greater resolution in the grid can be specified where needed.	http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home?selection=cequalw2 http://www.ce.pdx.edu/w2
CH3D-SED	1, 2, or 3	The CH3D numerical modeling system can be used to investigate sedimentation on bendways, crossings, and distributaries. Applications address dredging, channel evolution, and channel training structure evaluations.	http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Software;22
EFDC	1, 2, or 3	The Environmental Fluid Dynamics Code is a single source, three-dimensional, finite-difference modeling system having hydrodynamic, water quality-eutrophication, sediment transport and toxic contaminant transport components linked together.	John Hamrick developed this at the Virginia Institute of Marine Science 1990-1991. Dr. John Hamrick, Tetra Tech, Inc. 10306 Eaton Place, Suite 340 Fairfax, VA 22030
EFM	1	Ecosystem Functions Model (EFM) is a planning tool that analyzes ecosystem response to changes in flow regime. EFM allows environmental planners, biologists, and engineers to determine whether proposed alternatives (e.g., reservoir operations, levee alignments) would maintain, enhance, or diminish ecosystem health. Project teams can use EFM software to visualize existing ecologic conditions, highlight promising restoration sites, and assess and rank alternatives according to the relative enhancement (or decline) of ecosystem aspects. The hydraulic modeling portion of the EFM process is performed by existing independent software, such as HEC-RAS.	http://el.erdc.usace.army.mil/elpubs/pdf/smartnote04-4.pdf

Model	Dimension	Description	Model Resources
FESWMS-2DH	2	FESWMS-2DH is a finite element surface water modeling system for two-dimensional flow in a horizontal plane. The model can simulate steady and unsteady surface water flow and is useful for simulating two-dimensional flow where complicated hydraulic conditions exist (e.g., highway crossings of streams and flood rivers). It can also be applied to many types of steady or unsteady flow problems. (Last updated: 1995)	http://water.usgs.gov/cgi-bin/man_wrdapp?feswms-2dh
HEC-6	1	HEC-6 is a one-dimensional, moveable boundary, open channel flow numeric model designed to simulate and predict changes in river profiles resulting from scour and deposition over moderate time periods, typically years. Latest revision occurred in 1993.	http://www.hec.usace.army.mil/software/legacysoftware/hec6/hec6.htm
HEC-HMS	1	The HEC-HMS model is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is applicable in a wide range of geographic areas for solving the widest possible range of problems, including large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.	http://www.hec.usace.army.mil/software/hec-hms/index.html http://el.erdc.usace.army.mil/elpubs/pdf/smartnote04-3.pdf

Model	Dimension	Description	Model Resources
HEC-RAS	1	HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment. The system is comprised of a graphical interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The model performs one-dimensional steady flow, unsteady flow, and sediment transport calculations. The key element is that all three components will use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once basic water surface profiles are computed. The HEC-RAS modeling system was developed as a part of the Hydrologic Engineering Center's "Next Generation" (NexGen) of hydrologic engineering software. The NexGen project encompasses several aspects of hydrologic engineering, including: rainfall-runoff analysis; river hydraulics; reservoir system simulation; flood damage analysis; and real-time river forecasting for reservoir operations.	http://www.hec.usace.army.mil/software/hec-ras
HIVEL2D	1, 2	HIVEL2D is a free-surface, depth averaged model designed specifically to simulate flow in typical high-velocity channels.	http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software;6
RiverWare™	1	RiverWare™ is a reservoir and river modeling software decision support tool. With RiverWare™, users can model the topology, physical processes and operating policies of river and reservoir systems, and make better decisions about how to operate these systems by understanding and evaluating the trade-offs among the various management objectives. Water management professionals can improve their management of river and reservoir systems by using the software. The Bureau of Reclamation, the Tennessee Valley Authority, and the USACE sponsor ongoing RiverWare™ research and development.	http://cadswes.colorado.edu/riverware

Model	Dimension	Description	Model Resources
SAM	1	The model calculates the width, depth, slope and n-values for stable channels in alluvial material. SAM can be used to evaluate erosion, entrainment, transportation, and deposition in alluvial streams. Channel stability can be evaluated, and the evaluation used to determine the cost of maintaining a constructed project. The model is currently being improved and enhanced at WES.	http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software;2
SIAM	N/A	SIAM is a model designed to simulate the movement of sediment through a drainage network from source to outlet. It allows for evaluation of numerous sediment management alternatives relatively quickly. The model provides an intermediate level of analysis more quantitative than a conventional geomorphic evaluation, but less specific than a numerical, mobile-boundary simulation. SIAM is to be incorporated into a future release of HEC-RAS.	http://www.usbr.gov/pmts/sediment/model/srhsiam/index.html http://www.wes.army.mil/rsm/pubs/pdfs/RSM-2-WS04.pdf
SMS (RMA2 and RMA4)	1, 2	The Surface-Water Modeling System is a generalized numerical modeling system for open-channel flows, sedimentation, and constituent transport.	http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software;4
TABS-MD (RMA2, RMA4, RMA10, SED2D)	1, 2, or 3	The multi-dimensional numerical modeling system is a collection of generalized computer programs and utility codes, designed for studying multidimensional hydrodynamics in rivers, reservoirs, bays, and estuaries. The models can be applied to study project impacts of flows, sedimentation, constituent transport, and salinity.	http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=Software;10
WASP	1, 2, or 3	Water Quality Analysis Simulation Program. Framework for modeling contaminant fate and transport in surface waters. The WASP framework can be used to model biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination.	http://www.epa.gov/athens/wwqtsc/html/wasp.html

Model	Dimension	Description	Model Resources
Models to Analyze Watershed Runoff and Assess Practices to Reduce Impacts of Hydromodification			
BMP Decision Support System (BMP-DSS)	1	BMP-DSS is a decision-making tool for placement of BMPs/LID practices at strategic locations in urban watersheds based on integrated data collection and hydrologic/hydraulic/water quality modeling. The system uses GIS technology, integrates BMP processes simulation models, and applies system optimization techniques for BMP placement and selection. The system also provides interfaces for BMP placement, BMP attribute data input, and decision optimization management. The system includes a stand-alone BMP simulation and evaluation module, which complements both research and regulatory nonpoint source control assessment efforts and allows flexibility in examining various BMP design alternatives.	Developed by the EPA and Prince George's County Department of Environmental Resources. Contact Dr. Mow-Soung Cheng at 301-883-5836 for more information.
HSPF	1	Hydrological Simulation Program——FORTRAN (HSPF) is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF incorporates watershed-scale ARM and NPS models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. It is the only 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 a watershed. HSPF simulates three sediment types (sand, silt, and clay) in addition to a single organic chemical and transformation products of that chemical.	http://www.epa.gov/ceampubl/swater/hspf/index.htm

Model	Dimension	Description	Model Resources
LSPC	1	LSPC is the Loading Simulation Program in C++, a watershed modeling system that includes streamlined Hydrologic Simulation Program Fortran (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model. LSPC is derived from the Mining Data Analysis System (MDAS), which was developed by EPA Region 3 and has been widely used for mining applications and TMDLs. A key data management feature of this system is that it uses a Microsoft Access database to manage model data and weather text files for driving the simulation. The system also contains a module to assist in TMDL calculation and source allocations. For each model run, it automatically generates comprehensive text-file output by subwatershed for all land-layers, reaches, and simulated modules, which can be expressed on hourly or daily intervals. Output from LSPC has been linked to other model applications such as EFDC, WASP, and CE-QUAL-W2.	http://www.epa.gov/ATHENS/wwqtsc/html/lspc.html
Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds—Urban Catchment Model (P8–UCM)	1	P8–UCM is a model for predicting the generation and transport of stormwater pollutants in urban watersheds. Continuous water balance and mass balance calculations are performed on a user-defined system consisting of watersheds, devices (runoff storage/treatment areas, BMPs), particle classes, and water quality components. Simulations are driven by continuous hourly rainfall and daily air temperature time series data. The model simulates pollutant transport and removal in a variety of treatment devices (BMPs).	http://wwwalker.net/p8

Model	Dimension	Description	Model Resources
Storm Water Management Model (SWMM)	1	SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.	http://www.epa.gov/ednnrmrl/models/swmm/index.htm

Table 8.2 lists some of the available assessment models and approaches for assessing the biological impacts of channelization. The table also provides a quick description of the model or approach, as well as sources of additional information.

Table 8.2 Assessment Models and Approaches

Model or Assessment Approach	Description	Model Resources
Assessment Models		
AQUATOX	A freshwater ecosystem simulation model designed to predict the fate of various pollutants such as nutrients and organic toxicants and their effects on the ecosystem, including fish, invertebrates, and aquatic plants (including periphyton).	http://epa.gov/waterscience/models/aquatox
Cornell Mixing Zone Expert System (CORMIX)	A water quality modeling and decision support system designed for environmental impact assessment of mixing zones resulting from wastewater discharge from point sources. The system emphasizes the role of boundary interaction to predict plume geometry and dilution in relation to regulatory mixing zone requirements.	http://www.epa.gov/waterscience/models/cormix.html
HEC-HMS, Hydrologic Modeling System	A system designed to simulate the precipitation-runoff processes of dendritic watershed systems. In addition to unit hydrograph and hydrologic routing options, capabilities include a linear quasi-distributed runoff transform (ModClark) for use with gridded precipitation, continuous simulation with either a one-layer or more complex five-layer soil moisture method, and a versatile parameter estimation option.	http://www.hec.usace.army.mil/software/hec-hms/index.html
HEC-RAS, River Analysis System	The HEC-RAS system is used to calculate water surface profiles for both steady and unsteady gradually varied flow. The system can handle a full network of channels, a dendritic system, or a single river reach.	http://www.hec.usace.army.mil/software/hec-ras/hecras-hecras.html http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/Ras.html

Model or	Description	Model Resources
Physical Habitat Simulation Model (PHABSIM)	A set of computer programs designed to predict the microhabitat (depth, velocities, channel indices) conditions in rivers at different flow levels and the relative suitability of those conditions for different life stages of aquatic life. (Serves as the key microhabitat simulation component of IFIM.)	http://www.fort.usgs.gov/Products/Software/PHABSIM
Riverine Community Habitat Assessment and Restoration Concept (RCHARC)	A simulation approach using computer models to compare hydraulic conditions and microhabitats of a reference reach to alternative study reach(es).	Nestler, J., T. Schneider, and D. Latka. 1993. RCHARC: A new method for physical habitat analysis. *Engineering Hydrology*, 294-99.
RiverWare™	RiverWare™ is a reservoir and river modeling software decision support tool. With RiverWare™, users can model the topology, physical processes, and operating policies of river and reservoir systems, and make better decisions about how to operate these systems by understanding and evaluating the trade-offs among the various management objectives. Water management professionals can improve their management of river and reservoir systems by using the software. The Bureau of Reclamation, the Tennessee Valley Authority, and the Army Corps of Engineers sponsor ongoing RiverWare™ research and development.	http://cadswes.colorado.edu/riverware
Salmonid Population Model (SALMOD)	A computer model that simulates the dynamics (spawning, growth, movement, and mortality) of freshwater salmonid populations, both anadromous and resident, under various habitat quality and capacities.	http://www.fort.usgs.gov/Products/Software/SALMOD
Assessment Approaches		
A Procedure to Estimate the Response of Aquatic Systems to Changes in Phosphorus and Nitrogen Inputs	A simple tool to estimate the responsiveness of a waterbody to changes in the loading of phosphorus and nitrogen using a dichotomous key that classifies it according to key characteristics.	ftp://ftp.wcc.nrcs.usda.gov/downloads/wqam/aqusens.pdf

Model or	Description	Model Resources
EPA Volunteer Stream Monitoring Methods	A series of methods geared for volunteer monitoring programs offering simple to advanced techniques for monitoring macroinvertebrates, habitat, water quality, and physical conditions.	http://www.epa.gov/owow/monitoring/volunteer/stream
Habitat Evaluation Procedures/Habitat Suitability Index (HEP/HSI)	HEP is an evaluation method that determines the suitability of available habitat for select aquatic and terrestrial wildlife species and measures the impact of proposed land or water use changes on that habitat. HSI is a measure of habitat suitability.	http://policy.fws.gov/870fw1.html http://www.fort.usgs.gov/Products/Software/HEP http://www.fort.usgs.gov/Products/Software/HSI
Index of Biological Integrity (IBI)	An aquatic ecosystem health index using measures of total native fish species composition, indicator species composition, pollutant intolerant and tolerant species composition, and fish condition.	http://www.epa.gov/owow/wetlands/wqual/bio_fact/fact5.html
Indicators of Hydrologic Alteration (IHA)	A method for assessing the degree of hydrologic alteration attributable to human impacts within an ecosystem. The method takes daily stream flow values and calculates indices relating to the five components of flow regime critical for ecological processes: magnitude, frequency, duration, timing, and rate of change of hydrologic conditions.	http://www.nature.org/initiatives/freshwater/conservationtools/art17004.html
Instream Flow Incremental Methodology (IFIM)	A river network analysis that incorporates fish habitat, recreational opportunity, and woody vegetation responses to alternative water management schemes. Information is presented as a time series of flow and habitat at select points within the network.	http://www.fort.usgs.gov/Products/Software/IFIM
Invertebrate Community Index (ICI)	An invertebrate community health index using ten structural and compositional invertebrate community metrics including number of mayfly, caddisfly, and dipteran taxa.	http://www.epa.state.oh.us/dsw/bioassess/BioCriteriaProtAqLife.html

Model or	Description	Model Resources
(Modified) Index of Well-Being (IWB)	The IWB is a fish community health index using measures of fish species abundance and diversity estimates. The *modified* index of well being factors out 13 pollutant tolerant species of fish from certain calculations to prevent false high readings on polluted streams which have large populations of pollutant tolerant fish.	http://www.epa.state.oh.us/dsw/bioassess/BioCriteriaProtAqLife.html
Rapid Bioassessment Protocols (RBP)	A set of protocols that offer cost-effective techniques of varying complexity to characterize the biological integrity of streams and rivers using the collection and analysis of biological, physical, and chemical data. It focuses on periphyton, benthic macroinvertebrates, and fish assemblages, and on assessing the quality of the physical habitat.	http://www.epa.gov/owow/monitoring/rbp
Rapid Channel Assessment (RCA)	A reference stream/integrated ranking approach to evaluate the physical condition of a stream channel based on channel geometry, percent channel-bank scour, sediment size distribution and embeddedness, large wood debris, and thalweg profiles.	CWP. 1998. *Rapid Watershed Planning Handbook: A Comprehensive Guide for Managing Urbanizing Watersheds*. Center for Watershed Protection, Ellicott City, MD. For a copy contact: The Center for Watershed Protection, 8391 Main Street Ellicott City, MD 21043, email: center@cwp.org.
Rapid Stream Assessment Technique (RSAT)	A reference stream/integrated ranking approach to evaluate steam health based on chemical stability, channel scouring/sediment deposition, physical instream habitat, water quality, riparian habitat, and biological indicators.	CWP. 1998. *Rapid Watershed Planning Handbook: A Comprehensive Guide for Managing Urbanizing Watersheds*. Center for Watershed Protection, Ellicott City, MD. For a copy contact: The Center for Watershed Protection, 8391 Main Street Ellicott City, MD 21043, email: center@cwp.org. http://www.stormwatercenter.net
Rosgen's Stream Classification Method	A classification method that uses morphological stream characteristics to organize streams into relatively homogeneous stream types to predict stream behavior and to apply interpretive information.	Reference: Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO. For a copy contact: Wildland Hydrology Books, 1481 Stevens Lake Road, Pagosa Springs, CO 81147.

Model or	Description	Model Resources
Stream Network/Stream Segment Temperature Models (SNTEMP/SSTEMP)	Developed to help predict the consequences of stream manipulation on water temperatures, these computer models simulate mean daily water temperatures for streams and rivers from data describing the stream's geometry, meteorology, and hydrology. SNTEMP is for a stream network with multiple tributaries for multiple time periods. SSTEMP is a scaled down version suitable for single (to a few) reaches and single (to a few) time periods.	http://www.fort.usgs.gov/Products/Software/SNTEMP
Stream Visual Assessment Protocol (SVAP)	A simple procedure to evaluate the condition of a stream based on visual characteristics. It also identifies opportunities to enhance biological value and conveys information on how streams function.	ftp://ftp.wcc.nrcs.usda.gov/downloads/wqam/svapfnl.pdf
Systems Impact Assessment Model (SIAM)	An integrated set of models used to aid the evaluation of water management alternatives, it address significant interrelationships among selected physical (temperature, microhabitat), chemical (dissolved oxygen, water temperature), and biological variables (young-of-year Chinook salmon production), and stream flow. Developed for the Klamath River in northern California.	http://www.fort.usgs.gov/Products/Software/SIAM
Time-Series Library (TSLIB)	A set of DOS-based computer programs to create monthly or daily habitat time-series and habitat-duration curves using the habitat-discharge relationship produced by PHABSIM. (Can serve as the hydraulic component of IFIM).	http://www.fort.usgs.gov/Products/Software/TSLIB
TR-20, Computer Program for Project Formulation Hydrology	A physically based watershed scale runoff event model that computes direct runoff and develops hydrographs resulting from any synthetic or natural rainstorm. Developed hydrographs are routed through stream and valley reaches as well as through reservoirs.	http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_ Models/WinTR20.html
TR-55, Urban Hydrology for Small Watersheds	Simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs.	http://www.info.usda.gov/CED/ftp/CED/tr55.pdf

Examples of Channel Modification Activities and Associated Models/Practices

Modeling for Impoundments

A low-complexity option for modeling impoundments is to use simple models like the Bathtub model to simulate the waterbody. Compared to more complex multi-dimensional models, which use multiple computational cells to estimate volumetric and contaminant fluxes between the cells, Bathtub-type models typically use a single cell. This single cell, while a simplification of the system, may be appropriate if the system is fully mixed in both the horizontal and vertical dimensions. This approach can also be economically developed using spreadsheets (such as Excel) to calculate the results. However, a Bathtub-type model has limited utility if the water body is stratified or if results are required at more than one location in the system.

Another example of a modeling tool that has the ability to simulate impoundments is CE-QUAL-W2, a two-dimensional hydrodynamic water quality model. CE-QUAL-W2 provides results for either a horizontal or cross-sectional, two-dimensional plane. Because the model assumes a vertically or horizontally-mixed environment, it is best suited for relatively long and narrow water bodies (rivers, lakes, reservoirs, and estuaries) that exhibit longitudinal or vertical water quality stratification. The water quality portion of CE-QUAL-W2 includes the major processes of eutrophication kinetics and a single algal compartment. The bottom sediment compartment stores settled particles, releases nutrients to the water column, and exerts sediment oxygen demand based on user-supplied fluxes; a full sediment diagenesis (i.e., the process of chemical and physical change in deposited sediment during its conversion to rock) model is under development.

The Environmental Fluid Dynamics Code (EFDC) is a general-purpose modeling package for simulating one- or multi-dimensional flow, transport, and bio-geochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model was originally developed by Hamrick in 1992 at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software. This model is now EPA-supported as a component of EPA Region 2's PRVI BASINS software system and EPA's TMDL Toolbox,[2] and has been used extensively to support TMDL development throughout the country. In addition to hydrodynamic, salinity, and temperature transport simulation capabilities, EFDC is capable of simulating cohesive and non-cohesive sediment transport, near field and far field discharge dilution from multiple sources, eutrophication processes, the transport and fate of toxic contaminants in the water and sediment phases, and the transport and fate of various life stages of finfish and shellfish.

Modeling for Estuary Tidal Flow Restrictions

Artificial hydraulic structures have the ability to alter natural flow patterns (hydrodynamic) in an estuary, which may modify erosion patterns, salinity regimes, and the fate and transport of pollutants. Some examples of artificial hydraulic structures include culverts, bridges, tide gates,

[2] http://www.epa.gov/athens/wwqtsc/html/efdc.html

and weir structures. Installation or removal of these structures may cause a significant change in local hydrodynamics, and tools may be used to estimate the impacts prior to the modification.

The EFDC model, as described above, allows modelers to evaluate the impacts of hydraulic structures, such as culverts, bridges, tide gates, and weirs. Due to the flexibility of EFDC, each of these structures can also be conceptually represented in a variety of ways. For example, the weir equation can be applied to locations in the modeling grid to estimate water surface-dependent flow through one or more grid cells. This enables a modeler to evaluate the effect of placement of structures that modify surface flow patterns (such as a weir). Structures such as piers and impermeable barriers (e.g. jetties, breakwaters) can also be simulated using this code.

Another modeling tool that can address estuary tidal flow restrictions is the Finite Element Surface Water Modeling System (FESWMS) model. This modeling code was developed by the Federal Highway Administration (FHA) and is distributed by the U.S Geological Survey (USGS). FESWMS is a hydrodynamic modeling code that simulates two-dimensional, depth-integrated, steady or unsteady surface-water flows. It supports both super and subcritical flow analysis, and area wetting and drying. FESWMS is also suited for modeling regions involving flow control structures, such as are encountered at the intersection of roadways and waterways. Specifically, the FESWMS model allows the user to include weirs, culverts, drop inlets, and bridge piers into a standard two-dimensional finite element model. FESWMS does not have three-dimensional capabilities.

Modeling for Estuary Flow Regime Alterations

A number of structures or processes can alter the flow regime of a system. Flow contributions to an estuary can be altered by upstream rediversions or basin transfers, dams and dam releases, or other channel modifications. For example, when freshwater flows patterns are altered by the presence and operation of a dam, EFDC can be used to model the impact to downstream estuaries. EFDC can provide modelers with a time series representation of flow that is withdrawn from a simulated reservoir/dam system. Coupling the time series flow projections with hydrodynamic analysis of the receiving esturay enables modelers to determine potential impacts of altered flow patterms and to evaluate various spill options for the dam operation. Structures within the estuary that may alter the flow patterns include marinas, piers, jetties, and other similar type structures. Flow regime alterations due to these structures can be simulated using the same modeling tools described in the Flow Restrictions section above. Flow restrictions are the cause of most changes in the flow regime, so the simulation of the causes of restriction using a process-based modeling tool produces the desired flow alterations. Therefore, EFDC and FESWMS can be utilized in the same manner to obtain flow regime results.

Temperature Restoration Practices

Several computer models that predict instream water temperature are currently available. These models vary in the complexity of detail with which site characteristics, including meteorology, hydrology, stream geometry, and riparian vegetation, are described. The U.S. Fish and Wildlife Service developed an instream surface water temperature model (Theurer et al., 1984) to predict mean daily temperature and diurnal fluctuations in surface water temperatures throughout a stream system. The model, Stream Network Temperature Model (SNTEMP), can be applied to any size watershed or river system. This predictive model uses either historical or synthetic hydrological, meteorological, and stream geometry characteristics to describe the ambient conditions. The purpose of the model is to predict the longitudinal temperature and its temporal variations. The instream surface water temperature model has been used satisfactorily to evaluate the impacts of riparian vegetation, reservoir releases, and stream withdrawal and returns on surface water temperature. In the Upper Colorado River Basin, the model was used to study the impact of temperature on endangered species (Theurer et al., 1982). It also has been used in smaller ungauged watersheds to study the impacts of riparian vegetation on salmonid habitat.[3]

The Stream Segment Temperature Model (SSTEMP) is a much-scaled down version of the SNTEMP model developed by the USGS Biological Resource Division. Unlike the large network model (SNTEMP), this program only handles single stream segments for a single time period (e.g., month, week, day) for any given "run." Initially designed as a training tool, SSTEMP may be used satisfactorily for a variety of simple cases that one might face on a day-to-day basis. It is especially useful to perform sensitivity and uncertainty analysis. The model predicts minimum 24-hour temperatures, mean 24-hour temperatures, and maximum 24-hour stream temperatures for a given day, as well as a variety of intermediate values. The SSTEMP model identifies current stream and/or watershed characteristics that control stream temperatures. The model also quantifies the maximum loading capacity of the stream to meet water quality standards for temperature. This model is important for estimating the effect of changing controls or factors (such as riparian grazing, stream channel alteration, and reduced streamflow) on stream temperature. The model can also be used to help identify possible implementation activities to improve stream temperature by targeting those factors causing impairment to the stream. Good input data and an awareness of the model's assumptions are critical to obtaining reliable predictions. SSTEMP may be used to evaluate alternative reservoir release proposals, analyze the effects of changing riparian shade or the physical features of a stream, and examine the effects of different withdrawals and returns on instream temperature.[4]

Selecting Appropriate Models

Although a wide range of adequate hydrodynamic and surface water quality models are available, the central issue in selecting appropriate models for evaluating hydromodification projects is the appropriate match of the financial and geographical scale of the proposed project with the cost required to perform a credible technical evaluation of the projected environmental impact. It is highly unlikely, for example, that a proposal for a relatively small stream channel modification project, such as installing culverts in a stream segment, would be expected or required to contain a state-of-the-art hydrodynamic and surface water quality analysis that requires one or more person-years of effort. In such projects, a simplified, desktop approach (e.g., HEC-RAS Model) requiring less time and money would most likely be sufficient (USACE, 2002a). In contrast, substantial technical assessment of the long-term environmental impacts would be expected for channelization proposed as part of construction of a major harbor facility or as part of a system of navigation and flood control locks and dams. The assessment should

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[3] For more information or to download SNTEMP, see the U.S. Geological Survey Web site: http://www.fort.usgs.gov/Products/Software/SNTEMP.

[4] More information about the model is available on the U.S. Geological Survey Web site: http://www.mesc.usgs.gov/products/software/default.asp (navigate to Stream Network Temperature Model and Stream Segment Temperature Model).

incorporate the use of detailed 2D or 3D hydrodynamic models coupled with sediment transport and surface water quality models.

In general, six criteria can be used to review available models for potential application in a given hydromodification project:

1. Time and resources available for model application
2. Ease of application
3. Availability of documentation
4. Applicability of modeled processes and constituents to project objectives and concerns
5. Hydrodynamic modeling capabilities
6. Demonstrated applicability to size and type of project

The Center for Exposure Assessment Modeling (CEAM),[5] EPA Environmental Research Laboratory, Athens, Georgia, provides continual support for several hydrodynamic and surface water quality models, such as HSCTM2D, HSPF, PRZM3, and SED3D. Another source of information and technical support is the Waterways Experiment Station, USACE, Vicksburg, Mississippi.[6] Although a number of available models are in the public domain, costs associated with setting up and operating these models may exceed the project's available resources. For a simple to moderately difficult application, the approximate level of effort varies, but could range from 1 to 12 person-months.

Several factors need to be considered in the application of mathematical models to predict impacts from hydromodification projects including:

- Variations and uncertainties in the accuracy of these models when they are applied to the short- and long-term response of natural systems.
- Availability of relevant information (data collection) to derive the simulations and validate the modeling results.

The cost of a given modeling project depends on a number of factors. Questions need to be asked prior to the start of a modeling project to determine the purpose and future use of the model, and/or its results. For example, the modeler needs to know if the model results are to be used deterministically (the model assumes there is only one possible result that is known for each alternative course or action), or if the model is to be used for a heuristic (involving or serving as an aid to learning, discovery, or problem-solving by experimental and especially trial-and-error methods) scoping exercise to identify data gaps in a system. In a deterministic study, the results are traditionally compared to observed data in an effort regarded as calibration and validation. The model must therefore be rigorous enough to represent the system accurately. The complexity of the system under study is also a consideration that must be made prior to the project. The complexity of the system generally correlates well with the level of complexity of the model required to simulate it. Likewise, the more complex the model is, the more intensive it is to develop and run, and the more costly the modeling project is.

[5] http://www.epa.gov/ceampubl
[6] http://www.erdc.usace.army.mil

A number of approaches are available to model a given system, and the discussion above only highlights a few of the modeling tools currently available. The cost to set up a model for a given system varies tremendously, based not only on the modeling code selected, but also on what the modeler decides to simulate. For example, a modeler may aim to obtain flow results for an estuary using a given model. In reality, surface winds in that estuary may or may not be influencing the flow regime. If observed wind data is available from a weather station nearby, the modeler may choose to incorporate these data into the model to better represent that influence. The modeler may also choose not to incorporate these data, or the data may not be available. Although the modeler is utilizing the same modeling code, the decision regarding whether or not to simulate the wind conditions is not only a question regarding the model's purpose, but also what the development of this model will cost.

Modeling tools can range from simple spreadsheet tools using "back of the envelope" type calculations, to complex processed based models that must be run on high performance computing systems. As discussed previously, the tool selected for a given modeling project needs to be chosen with a number of questions in mind. As a result, each system can be modeled in a number of different ways with a number of different modeling codes. Therefore, the range in cost for even a single estuary or impoundment may range tenfold depending on the model's purpose. Typically, the cost of developing a model may range from a few thousand dollars for a simple spreadsheet model, to in excess of one million dollars for a more robust modeling system.