PREFACE

This model inventory was prepared for the Great Lakes Commission as a component of an ongoing project, Development of a Water Resources Decision Support System for the Great Lakes/St. Lawrence System. The project is sponsored by the Great Lakes Protection Fund.

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EXECUTIVE SUMMARY

This document presents a descriptive inventory of models with prospective relevance to ecological impact assessment of water withdrawals in the Great Lakes-St. Lawrence Basin. The inventory was prepared for the Great Lakes Commission as a component of an ongoing project, Development of a Water Resources Decision Support System for the Great Lakes/St. Lawrence System. Through this project, the Commission is developing the framework for a state-of-the-art decision support system that will provide the data, information and process required to ensure timely and well informed public policy decisions concerning the use and management of ground and surface water. The Great Lakes Protection Fund is supporting this effort.

The identification of relevant models was based on a literature and web-based search, as well as best professional judgment. Models in five categories were reviewed: hydrodynamic/hydraulic; surface water quality; hydrology/watershed; ecological effects; and groundwater. For each model, information related to key features is provided, including: the primary purpose of the model; previous applications; the applicability to assessing ecological impacts of water withdrawals; ease of use; strengths and weaknesses; and information on how to obtain the model. This information is found in the model review sheets in Appendix A. A list of other models that may also have relevance, but are not as widely distributed or used, is also included in this report (see Appendix B).

Most of the models reviewed in the inventory are distributed as stand-alone models, and they generally address one or more aspects of the overall problem, such as hydrodynamics, sediment transport, water quality, or ecological effects. Based on the current inventory, there is no single model that can, by itself, quantify the range of potential ecological impacts of a particular water withdrawal scenario. However, a suite of linked models can be used to address these types of management questions for different withdrawal scenarios. For example, a linked modeling framework comprised of groundwater, hydrodynamic, surface water quality, and ecological effects models may be used to evaluate the impact of a groundwater withdrawal on potentially impacted surface water ecosystems.

It is recommended that future studies build on this model inventory by developing linked model frameworks for selected water withdrawal scenarios. Such frameworks would be valuable tools in any decision support system that is developed for the Great Lakes.

1. INTRODUCTION

The Great Lakes Commission is currently developing the framework for a decision support system that will provide the data, information and process required to ensure timely and well-informed public policy decisions concerning the use and management of ground and surface water in the Great Lakes Basin. The Great Lakes Protection Fund is supporting this effort, which is titled: Development of a Water Resources Decision Support System for the Great Lakes/St. Lawrence System. Project Element Four addresses the compilation of an inventory of information on ecological impacts of current and prospective water use. One Element Four task involves the development of an inventory of existing models that may be used to contribute to a better understanding of ecological impacts. The outcome of this task will allow the policy/management community to determine model applicability to a decision support system (Great Lakes Commission, 2000).

1.1 STUDY OBJECTIVES

Specific objectives of the model review were to:

- Identify models applicable directly and/or indirectly to the assessment of the ecological impacts of water withdrawals in the Great Lakes basin;
- For the selected models, identify key model characteristics, including the model purpose, past applications and experience, data requirements, strengths and weaknesses, ease of use, and applicability to assessing the effects of water withdrawals; and
- Compile the information into a user-friendly, descriptive inventory that provides supporting information.

1.2 STUDY APPROACH

A literature and web-based search was first conducted to identify relevant models. Models in 5 categories were reviewed: hydrodynamic/hydraulic; surface water quality; hydrology/watershed; ecological effects; and groundwater. Models included in the inventory were selected on the basis of their relevance to the problem, their availability for general use, and their wide-spread use and acceptance. A review sheet that describes key model characteristics and capabilities and other information was then prepared for each selected model. A list of other models that may also have relevance, but are not as widely distributed and used is also included (see Appendix B). For completeness, this list includes the models for which review sheets were prepared in Appendix A.

2. DESCRIPTIVE MODEL INVENTORY

The descriptive model inventory is presented in Appendix A. Review sheets are provided for 38 models. The models fall into at least one of five categories: hydrodynamic/hydraulic; surface water quality; hydrology/watershed; ecological effects; and groundwater. The model category is indicated at the top of each sheet. The model review sheets are organized alphabetically by model name.

While the models included in the descriptive model inventory are the models that are considered through this review to have the most relevance to assessing the ecological effect of water withdrawals and have seen general acceptance among the modeling community, it is recognized that other models exist that may also be relevant. Appendix B provides an overview of these models by category. Each table in Appendix B lists potentially relevant models in a particular category, and provides a brief description and information on the supporting agency/developer. The models that are described in detail in the descriptive model inventory are included in these tables as well, for completeness.

2.1 INFORMATION PROVIDED IN THE INVENTORY

For each selected model, the descriptive inventory in Appendix A provides the following key information:

- Category of model
- Developer and distributor
- Primary purpose
- Applications and experience
- Overview of characteristics
- Applicability for assessing ecological impacts of withdrawals
- Data requirements
- Ease of use
- Strengths and weaknesses
- Other notes and reference

Where possible, references to useful web sites and other references are provided. In a limited number of cases, a particular information box blank was left blank; this was done in cases where the indicated information was not found in the literature and the authors did not have direct experience with the model of concern.

2.2 DESCRIPTION OF MODEL CATEGORIES

The first row in each model sheet in Appendix A indicates the model category. Models that address multiple processes are classified in more than one category. For example, a model that is described as a hydrodynamic-water quality model is included in both categories. It should be noted that no geomorphic models for nearshore zones were included in the inventory. Such models have been developed for some Great Lakes rivers, and they focus on hydrodynamic and sediment transport processes. Such models should be reviewed in the future to assess their applicability to water withdrawal scenarios.

2.2.1 Hydrodynamic/Hydraulic Models

Hydrodynamic/hydraulic models provide a description of circulation, mixing and density stratification processes that can affect the water quality and transport of pollutants within a water body. These models use waterbody geometry, boundary conditions, inflows, withdrawals, and meteorological data to simulate water levels, flow velocities, salinities, temperatures, and velocity field. Information on physical properties of water body such as depth, slope of bed, morphology of river channels, surface area, wind speed, mixing depth, precipitation and temperature and pressure regimes are examples of the parameters that are used as input to these models. Physical processes simulated by hydrodynamic models include tidal, wind, and buoyancy or density forcing, and turbulent momentum and mass transport. The spatial dimensions of these models vary from 1-D longitudinal, 2-D in the longitudinal and vertical, 2-D in the horizontal (vertically-averaged), to fully 3-D. Hydrodynamic models use numerical solutions to fundamental governing equations for the conservation of momentum and/or mass to predict water movements.

Some hydrodynamic models (e.g. EFDC, CH3D-WES, DYNHYD5) are distributed as stand alone models and can be coupled internally or externally with water quality models such as WASP5, CE-QUAL-W2, and CE-QUAL-ICM. Some hydrodynamic models simulate a thermal balance for the system and generate turbulent shear stresses for sediment transport models.

Hydrodynamic models may also form the transport foundation for lake or river mass balance models. They use hydrometeorological forcing functions to predict the transport that is needed for a constituent mass balance simulation. A mass balance design based upon hydrodynamic transport is advantageous, for example, when applying site-specific mass balance models to other locations.

A hydraulic model can be used to simulate variations in the composition and distribution of habitats during different flow regimes. This information is important for developing habitat and bioenergetic models for fish.

2.2.2 Hydrologic/Watershed Models

Hydrologic/watershed models are useful for assessing hydrology for managing the water resources of watersheds. This category includes the models that simulate the generation and movement of water and water-borne pollutants from the point of origin to discharge into receiving waters. These models can be used to quantify total watershed contributions of flow, sediment, nutrients, and other constituents of interest. The hydrologic/watershed models can be applied for evaluating surface and subsurface pollutant transport to receiving water with subsequent simulation of instream transport and transformations, watershed hydrology and water quality for both conventional and toxic pollutants.

Generally, these models require hydrometeorologic data such as rainfall, records of evapotranspiration, temperature, humidity, and solar intensity. The watershed loading models evaluate the effects of land uses and practices, land cover, and soil properties on pollutant loadings to waterbodies. Land use practices, including the implementation of best management practices (BMPs) for control of non-point water and pollution sources, can also alter the river flows, which could be a result of construction of regulated structures such as dams and reservoirs, increased agricultural uses, changes in forest areas, and increased urban land use. The flow conditions in the watershed and associated pollutant loadings can also be affected by the discharge of residual material from waste treatment plants, from combined sewer overflows, or from agricultural and urban runoffs.

Available hydrologic/watershed models vary from simple methods to detailed loading models depending on their capabilities. Simple methods have very limited predictive capabilities and generally provide rough estimates since they are typically derived from empirical relationships. Detailed models are generally complex models with greater spatial and temporal resolutions, and they use storm events or continuous simulation to predict flow and pollutant concentrations for a range of flow conditions. They include physical processes of infiltration, runoff, pollutant affects, groundwater and surface water interactions. Applications for these models vary depending on data availability and modeling needs.

Some watershed models such as HSPF are developed for simulating water quality and quantity for a range of pollutants and are extensively used in both screening level and detailed analyses. Some hydrologic models are capable of assessing water resources over the long term while others simulate short term predictions. Models such as the large basin runoff model (LBRM) built by the Great Lakes Environmental Research Laboratory (GLERL) are designed as a continuous-time flow representation for assessing water resources questions over the long term.

2.2.3 Surface Water Quality Models

Surface water quality models (models for computing water quality in lakes, rivers and streams, estuaries, and nearshore areas as a function of loads and other forcing conditions) address problems associated with water quality variables that can result in fish kills, taste and odor problems, human health impacts, and other ecosystem disturbances. This category of models includes models of dissolved oxygen, nutrient-eutrophication, sediment transport, and fate and transport of contaminants (including conventional and toxic pollutants and pathogens). Surface water quality models are used to analyze water quality related problems and to synthesize the principal components: inputs; reactions and physical transport; and outputs. The analysis of pollutants in surface waters describes load-response relationships, cause-effect mechanisms, and, in some cases, the impact of pollutants on biota in the system.

These models focus on the objective of protecting plants, animals, humans, wildlife, aquatic life, and the environment from the negative effects pollutants and toxic substances.

Some water quality models simulate the effect of pollution discharges from various sources to air, water and land in a variety of ways. The external inputs include point and non-point sources. Point sources consider the municipal point sources that result in discharges of treated and partially treated sewage and industrial discharges. Municipal discharges contain partially treated sewage associated with bacteria and organic matter, biochemical oxygen demand (BOD), nutrients and toxic substances, whereas industrial discharges contain nutrients, BOD, metals and toxic chemicals. Non-point sources include agricultural, atmospheric, silviculture, urban and suburban runoff, and groundwater inputs to a receiving surface water body.

The parameters simulated include nutrients (generally phosphorus, nitrogen, silicon), dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), chlorophyll, temperature, phytoplankton, zooplankton, and fecal coliform. Model process coefficients, initial conditions and boundary conditions are required as inputs to water quality models. These models simulate physical (dilution, advection, dispersion), chemical, and biological processes (e.g.,nutrient-algal cycle, algal growth and kinetics, DO-BOD cycle, decay, benthic algae, and sediment digenesis). The processes incorporated into a model help to define the ability of that model to address specific water quality problems.

Eutrophication models predict the production, transformation, and decay of phytoplankton biomass in response to changes in nutrients, temperature and light. These types of models simulate autochthonous solids loads (primary production), transformation and decay rates that can be used as inputs to a sediment transport or to a contaminant fate and transport model. In some cases, eutrophication and sorbent dynamic models are coupled together, which derive and form the basis for the hydrophobic contaminant transport models. The biomass growth rate components of eutrophication model can be linked to a food web bioaccumulation model to predict the contaminant body burden in species.

2.2.4 Groundwater Models

Groundwater models address issues related to water supply, sub-surface containment transport, remediation, and mine dewatering. These models can be used for tracking pollutants in the saturated and unsaturated zones, evaluating the transport of pollutants due to migration and interactions of groundwater and surface water. Groundwater withdrawals can result in lower river and stream water levels. The hydrology of the watershed can be impacted due to precipitation, runoff, groundwater, surface storage, and river water levels. In fact, the watershed hydrology includes (indirectly) the groundwater components while assessing the impact of water quantity on watersheds.

Groundwater flow can be affected by surface runoff and infiltration in the soil zone, which is a function of moisture content of the soil. Groundwater flow and evapotranspiration from the groundwater zone depend on the groundwater zone moisture content. Soil moisture evaporates, or it can be transpired by vegetation and these processes depend on solar radiation, temperature, humidity, wind speed and type of vegetation. Soil and groundwater storage can affect river supplies. Coupled watershed and groundwater models can simulate the effect of water fluctuations on groundwater flow and its influence on watershed hydrology.

Groundwater models generally require a large amount of information and a complete description of the flow system. Data on spatial orientation of geologic units, topography, hydraulic parameters (hydraulic conductivity, transmissivity, specific yield, etc.), boundary conditions (location of impermeable boundaries and constant heads), and stresses (pumping wells, recharge from precipitation, rivers, drains, etc.) are examples of required inputs.

Groundwater models also differ in their capabilities; some track multi-phase constituents such as oil and gas in groundwater, and others include the ability to model the fate and transport of constituents such as temperature, salinity, metals, nutrients, and organic compounds. For most of the groundwater models, a high level of expertise is required.

2.2.5 Ecological Effects Models

This category includes a wide variety of models and techniques for the ecological assessment of aquatic system. It includes habitat and species classification, index systems, as well as toxicological and ecological models that simulate the effect of stressors on habitats. These types of models can examine or predict the status of a habitat, biological population, or biological community. The effect of water withdrawals can cause changes in the features of the system such as depth, velocity, temperature, oxygen, surface area and vegetation, and this information can be used for evaluating the effect on aquatic ecosystem. To the extent that an aquatic ecosystem model responds to these hydraulic and hydrologic changes, it has value in relation to the problem at hand.

Ecological effects models for addressing the impacts of water withdrawals include a wide range of evaluation and assessment techniques that affect the ecosystem structure and function. Changes in water quantity, water quality, and sediment dynamics driven by water withdrawals can affect the following components and interactions in an aquatic ecosystem:

- Species habitat;
- Production and diversity of flora;
- Acute and chronic toxicity to any species;
- Population levels;
- Growth of species (that can affect the bioenergetics costs);

- Predator-prey relationships;
- Food web structure;
- Energy flow and nutrient cycling; and
- Bioaccumulation of contaminants.

Specifically, for dealing with issues related to fish species, the effects models should incorporate the effect of hydraulic conditions on:

- Fish stranding under various climatic and diurnal conditions;
- Fish behavior and shelter-type that can vary with flow conditions;
- Effects on the shift in substrate type, vegetation, and water quality that may affect fish behavior, recruitment and survival; and
- Effects on the activities and bioenergetics of different lifestages and species.

Because of the inherent connection between species and its habitat, the effects models are best suited when used in combination with each other, as well as with other categories of models. Several environmental impact assessment modeling frameworks have been developed to assess the effects of different flow conditions on aquatic ecosystems. For example, the Instream Flow Incremental Methodology (IFIM) is a habitat-based impact assessment and water management tool used to manage fishery habitat in a stream. These steady flow frameworks would need to be modified to include the potential effects due to changes in flow conditions on habitat and aquatic biota. Instream flow requirements procedures determine the amounts of streamflow necessary to sustain instream values at acceptable levels.

3. HOW TO USE THE INVENTORY

The selection of the appropriate models to address a particular management question is based on many considerations, including management objectives, data availability, and available resources. The models presented in the descriptive model inventory differ in their capabilities, complexity, and resource requirements. The model inventory provides useful information to support the model selection process. However, model users should carefully define the management problems, and gain a full understanding of the system before selecting models from this inventory. The data needs associated with many of these models may require significant resources to apply them on a site-specific basis; resource and data availability for a given site are critical considerations in the model selection process.

In some contexts, a set of models might be needed to address multiple stressors and the interrelationship of various processes and components. In this case, the objectives can be met by using a combination of models. An integrated modeling framework comprised of a suite of models can be useful for assessing the effect of water use and water withdrawals on ecosystems. However, model linkage compatibilities must be considered, and accomplishing this in a credible fashion may take significant resources.

Generally, the complexity of a modeling application should increase (as does the costs associated with their development and application) as the complexity of the nature of the management problems increases. The model inventory describes models that range from simple to complex. Simple models require less expertise and less data, so they can be used by a wider community, but often they are limited in the management questions that they can credibly address. Complex models generally have high spatial, temporal and process resolutions, require large data sets, and involve extensive computation efforts. These models can be used by a limited number of experts. Also, in some cases these more complex models have undergone limited field testing (i.e., ground-truthing on a variety of systems) and great care should be taken in applying them on a site-specific basis without rigorous calibration.

For selecting models from this inventory, user-specific information for the following factors will help meet the needs:

- Management Objective: A clear definition of the problem must be outlined.
- Global Modeling Objective: Define the specific modeling need.
- Spatial and Temporal Scales: Define the resolution needs including the aspects like steady-state or time varying.
- Constituents of concern/stressors: Identify the conventional and toxic pollutants and biota that play a role in problem definition.
- Resources available: Identify available system specific inputs, calibration, and validation data set.

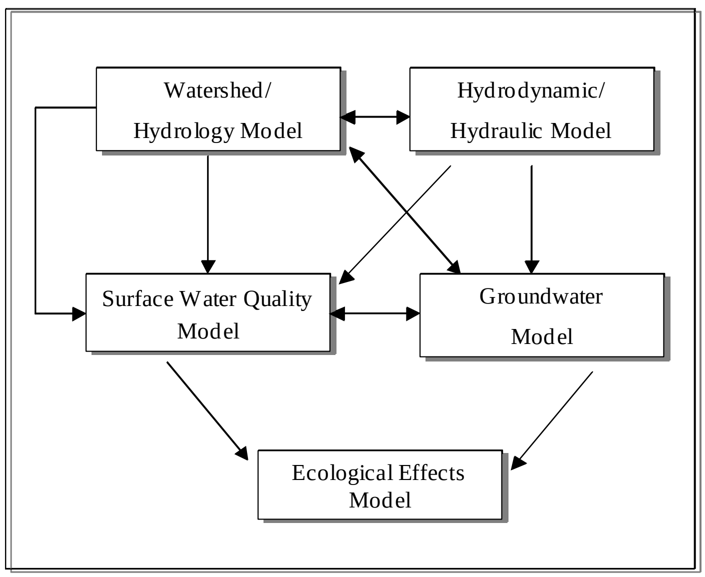
- Constraints: Identify the availability of modeling expertise, ease of use concerns, the model accuracy, and details required.
- Level of analysis: Define whether the analysis is a screening level or detailed.

Along with these factors, additional information on waterbody type and model availability, and input/output aids such as GUIs, graphics, and post-processors can be useful in selecting models. Additionally, hydrodynamic model results can be scaled to provide transport predictions at desired spatial and temporal scales. The selection of hydrodynamic models depends on the type of water body and circulation processes that affect the water quality conditions. For dealing with combined effects of eutrophication and contamination in an ecosystem, models that consider these problems in a single framework can be applied.

4. RECOMMENDATIONS

The models reviewed in this report generally address one or more system processes, such as hydrodynamics, sediment transport, water quality, or ecological effects. Based on the current inventory, there is no single model that can, by itself, quantify the ecological impacts of a particular water withdrawal scenario. However, a suite of linked models can be used to address these types of management questions for different withdrawal scenarios. For a withdrawal from a river, for example, a model framework may be comprised of a watershed hydrologic model, a river water quality model, and one or more ecological effects models.

The figure below illustrates the five categories of models and their potential interconnectivity. The output from one category of model can serve as an input to another category of model.



Interconnectivity of Five Categories of Models

The model frameworks can be built from the existing state-of-the-science models reviewed in this inventory. Linked model frameworks for selected withdrawal scenarios could provide very useful assessment tools in any decision support system framework that is developed for the Great Lakes.

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Appendix A

Descriptive Model Inventory

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☑Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	Aquatic Landscape Inventory System (ALIS) and associated database
Developed by:	Ontario Ministry of Natural Resources, Geomatics and Aquatic Ecosystems Science Sections
Distributed by:	Ontario Ministry of Natural Resources
Primary Purpose:	Conduct landscape level inventories of aquatic ecosystems. Measure a variety of attributes for individual sites. Provide procedures for stratifying systems based on a variety of attributes and a database for querying, summarizing and classifying individual units (segments) of waterbodies
Applications and Experience:	Application is being used to produce a blueprint of the biodiversity of the Great Lakes Basin (Ontario side), an inventory of Lake Huron watersheds, and to develop bioregional models for Lake Ontario
Overview of Characteristics:	Attributes measured include: surficial geology, upstream catchment area, segment slope, connectivity, position in the watershed, landuse, hydrography, barriers
Applicability for Assessing Ecological Impacts of Withdrawals:	Can be used to measure attributes of sites and catchments in support of model development or data can be used to apply existing models by incorporating the models into the access database.
Data Requirements:	Flow corrected Digital elevation model, Arc info 7.0, Access 97, datalayers for surficial geology, waterflow and landuse
Ease of Use:	Requires GIS expertise to run application and pentium 2 or greater. Minimal experience using Access required for use of the database
Strengths and Weaknesses:	▪ Strengths: objective, repeatable, defensible and efficient means of conducting landscape inventories. Flexibility is built into the system to allow users to define parameters and thresholds for applications. New attributes can be easily added in (i.e., bedrock geology). Easily incorporates summary models and new outputs (i.e., working on flow model outputs). ▪ Weaknesses: datasets can be large and overwhelming. Computer time required to run on large watersheds can be long (4 weeks). A database manager is required to maintain datasets and produce queries
Other Notes:	Contact Les Stanfield (613-476-8777) or Randal Kuyvenhoven (705-755-5024)

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	AQUATOX: A SIMULATION MODEL FOR AQUATIC ECOSYSTEMS
Developed by:	Developed for EPA by Richard A. Park and Jonathan S. Clough
Distributed by:	U.S. EPA Office of Science and Technology http://www.epa.gov/waterscience/models/aquatox
Primary Purpose:	Predicts the fate of various pollutants, such as nutrients and organic chemicals, and their effects on the ecosystem, including fish, invertebrates, and aquatic plants. Potential applications would include development of water quality nutrient criteria, TMDLs, and analysis of management alternatives.
Applications and Experience:	AQUATOX has been applied for nutrient analysis for Onondaga Lake, New York and Coralville Reservoir, Iowa, and for PCB bioaccumulation in Lake Ontario.
Overview of Characteristics:	AQUATOX is a process-based model that explicitly simulates numerous biological and ecological processes, including food consumption; growth and reproduction; natural mortality; acute and chronic toxicity; trophic interactions; nutrient cycling and oxygen dynamics; partitioning of organic toxicants to water, biota, and sediments; toxic organic chemical transformations; and bioaccumulation through gills and diet. Constituents modeled: Multiple algal species, submerged aquatic vegetation, benthic invertebrates, zooplankton, fish, nutrients, dissolved oxygen, sediments, toxic organic chemicals. Model output is provided in terms of time-varying biomass of the various plants and animals; chemical concentrations in water; and concentrations of the organic toxicant in water, organic sediments, and biota. Output can be exported to spreadsheet programs. The program also has graphing capability and allows uncertainty and sensitivity analyses. AQUATOX has a myriad of potential applications to water management issues and programs, including water quality criteria and standards, TMDLs (Total Maximum Daily Loads), and ecological risk assessments of aquatic systems. AQUATOX can be used to predict ecological responses to proposed management alternatives. It may help to determine the most important of several environmental stressors, e.g. where there are both nutrients and toxic pollutants.
Applicability for Assessing Ecological Impacts of Withdrawals:	AQUATOX evaluates ecological risk assessment by considering water quality and TMDLs. It could be a useful tool for addressing ecological responses to management decisions.
Data Requirements:	Model requires waterbody loadings, general site characteristics, chemical characteristics for organic toxicants, and biological characteristics for plants and animals. AQUATOX includes data libraries that provide default data.
Ease of Use:	Windows-based; designed to be user-friendly. Requires a trained user with significant modeling experience.
Strengths and Weaknesses:	▪ AQUATOX is well suited for analysis of waterbodies under stress from nutrient enrichment, such as nuisance algal blooms. Potential applications would include development of water quality nutrient criteria, TMDLs, and analysis of management alternatives. ▪ AQUATOX is one of the few general ecological risk models that represents the combined fate and effects of toxic chemicals. ▪ The model has large resource requirements and requires a trained user.
Other Notes:	U.S. EPA, 2000. AQUATOX A Modular Fate & Effects Model for Aquatic Ecosystems. EPA-823-R-006 (User's Manual); EPA-823-R-007 (Technical Documentation); EPA-823-R-008 (Model Validation Reports).

Category of Model:	☑ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	ATLSS: Across Trophic Level System Simulation for the Freshwater Wetlands of the Everglades and Big Cypress Swamp
Developed by:	Coordinated through: Biological Resources Division (BRD), U.S. Geological Survey (USGS) Coordinated by: Donald L. DeAngelis, Adjunct Professor, Miami University (ddeangel@fig.cox.miami.edu) (305) 284-1690. The model components constructed at the Institute for Environmental Modeling of the University of Tennessee at Knoxville (UTK) were coordinated by Louis Gross (Professor of Ecology and Mathematics, UTK) and Michael Huston (Oak Ridge National Laboratory/UTK Collaborating Scientist and Professor of Ecology, UTK), with code development and production carried out by Ethel Jane Comiskey, Mark Palmer, Michael Peek, and Scott Sylvester. Particular models were developed by with the assistance of several UTK graduate students including Holly Gaff, Phil Nott, Rene' Salinas and Maurice Shorrosh. Other key personnel involved in the modeling components of the project include: D. Martin Fleming (Scientist, NBS), Paul Fishwick (University of Florida), William Loftus (Scientist, NBS), Robert Ulanowicz (Professor, Chesapeake Biological Laboratory, University of Maryland); and Wilfried Wolff (Scientist, Forschungszentrum Julich, Germany). Financial support for the project was provided by several agencies, all coordinated through the BRD.
Distributed by:	
Primary Purpose:	The system was used to compare the future effects of alternative hydrologic scenarios on the biotic components of the systems. Due to the varying scales at which trophic interactions occur, and the importance of population structure and individual behavior for population prediction in higher trophic level organisms, use of a single modeling approach was not appropriate
Applications and Experience:	Used extensively in Florida Everglades Restoration planning to establish the quantity, quality, timing, and distribution of deliveries of water best suited for different portions of the ecosystem. The challenge for restoration lies in balancing the hydrologic conditions needed by communities of plants and animals, while maintaining supplies and flood control for a large and expanding population. Application of ATLSS models as part of the Central and South Florida Comprehensive plan for the U.S. Army Corps of Engineers (completed 10/97)
Overview of Characteristics:	ATLSS is an integrated set of computer simulation models encompassing principle components of the biotic community in a spatially explicit way across the South Florida landscape. An integrated modeling system is defined as models that are constructed to allow coupling or linkage of the various trophic levels across a spatially explicit (grid based) landscape structure. This landscape structure incorporates remote sensing information on elevation, vegetation, etc, and simulation model outputs from other landscape models (e.g. hydrology, landscape, and plant community succession models). A set of models was designed to integrate three approaches for different trophic levels of the system: (1) process models for lower trophic levels (including benthic insects, periphyton and zooplankton), (2) structured population models for five functional groups of fish and macroinvertebrates, and (3) individual-based models for large consumers (wood storks, great blue herons, white ibis, American alligators, white-tailed deer, and Florida panther). These models were integrated across the freshwater landscape of the Everglades and Big Cypress Swamp and coupled to GIS maps for cover type. Spatial scales of resolution for the models are as small as 100 m, with the capability to vary this based upon the scale of available input data. The system is coupled to a hydrology model, and used to assess the effects of alternative proposed restoration scenarios on trophic structure.
Applicability for Assessing Ecological Impacts of Withdrawals:	Provides the ability to evaluate the effects of alternate hydrologic conditions on a variety of trophic levels.
Data Requirements:	Requires detailed data for both physical (hydrologic data) and biological information about the hydrologic requirements of a variety of species (e.g., alligator) over their lifecycles. Integrated or supporting models: Landscape Model (completed 06/96); Vegetation biomass production model (completed 06/96); Lower trophic level model (completed 06/96); Fish functional group model (completed 06/97); Cape sable seaside sparrow model (completed 08/97); Florida panther/white-tailed deer model (completed 06/97).
Ease of Use:	Requires the expertise of many with specific knowledge about the features they are modeling.

Strengths and Weaknesses:	Provides very comprehensive modeling. Requires large amounts of processing, data collection and requires the expertise of many with specific knowledge about the features they are modeling.
Other Notes:	http://sofia.usgs.gov/metadata/sflwww/metdeang.html http://www.fcsc.usgs.gov/Ecosystem_Modeling/Modeling_Current_Projects/Modeling_ATLSS/modeling_atlss.html http://www.fcsc.usgs.gov/atlssflier.pdf

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☑ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	BASINS: **B**etter **A**ssessment **S**cience **I**ntegrating point and **N**onpoint **S**ources
Developed by:	Office of Science and Technology Office of Water USEPA 1200 Pennsylvania Avenue, NW, Washington, DC 20460
Distributed by:	USEPA Office of Science of Technology http://www.epa.gov/ost/basins
Primary Purpose:	Primary purpose is (1) to facilitate examination of environmental information, (2) to provide an integrated watershed and modeling framework, and (3) to support analysis of point and nonpoint source management alternatives.
Applications and Experience:	Beside BASINS' primary role in creating TMDL analysis, it has been useful in identifying impaired surface waters from point and nonpoint pollution, wet weather combined sewer overflows (CSO), storm water management issues, and drinking water source protection. BASINS also has been used in urban/rural landuse evaluations, animal feeding operations, and habitat management practices. Another unexpected use of BASINS is providing schools and educational institutions with a quick, free resource of GIS and surface water data for the United States. BASINS wide range of application is possible because of its linkage to water quality and watershed models such as HSPF, QUAL2E, SWAT, and PLOAD.
Overview of Characteristics:	BASINS integrates a geographic information system (GIS), national watershed and meteorologic data, and state-of-the-art environmental assessment and modeling tools into one convenient package. The components include: ▪ Nationally derived databases with Data Extraction and Project Builder tools ▪ Assessment tools (TARGET, ASSESS, and Data Mining) that address large- and small-scale characterization needs, ▪ Utilities to facilitate importing local data and for organizing and evaluating data, ▪ Watershed Delineation tools, ▪ Utilities for classifying elevation (DEM), land use, soils, and water quality data, ▪ Watershed Characterization Reports that facilitate compilation and output of information on selected watersheds, ▪ An in-stream water quality model ▪ Two watershed loading and transport models, and ▪ A simplified GIS based nonpoint annual loading model. BASINS includes: ▪ WinHSPF is a simplified version of the HSPF model. It has the same objectives as HSPF (See HSPF review sheet for more detail). ▪ QUAL2E: The enhanced Stream Water Quality Model with Uncertainty Analysis (See QUAL 2E model review sheet for more detail). ▪ TOXIROUTE: is a modified version of Pollutant (PROUTE). ▪ A watershed model called Soil Water Assessment Tool (SWAT), developed by the U.S. Department of Agriculture's ARS (See SWAT review sheet for more detail). ▪ An automatic delineation tool that allows users to delineate watershed based on a Digital Elevation Model (DEM) grid formatted data. ▪ An enhanced manual delineation tool that allows users additional flexibility in editing shapes and attributes of manually delineated watersheds. ▪ PLOAD, a model developed by CH2M-Hill, which uses export coefficients to estimate watershed loading. ▪ A time series data management utility called WDMUtil. ▪ A grid projector that allows the user to project grid data. ▪ An improved Permit Compliance System Point source (PCS) database with annual loadings updates through 1999. BASINS supports the development of total maximum daily loads (TMDLs), which require a watershed-based approach that integrates both point and nonpoint sources. It can support the analysis of a variety of pollutants at multiple scales, using tools that range from simple to sophisticated.

Applicability for Assessing Ecological Impacts of Withdrawals:	BASINS is well suited to bring together spatially and temporally spaced data into a single framework. The models included with BASINS are suitable for water quantity and quality analysis involving various types of withdrawals and environmental conditions. For information regarding model capabilities see the respective review sheet.
Data Requirements:	Data needs for BASINS are extensive. Much of the necessary data is provided with the software, and more detailed, site-specific data can be added if desired. Data requirements for WinHSPF, SWAT, QUAL2E, and PLOAD are found on their respective review sheets.
Ease of Use:	BASINS includes an internal database management system to process the large amounts of simulation input and output; Automatic linkage to necessary GIS coverages provided as part of the BASINS software; and default values provided for most model inputs. Proper model selection and application requires significant judgment and expertise on the part of the user.
Strengths and Weaknesses:	Overcoming the lack of integration, limited coordination, and time-intensive execution typical of more traditional assessment tools, BASINS makes watershed and water quality studies easier by bringing key data and analytical components together "under one roof." The primary limitation of BASINS corresponds to its extensive resource requirements. There is also concern that providing automated access and/or default values for all model inputs and data will lead to applications that do not adequately describe the system. There is lack of data for many watersheds.
Other Notes:	USEPA, 1998. Better Assessment Science Integrating Point and Nonpoint Sources. Office of Water, Washington, D.C. EPA-823-B-98-006.

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Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	CE-QUAL-ICM: A Three-Dimensional Time-variable Integrated-Compartment Eutrophication Model
Developed by:	Water Quality and Contaminant Modeling Branch, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, 2909 Halls Ferry Road, Vicksburg, MS 39180, (601) 634-3785
Distributed by:	Same as above
Primary Purpose:	Simulate time-varying concentrations of water quality constituents by coupling hydrodynamic and water quality components.
Applications and Experience:	Used in conjunction with a hydrodynamic model and a benthic-sediment model to develop a state-of-the-art 3-D model of the Chesapeake Bay. The model was employed to simulate long-term trends in Chesapeake Bay eutrophication (Cerco, 1995). Mark *et al.* (1992) used CE-QUAL-ICM to assess the water quality impacts of a confined disposal facility in Green Bay, Wisconsin. The model may be applied to most waterbodies in One-Dimensional (1-D), Two-Dimensional (2-D), or Three-Dimensional (3-D) and for unsteady flows.
Overview of Characteristics:	**Model Processes:** ▪ Temperature, Salinity, Dissolved Oxygen(DO)-carbon balance ▪ Nitrogen cycle, Phosphorus cycle, Silicon cycle ▪ Phytoplankton (up to 3 species), Zooplankton ▪ Bacteria ▪ First-order decay ▪ Sediment process rates may be input or simulated using the diagenesis submodel **Method/Techniques:** CE-QUAL-ICM incorporates detailed algorithms for water quality kinetics. Interactions among state variables are described in 80 partial-differential equations that employ over 140 parameters (Cerco and Cole, 1993). An improved finite-difference method is used to solve the mass conservation equation for each cell in the computational grid and for each state variable. The state variables can be categorized into six groups and cycles-the physical group, and the carbon, nitrogen, phosphorus, silica, and dissolved oxygen (DO) cycles. The model predicts time-varying concentrations of water quality constituents. It incorporates advective and dispersive transport and considers sediment diagenesis benthic exchange.
Applicability for Assessing Ecological Impacts of Withdrawals:	As CE-QUAL-ICM predicts time-varying concentrations of water quality constituents in two-dimensions and water quality component is modular, it can be coupled to ecological impact model to simulate the impacts of withdrawals.
Data Requirements:	Geometric data to define the finite difference representation of the waterbody have to be defined, and approximately 140 are parameters needed to specify kinetic interactions. Initial and boundary conditions have to be specified.
Ease of Use:	Application of model requires extensive modeling experience.
Strengths and Weaknesses:	Although the model has full capabilities to simulate state-of-the-art water quality kinetics, it is potentially limited by available data for calibration and verification. In addition, the model may require significant technical expertise in aquatic biology and chemistry to be used appropriately.
Other Notes:	Information available at: http://www.epa.gov/ednnrmrl/tools/model/ce-icm.htm http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☑ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	CE-QUAL-RIV1: Hydrodynamic and Water Quality Model for Streams
Developed by:	Water Quality and contaminant Modeling Branch, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180
Distributed by:	Same as above
Primary Purpose:	To simulate transient water quality conditions associated with highly unsteady flows that can occur in regulated rivers.
Applications and Experience:	Applied to provide examples of potential water quality impacts associated with operations alternatives for a regulation dam proposed for construction downstream from Buford Dam on the Chattahoochee River near Atlanta, Georgia (Zimmerman and Dortch, 1989). The RIV1Q component of CE-QUAL-RIV1 was used to develop statistical relationships to allow prediction of downstream water temperatures associated with different operational scenarios (Nestler *et al*., 1993).
Overview of Characteristics:	**Model Processes:** ▪ Temperature, Salinity, DO-BOD, Nitrogen cycle, Phosphorus cycle ▪ Phytoplankton in water column ▪ Benthic algae and macrophytes ▪ Bacteria ▪ First-order decay **Method/Techniques:** The model consists of two codes: RIV1H, a stand-alone hydraulic routing code, and RIV1Q, a water quality code that uses output from RIV1H to provide dynamic water quality simulation. An implicit, finite-difference method is used to solve the continuity and momentum equations in RIV1H, with cross-sectional area and discharge as dependent variables. RIV1H allows the simulation of dynamically coupled, branched river systems with multiple control structures. In RIV1Q, an explicit, finite-difference method is used to solve the constituent advective transport and reaction equations and calculate dynamic changes in the concentrations of water quality variables. **Type of modeling/Application:** ▪ Rivers and estuaries ▪ Far-field ▪ One-dimensional, branching ▪ Unsteady flow ▪ Predicts time-varying concentrations of water quality constituents ▪ Advective and dispersive transport ▪ Finite difference
Applicability for Assessing Ecological Impacts of withdrawals:	With changes in discharge conditions i.e. for unsteady flows, the model can be used to simulate the concentration of water quality variables. The model can be used to evaluate the ecological impacts caused by change in concentrations under different scenarios of discharge conditions (water use and withdrawals)
Data Requirements:	RIV1H requires river geometry and boundary conditions to perform hydraulic calculations. Geometric data include locations of control structures, streambed elevations, river cross sections, and distances between nodes. Manning's coefficients are used to describe channel roughness. Boundary conditions include initial flow rates and stages, lateral inflows or withdrawals, and boundary conditions defined by discharge, stage, or a stage-discharge rating curve. RIV1Q requires initial instream and inflow boundary water quality concentrations, meteorologic data for temperature computations, and rate coefficients.
Ease of Use:	No user-friendly interface, standard ASCII input file. Application of model requires significant modeling experience.
Strengths and Weaknesses:	The model has a link to an efficient hydrodynamic model. It is well suited for receiving water applications, provided that the necessary data are available. The model has large resource requirements and requires a trained user. It does not include sediment quality component. The program may exhibit numerical instability under certain conditions. Model is only applicable to situations where flow is predominantly one-dimensional. It simulates conventional pollutants only, and contains limited eutrophication kinetics.
Other Notes:	Environmental Laboratory, 1990**.** CE-QUAL-RIV1: A dynamic, one-dimensional (longitudinal) water quality model for streams: User's manual, instruction report. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☑ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model
Developed by:	Water Quality and Contaminant Modeling Branch, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, 2909 Halls Ferry Road, Vicksburg, MS 39180
Distributed by:	Same as above
Primary Purpose:	Simulate time-varying concentrations of water quality constituents by coupling hydrodynamic and water quality components.
Applications and Experience:	The model has been applied to many rivers, lakes, reservoirs, and estuaries (Adams *et al.*, 1993; Hall, 1987; Martin, 1988). Barnese and Bohannon (1994) report initial efforts to apply CE-QUAL-W2 to Taylorsville Lake in Kentucky.
Overview of Characteristics:	**Model Processes:** ▪ Temperature, Salinity, DO-carbon balance ▪ Nitrogen cycle, Phosphorus cycle, Silicon cycle ▪ Phytoplankton ▪ Bacteria ▪ First-order decay **Method/Techniques:** CE-QUAL-W2 is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality model. The hydrodynamic and water quality routines are directly couple; however, the water quality routines can be updated less frequently than the hydrodynamic time step, which can reduce the computation burden for complex systems. **Type of Modeling/Application:** ▪ May be applied to most water bodies in 1-D or laterally averaged 2-D (X/Z) ▪ Unsteady flow ▪ Predicts time-varying concentrations of water quality constituents ▪ Advective and dispersive transport ▪ Finite difference
Applicability for Assessing Ecological Impacts of Withdrawals:	As it predicts time-varying concentrations of water quality constituents in two-dimensions and water quality component is modular, it can be coupled to ecological impact model to simulate the impacts of withdrawals.
Data Requirements:	Geometry data are required to define the finite difference representation of the water body. Initial and boundary conditions have to be specified. Required hydraulic parameters include horizontal and vertical dispersion coefficients for momentum and temperature/constituents and the Chezy coefficient, used to calculate boundary friction. Simulation of water quality kinetics requires the specification of approximately 60 coefficients. Finally, data are required to provide boundary conditions and assess model performance during calibration.
Ease of Use:	Without the use of a commercial interface, the model cannot be considered user-friendly. The application of CE-QUAL-W2 requires extensive modeling experience.
Strengths and Weaknesses:	Because the model assumes lateral homogeneity, it is best suited for relatively strong longitudinal and vertical water quality gradients; it may be inapproapriate for large waterbodies. The model has extensive data requirement. It contains only one algal compartment. Algal succession cannot be modeled. Zooplankton and macrophytes are not modeled.

Other Notes:	Cole, T. M. and Buchak, E.M. (1995). CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 2.0. Instruction Report EL-95-, US Army Engineer Waterways Experiment Station, Vicksburg, MS. Information available at http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☑ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	CH3D-WES: Curvilinear Hydrodynamics in Three-Dimensions - Waterways Experiment Station
Developed by:	Water Quality and Contaminant Modeling Branch, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199
Distributed by:	Same as above
Primary Purpose:	To predict the system response to water levels, flow velocities, salinities, temperatures, and velocity field.
Applications and Experience:	Johnson *et al.* (1993) validated the model by applying it to six data sets. The first three data sets contained approximately one month's worth of data each and represented a dry summer condition, a spring runoff, and a fall wind-mixing event. The last three applications were year-long simulations for 1984 (a wet year), 1985 (a dry year), and 1986 (an average year). Results demonstrate that the model is a good representation of the hydrodynamics of the Chesapeake Bay and its major tributaries. Cerco and Cole (1993) used CH3D-WES in conjunction with CE-QUAL-ICM to predict water column and sediment processes that affect water quality in the Chesapeake Bay. Data from 1984-1986 were used and the linked modeling approach was successful in predicting the spring algal bloom, onset and breakup of summer anoxia, and coupling of organic particle deposition with sediment-water nutrient and oxygen fluxes.
Overview of Characteristics:	CH3D-WES makes hydrodynamic computations on a curvilinear or boundary-fitted planform grid. Deep navigation channels and irregular shorelines can be modeled because of the boundary-fitted coordinates feature of the model. Vertical turbulence is predicted by the model and is crucial to a successful simulation of stratification, destratification, and anoxia. A second-order model based upon the assumption of local equilibrium of turbulence is employed. **Type of Modeling/Application:** ▪ Hydrodynamic model developed for the Chesapeake Bay Program. ▪ Physical processes impacting circulation and vertical mixing that can be modeled include tides, wind, density effects (salinity and temperature), freshwater inflows, turbulence, and the effect of the Earth's rotation.
Applicability for Assessing Ecological Impacts of Withdrawals:	It can be used to predict system response to water levels, flow velocities, salinities, temperatures, and the 3-D velocity field. It can be used in conjunction with CE-QUAL-ICM to predict water column and sediment processes that affect water quality parameters. This could further be coupled to ecological effects models.
Data Requirements:	Basic inputs required are time-varying water-surface elevations, salinity, and temperature conditions at the ocean entrance and at freshwater inflows at the head of all tributaries. Time-varying wind and surface heat exchange data must also be prescribed at one or more locations. All input data, including initial conditions, bathymetry, boundary, and computational control data are input from fixed files.
Ease of Use:	No user-friendly interface. Requires extensive modeling experience.
Strengths and Weaknesses:	CH3D-WES is able to provide three-dimensional simulations. It is also linked to water quality model. Major weakness is the amount of resources necessary to successfully apply it. This model is applied to Chesapeake Bay but the formulation can be used for other systems as well.
Other Notes:	Johnson, B.H., Heath, R.E., Hsieh, B.B., Kim, K.W., and Butler, H.L. 1991. User's guide for a three-dimensional numerical hydrodynamic, salinity, and temperature model of Chesapeake Bay. Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, MS. Cerco, C.F. and Cole, T. 1993. Three dimensional eutrophication model of Chesapeake Bay. J. Environ. Eng. 119(6): 1006-1025. Information available at http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	ECOFATE
Developed by:	Frank P. Gobas
Distributed by:	Simon Fraser University
Primary Purpose:	The main purpose of EcoFate is to investigate whether existing or planned chemical emissions can be expected to pose an ecological or human health risk, meet environmental quality standards or criteria and to identify the "assimilative capacity" of ecosystems for chemical substances in terms of maximum daily loadings.
Applications and Experience:	Has been applied on the Fraser, Burrard, and Thompson Rivers, British Columbia. Evolved from bioaccumulation modeling in Lake Ontario.
Overview of Characteristics:	EcoFate consists of a combination of an environmental fate, food-web bioaccumulation, toxicological hazard, and human health risk assessment model, which are integrated to directly relate chemical emissions to concentrations, toxic effects and human health risks. Each of the models is based on best available knowledge of the mechanisms of chemical distribution, toxicity and risk. The assessments can be done on a time-dependent and time-independent (i.e. steady-state) basis.
Applicability for Assessing Ecological Impacts of Withdrawals:	Indirect effects of altered water levels on bioaccumulation properties of contaminants. Ecological changes in food webs and habitat use caused by changes in water level may affect bioaccumulation of hydrophobic compounds, metals, PAHs, etc. Water level changes may also change the fate-and-transport processes of contaminants in sediments. Hence, biota exposure can change.
Data Requirements:	Initial contaminant concentrations in fish tissue, sediments, and water. Fish age, weight, lipid content, and site-specific food web dynamics (e.g., diet preferences). Chemical properties, definition of food web, and chemical loading rates.
Ease of Use:	Windows-based application developed in Visual Basic with good user interfaces.
Strengths and Weaknesses:	▪ Widely accepted bioaccumulation framework ▪ Simplistic fate and transport; not linked to water withdrawals (watershed or hydrodynamic models)
Other Notes:	

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☑ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	EFDC: Environmental Fluid Dynamics Computer Code
Developed by:	John M. Hamrick, Tetra Tech, Inc. 10306 Eaton Place, Suite 340, Fairfax, VA 22030, 703-385-6000, ham@vixi.net or Virginia Institute of Marine Science School of Marine Science, The College of William and Mary, Gloucester Point, VA 23052, 804-642-7000
Distributed by:	Same as above
Primary Purpose:	Provide 3-D simulations of hydrodynamics and water quality components of a system.
Applications and Experience:	The EFDC model has been-used for modeling studies in the estuaries of the Chesapeake Bay System, the Indian River Lagoon and Lake Okeechobee in Florida, the Peconic Bay System in New York, Stephens Passage in Alaska, and Nan Wan Bay, Taiwan. The model has also been used to simulate large scale wetlands flow and transport in the Everglades.
Overview of Characteristics:	The EFDC model solves the vertically hydrostatic, free-surface, variable-density, turbulent-averaged equations of motion and transport equations for turbulence intensity and length scale, salinity, and temperature in a stretched, vertical coordinate system, and horizontal coordinate systems that may be Cartesian or curvilinear-orthogonal. Equations describing the transport of suspended sediment, toxic contaminants, and water quality state variables are also solved. Multiple size classes of cohesive and noncohesive sediments and associated deposition and resuspension processes and bed geomechanics are simulated. Toxics are transported in both the water and sediment phases in the water column and bed. The built in 20 state variable water quality model is based on the CE-QUAL-ICM reaction kinetic. The 10 state variable reduced water quality model is functionally equivalent to WASP5. Other model features include: drying and wetting, hydraulic structure representation, vegetation resistance, and Lagrangian particle tracking. The model also accepts radiation stress fields from wave refraction-diffraction models, which allows simulation of longshore currents and sediment transport. **Method/Techniques:** EFDC uses a finite difference scheme with three time levels and an internal-external mode splitting procedure to achieve separation of the internal shear or baroclinic mode from the external free-surface gravity wave or barotropic mode. An implicit external mode solution is used with simultaneous computation of a two-dimensional surface elevation field by a multicolor successive over relaxation procedure. The external solution is completed by calculation of the depth-integrated barotropic velocities using the new surface elevation field. Various options can be used for advective transport in EFDC. These include the "centered in time and space" scheme, and the "forward in time and upwind in space" scheme.
Applicability for Assessing Ecological Impacts of Withdrawals:	EFDC is applicable to rivers, lakes, reservoirs, estuaries, wetlands, and coastal regions. The coupled water quality/eutrophication and a toxicant transport and fate submodels included in the EFDC can be used to assess the ecological impacts of water quality and water quantity.
Data Requirements:	Input data to drive the model include open boundary water surface elevation, wind and atmospheric thermodynamic conditions, open boundary salinity and temperature, volumetric inflows and inflowing concentrations of sediment and water quality state variables. Input file templates are included with the source code and the user's manual to aid in input data preparation.
Ease of Use:	Technical expertise is required. No user-friendly interface. Input file templates are included with the model to aid in input data preparation.
Strengths and Weaknesses:	▪ Considerable technical expertise in hydrodynamics is required to use the model effectively. ▪ Expertise in eutrophication processes is required to use the water quality component. ▪ Requires extensive computer resources.
Other Notes:	Information available at: http://www.epa.gov/ednnrmrl/tools/model/efdc.htm, http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home, and Hamrick, J.M., 1996. *A User's Manual for the Environmental Fluid Dynamics Computer Code (EFDC).* The College of William and Mary, Virginia Institute of Marine Science. Special Report 331. Gloucester Point, VA.

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	EUTROMOD: Watershed and Lake Modeling Procedure
Developed by:	Reckhow, K.H.
Distributed by:	Model is available at www.nalms.org website, North American Lake Management Society (NALMS) PO Box 5443, Madison, WI 53705, (608) 233-2836
Primary Purpose:	EUTROMOD is a spreadsheet-based watershed and lake modeling procedure for eutrophication management, with an emphasis on uncertainty analysis. The model estimates nutrient loading, various trophic state parameters, and trihalomethane concentration in the lake using data pertaining to land use, pollutant concentrations, and lake characteristics. It predicts lakewide, growing season average conditions as a function of annual nutrient loadings.
Applications and Experience:	Used in conjunction with a GIS for establishing total maximum daily loads to Wister Lake, Oklahoma (Hession *et al.*, 1995).
Overview of Characteristics:	**Model Processes:** ▪ Annual watershed point and nonpoint source loadings ▪ Nonlinear regression equations from multi-lake regional data sets in the United States used to predict lake response **Method/Techniques:** EUTROMOD uses several algorithms based on statistical relationships and a continuously stirred tank reactor (CSTR) model. The model was developed using empirical data from the USEPA's national eutrophication survey, with trophic state models used to relate phosphorus and nitrogen loading to in-lake nutrient concentrations. The phosphorus and nitrogen concentrations were then related to maximum chlorophyll level, Secchi disk depth, dominant algal species, hypolimnetic dissolved oxygen status, and trihalomethane concentration. EUTROMOD allows for uncertainty analysis by considering the error in regression equations employed, and using an annual mean precipitation and coefficient of variation to account for hydrologic variability.
Applicability for Assessing Ecological Impacts of Withdrawals:	EUTROMOD simulates total P and N concentrations in the lake based on all inputs, watershed characteristics, land use, precipitation, and evaporation. It also generates output on the probability of the blue-green algal dominance, which is directly applicable to evaluate the ecological impacts caused by water withdrawals.
Data Requirements:	Data required for simulating basin loadings and lake response include information about climate, watershed characteristics, and lake morphometry. Climate parameters include precipitation and lake evaporation estimates. Several parameters are needed to describe the watershed in terms of land use, soils, and topography. Lake morphometry is described using surface area and mean depth.
Ease of Use:	Spreadsheet-based; some modeling expertise required.
Strengths and Weaknesses:	EUTROMOD allows for uncertainty analysis by considering the error in regression equations using an annual mean precipitation and coefficient of variation to account for hydrologic variability. EUTROMOD is limited in its application because it is designed for watersheds in the southern United States and it provides predictions only of growing season averages. It is an empirical (not mechanistic) model.
Other Notes:	Hession, W. C., D. E. Storm, S. L. Burks, M. D. Smolen, R. Lakshminarayanan, and C. T. Haan. 1995. Using EUTROMOD with a GIS for establishing total maximum daily loads to Wister Lake, Oklahoma. In *Impact of animal waste on the land-water interface*, 53-60. Lewis Publishers. In press. Reckhow, K. H. 1990. *EUTROMOD spreadsheet program a regional modeling scheme for nutrient runoff and lake trophic state modeling*. School of Forestry and Environmental Studies, Duke University, Durham, NC. Model is available through www.nalms.org website; information is also available at the U.S.EPA website http://www.epa.gov/owow/tmdl/nutrient/linkage.html

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☑ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	ELM: Everglades Landscape Model
Developed by:	South Florida Water Management District: H. Carl Fitz - cfitz@sfwmd.gov
Distributed by:	
Primary Purpose:	The ELM is a regional scale ecological model designed to predict the landscape response to different water management scenarios in south Florida, USA. The ELM simulates changes to the hydrology, soil & water nutrients, periphyton biomass & community type, and vegetation biomass & community type in the Everglades region. It was designed to develop a set of integrated modules to simulate the biogeochemical processes associated with hydrology, nutrients, soil formation, and vegetation succession.
Applications and Experience:	Used by the South Florida Water Management District to test and establish regulation scenarios aimed at Everglades restoration.
Overview of Characteristics:	A spatially explicit model of ecosystem processes and landscape succession to evaluate landscape response to different water quantity/quality management scenarios. A GIS partitions the model area into ~10,000 1 km^2 grid cells, storing data such as initial habitat types, elevation, and water levels. An ecosystem unit model is replicated in each homogeneous cell and parameterized according to the habitat type. The unit model simulates hydrology, soil & water nutrients, periphyton biomass & community type, and vegetation biomass & community type, with numerous feedbacks among these components. Water and nutrients flux among the model's raster grid cells and canal vectors, with controls at management structures that alter water delivery in the system using output data from the South Florida Water Management Model. Unit model dynamics respond to the varying water quantity and quality in the landscape mosaic, while the pattern of vegetation (habitat) type may change in response to changing hydrology and nutrient availability. Most components of the Everglades Landscape Model have been calibrated with available data. Different algorithms and hypotheses concerning habitat transitions are being evaluated. The model is now one of the tools in a research and management program at the South Florida Water Management District (SFWMD) to aid in focusing research and evaluating changes in water management in the south Florida region.
Applicability for Assessing Ecological Impacts of Withdrawals:	Allows for the evaluation of ecological impacts associated with alternative water regulation scenarios in the Everglades. Focuses on the lower trophic dynamics of the system.
Data Requirements:	Elevation, hydraulic conductivity, meteorological, vegetation, habitats, total phosphorus in soil, macrophytes, standing detritus, etc.
Ease of Use:	Unknown
Strengths and Weaknesses:	Unknown
Other Notes:	http://www.sfwmd.gov/org/wrp/elm/index.html

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	EXAMS II: Exposure Analysis Modeling System
Developed by:	Burns L.A., US EPA/CEAM 960 College Station Road, Athens, GA 30605-2700
Distributed by:	Models are available for FTP from: ftp://ftp.epa.gov/epa_ceam/wwwhtml/ceamhome.htm
Primary Purpose:	EXAMSII is an interactive modeling system that uses the principle of mass balance and mathematical models of the kinetics and processes governing the transport and transformation of chemicals to provide predictions of their probable fate and persistence in aquatic ecosystems.
Applications and Experience:	EXAMSII has been used in a wide range of regulatory applications for the USEPA. The model has been validated and reviewed b independent experts (Mulkey *et al.*, 1986; Schnoor *et al.*, 1987).
Overview of Characteristics:	**Model Processes:** First-order decay, daughter products ▪ Process kinetics ▪ Equilibrium sorption ▪ Pore water advection ▪ Local sediment mixing The hydrologic transport processes considered in EXAMSII are advection and dispersion. The transformation processes included in the model are photolysis, hydrolysis, biotransformation, oxidation, and sorption with sediments and biota. Secondary daughter products and subsequent degradation of these products are also considered. EXAMSII includes separate mathematical models of the kinetics of the physical, chemical, and biological processes governing transport and transformations of chemicals. **The model can be applied to** ▪ Streams/Rivers and lakes/reservoirs in one, two, or three dimensions ▪ Steady flow ▪ Steady-state/Quasidynamic predictions ▪ Advective and dispersive transport ▪ Considers benthic exchange ▪ Inputs may be steady or variable
Applicability for Assessing Ecological Impacts of Withdrawals	EXAMS II considers hydrologic conditions and chemical loadings to predict the fate and transport of contaminants, which in turn can affect the contaminant concentration in biota.
Data Requirements:	Basic inputs include system geometry and hydrology specification, a set of chemical loadings on each sector of the ecosystem, and parameters that define the strength of the advective and dispersive transport pathways. Although EXAMSII allows for the entry of extensive environmental data, the program can be run with a much-reduced data set when the chemistry of a compound of interest precludes some of the transformation processes. Chemical parameters include molecular weight, solubility, and ionization constants of the compound. Sediment-sorption/biosorption, volatilization, photolysis, hydrolysis, oxidation, and biotransformation processes may also be specified.
Ease of Use:	Experience and expertise in FORTRAN and the EXAMS modeling system is required.
Strengths and Weaknesses:	▪ An advantage in using the model is its ability to accept standard water quality parameters, chemical data, and system characteristics for which information is readily available. ▪ Designed to evaluate consequences of long-term, primarily time-averaged chemical loadings, thus transient effects cannot be analyzed. ▪ Sorption isotherms are assumed to be linear, and biotransformation kinetics are assumed to be second-order rather than Michaelis-Menton-Monod. ▪ Chemicals are assumed not to radically change the environmental variables that drive their transformation.

Other Notes:	Mulkey, L.A., Ambrose, R. B., and Barnwell, T. O. 1986. Aquatic fate and transport modeling techniques for predicting environment exposure to organic pesticides and other toxicants: A comparative study. In Urban runoff pollution. Springer-Verlag, New York, NY. Schnoor, J.L., Sato, C., McKetchnie, and Sahoo, D. 1987. Processes, coefficients, and models for simulating toxic organics and heavy metals in surface waters. EPA/600/3-87/015. U.S. EPA, Athens, GA. Burns, L.A. 1990. Exposure analysis modeling system: User's guide for EXAMII Version 2.94. EPA/600/3-89/084. US EPA, Athens, GA.

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	FGETS: Food and Gill Exchange of Toxic Substances
Developed by:	Model Distribution Coordinator, Center for Exposure Assessment modeling (CEAM), USEPA, 960 College Station Road, Athens, GA 30605-2700, 706-355-8400
Distributed by:	Same as above
Primary Purpose:	Simulate the contaminant transfer in fish species through food and gill and also to estimate the time for chemical exposure that contributes to the lethal activity in fish.
Applications and Experience:	Used extensively for ecotoxicology studies. Version 3.0.18 was released in September 1994. FGETS operates on IBM PCs and compatibles in DOS
Overview of Characteristics:	FGETS considers both the biological attributes of the fish and the physicochemical properties of the chemical that determine diffusive exchange across gill membranes and intestinal mucosa. The model is based on a set of diffusion and forced convection partial differential equations, coupled to a process-based fish growth formulation. Fish bioaccumulation simulation modeling for laboratory conditions (constant flow or static exposure) or for field assessments (for multiple fish species that are exposed to constant to time-varying water concentrations and that feed on either single or multiple food resources). FGETS provides regulators and practitioners with an objective, process-based assessment of residue-based, toxicological responses and dietary exposures for fish assemblages.
Applicability for Assessing Ecological Impacts of Withdrawals:	Model can be used to evaluate temporal dynamics of a fish's whole body concentration of pollutants that are bioaccumulated from water and food. It can also be used to calculate the time to reach the chemical's lethal activity. FGETS directly evaluates ecological impacts due to chemical impairments.
Data Requirements:	Morphological, physiological, and trophic parameters that describe the gill morphometry, feeding and metabolic demands, and body composition for the species in question; and relevant physicochemical parameters that describe partitioning to the fish's lipid and structural organic fractions for a specific chemical
Ease of Use:	FGETS is easy to use. It has user-friendly interface. The default parameters are available.
Strengths and Weaknesses:	Simulates bioaccumulation of nonpolar organic pollutants in fish species depending on time-varying water concentrations. Chemical exchange rate are estimated using fundamental principles of passive diffusion and thermodynamics rather that phenomenological toxicokinetic data.
Other Notes:	

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	GBTOX – Green Bay Toxics Model
Developed by:	V. Bierman, J. DePinto, S. Hinz, R. Raghunathan
Distributed by:	U.S. EPA – Grosse Ile
Primary Purpose:	▪ Gain an understanding of the physical, chemical, and biological processes that control partitioning, transport and fate of toxic chemicals in Green Bay. ▪ Develop and apply predictive methodologies for evaluating regulatory and remedial action scenarios for toxic chemicals in Green Bay.
Applications and Experience:	The model has been applied to Green Bay. It's application could include other bay systems.
Overview of Characteristics:	GBTOX was developed within the WASP4 modeling framework maintained and distributed by the EPA/CEAM. The model is temporally dynamic and spatial segmented in horizontal and vertical. The model couples eutrophication, hydraulic transport model, sorbent dynamic, and food chain models. It conducts three separate mass balances: a water balance, an organic carbon sorbent balance, and a toxic chemical balance. Each balance include specification of external inputs, internal sources and sinks, and system outputs. The hydraulic transport model provides the advective flows and bulk dispersion coefficients that drive the transport of all constituents among water column segments of the system. Sorbent model considers three state variables: biotic carbon (BIC), particulate detrital carbon (PDC), and dissolved organic carbon (DOC). The eutrophication model is used to determine autochthonous organic carbon loadings.
Applicability for Assessing Ecological Impacts of Withdrawals:	GBTOX evaluates the chemical transport in surface waters in a temporal and spatial resolution by coupling several models including eutrophication, contaminant fate and transport, and food web models. This model can be used to quantify the ecological impacts of water withdrawals.
Data Requirements:	System specific data, external loadings/forcing functions, and initial and boundary conditions, model coefficients, contaminant specific data, dominant water circulation patterns, sediment characteristics, duration and extent of ice cover.
Ease of Use:	Experience in eutrophication and contaminant transport modeling is required.
Strengths and Weaknesses:	▪ GBTOX contains hydraulic transport model to predict the advective flows and bulk diffusion coefficients and deals with both eutrophication and contamination problems. ▪ There are inevitable uncertainties in the long term predictions of load-response relationships for Green Bay because they were based on a model calibrated for only a 15-month period.
Other Notes:	

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☑ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	GMS - Groundwater Modeling System
Developed by:	Developed under the direction of the U.S. Army Corps of Engineers and involves support from the Department of Defense, the Department of Energy, and the Environmental Protection Agency.
Distributed by:	The Scientific Software Group http://www.ground-water-models.com/products/gms_overview/gms_overview.html
Primary Purpose:	The Groundwater Modeling System is a comprehensive package which provides tools for every phase of a groundwater simulation including site characterization, model development, postprocessing, calibration, and visualization.
Applications and Experience:	GMS is used at hundreds of US government sites. GMS is also used at a large and rapidly growing number of private and international sites.
Overview of Characteristics:	GMS includes sophisticated groundwater modeling environment for MODFLOW, MODPATH, MT3D, FEMWATER, SEEP2D, SEAM3D, RT3D, UTCHEM, PEST and UCODE GMS Categories: flow models - pathlines/capture zones, flow models - saturated zone, flow models - unsaturated zone, geostatistical analysis, model interfaces and modeling shells, saltwater intrusion models, solute transport models - saturated zone, solute transport models - unsaturated zone, MODFLOW programs, flow models - localization, seepage analysis, bioremediation. GMS integrates and simplifies the process of groundwater flow and transport modeling by seamlessly integrating all the tools needed for a successful study. There are two main methods for building models in GMS, the grid approach and the conceptual modeling approach. With the grid approach, the first step is to create a grid or mesh. The model parameters, source/sink data, and boundary conditions are assigned directly to the cells, nodes, and elements of the grid or mesh. This approach is well-suited for very simple models. The most efficient approach for building realistic, complex models is the conceptual model approach. With this approach, a conceptual model is created using GIS objects, including points, arcs, and polygons. The conceptual model is constructed independently of a grid or mesh. It is a high-level description of the site including sources/sinks, the boundary of the domain to be modeled, recharge and evapotranspiration zones, and material zones within each of the layers. Once the conceptual model is complete, a grid or mesh is automatically constructed to fit the conceptual model, and the model data are converted from the conceptual model to the cells of the grid. **GMS FEATURES** • Imports/exports raster and vector GIS data from ARC/INFO, ArcView, and GRASS. • A Model Checker is provided in GMS for each model to check for potential problems prior to saving and running a model. • All models can be launched from a GMS menu. • Latest versions of all analysis codes are provided including executable, source code, and documentation. • Time-series plots of computed values at selected points can be generated. • Data Calculator can be used to combine data sets using any mathematical expression to generate a new data set. • Images can be copied to the clipboard and pasted into other applications for report generation. • A simple set of drawing tools are provided for adding titles, arrows, and other annotations to a plot in GMS. • Imports/exports DXF files including AutoCAD R13 format. **The components of GMS can be used for various purposes, such as** • Site characterization with 2D and 3D geostatistics • Flow modeling with MODFLOW • Transport modeling with MT3D • Reactive transport modeling with RT3D • Particle tracking with MODPATH • Parameter estimation with PEST/UCODE • Performing saturated and unsaturated flow and transport simulations with FEMWATER

Applicability for Assessing Ecological Impacts of Withdrawals:	Various components of GMS can be used to model flow, transport, and particle tracking. When coupled with a surface or runoff model the system could be useful for assessing the impacts of quantity of water.
Data Requirements:	Depending on the models MODFLOW, MODPATH, MT3D, RT3D, FEMWATER, SEEP2D, SEAM3D, PEST, UCODE and UTCHEM the data requirements
Ease of Use:	Highly-acclaimed technical documentation including an extensive reference manual and self-guided tutorials are available. However, experience with groundwater models is required.
Strengths and Weaknesses:	• GMS is the most sophisticated groundwater modeling environment. GMS integrates and simplifies the process of groundwater flow and transport modeling by seamlessly integrating all the tools needed for a successful study. • GMS is the only system, which supports TINs, solids, borehole data, 2D and 3D geostatistics, and both finite element and finite difference models in 2D and 3D.
Other Notes:	

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☑ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	HEC-2; U.S. Army Engineer Hydrologic Engineering Center
Developed by:	U.S. Army Engineer Hydrologic Engineering Center 3909 Halls Ferry Road, Vicksburg, MS 39180
Distributed by:	Same as above
Primary Purpose:	Compute water surface profiles and velocities for one-dimensional steady flow in rivers with irregular cross sections.
Applications and Experience:	This model has become the national standard for FEMA floodplain evaluations, including flood insurance and control studies, and river channel design. It is also being used to generate inputs for the SMPTOX4 model in support of a dioxin TMDL for the Ohio River.
Overview of Characteristics:	The HEC-2 program computes water surface profiles for one-dimensional steady, gradually varied flow in rivers of any cross section. Flow may be subcritical or supercritical. Various routines are available for modifying input cross section data; for example, for locating encroachments or inserting a trapezoidal excavation on cross sections. The water surface profile through structures such as bridges, culverts and weirs can be computed. Variable channel roughness and variable reach length between adjacent cross sections can be accommodated. This model is used for large rivers with tributaries and can accommodate dams. Printer plots can be made of the river cross sections and computed profiles. HEC-2 results are not directly linked to any water quality models; however, manual transfer of HEC-2 results into water quality models is typically an easy task due to the small number of outputs associated with steady state model applications. The HEC-2 code is also contained in the new HEC-RAS (River Analysis System), part of HEC's "Next Generation Software" that is ultimately designed to replace HEC-2 and other HEC models. Constituents modeled: Flow, velocity, channel depth and width as well as other hydraulic parameters such as the energy grade line, hydraulic losses and channel conveyance to name a few. Model Outputs: Same as modeled constituents.
Applicability for Assessing Ecological Impacts of Withdrawals:	The HEC-2 program can compute the water surface elevations, channel depth and channel velocity for both the pre and post withdrawal scenarios. The difference in the resulting water surface elevations can be used to predict the change in amount of underwater habitat, e.g., a lower water surface elevation can result in a reduction of the wetted perimeter of the cross section thus reducing the underwater habitat. The difference in channel velocity can also be used to predict the effects on underwater habitat, e.g., an increase in the channel velocity, accompanied by a decrease in channel depth will lead to increased bottom scour and the degradation of the underwater habitat.
Data Requirements:	Channel roughness and channel geometry, upstream and tributary flows and downstream boundary conditions. Geometry of any control structures such as weir, bridges or dams is also required or proper modeling of the system.
Ease of Use:	User-friendly interface contained only as part of HEC-RAS modeling system. Program runs in DOS mode and requires some training for developing the model input deck and interpreting model results.
Strengths and Weaknesses:	▪ It can provide stream geometry and velocity data for use to steady state water quality models. ▪ The model can only be applied for steady flow situations. ▪ The model is only a one-dimensional model, thus velocity results are both vertically and horizontally averaged and therefore, cross sectional velocity extremes are not predicted. Due to this averaging of velocities, the model is difficult to calibrate to collected velocity data.
Other Notes:	HEC-2, Water Surface Profiles, User's Manual, Sept, 1990 (Revised Feb 1991), 308 pp. PB91-142422 http://www.wrc-hec.usace.army.mil/software/software_catalog.html

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	HEP/HSI: Habitat Evaluation Procedures/Habitat Suitability Indices
Developed by:	U.S. Fish and Wildlife Service, National Ecology Research Center, 2627 Redwing Road, Fort Collins, CO 80526, (303) 226-9421, BBS: (303) 226-9365 (N/8/1) Internet: http://www.fws.gov
Distributed by:	Same as above
Primary Purpose:	A species-based evaluation method that determines the quality and quantity of available habitat for selected aquatic and terrestrial wildlife species, and measures the impact of proposed or anticipated land or water use changes on that habitat.
Applications and Experience:	Quantitative assessment of habitat conditions for wildlife species Comparison of the impacts of project alternatives on wildlife resources. Used extensively by the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, and the U.S. Bureau of Reclamation.
Overview of Characteristics:	Three software programs have been developed to assist with the HEP: ▪ HEP Accounting Program computes the values needed to use the HEP procedures. ▪ Habitat management Evaluation Method System (HMEM) software allows a user to investigate and compare the cost-effectiveness of different management alternatives to achieve desired HUs for a selected species. ▪ HSI modeling system software is used to compute an HSI value for selected species from field measurements of habitat variables. HEP analysis begins with three basic steps:(1) defining the study area, (2) Delineating cover types, and (3) selecting evaluation species. Evaluation species (i.e., indicator species) are used in HEP to quantify habitat units (HUs); a typical HEP study incorporates four to six species. The analysis is structured around the calculation of HUs for each evaluation species in the study area. The number of HUs is defined as the product of the Habitat Suitability Index (HSI, a measure of habitat quality) and the total area of available habitat (habitat quantity). HUs are then used to make comparisons of (1) the relative value of different areas at the same pint in time and/or (2) the relative value of the same area at future pints in time.
Applicability for Assessing Ecological Impacts of Withdrawals:	HEP/HSI evaluates the impact of water use changes on the aquatic habitat.
Data Requirements:	Data to be collected include delineation of cover types (e.g., deciduous forest, coniferous forest, grassland, residential woodland) within the project area; size (acreage) of existing habitat for each evaluation species; Habitat Suitability Index (HSI) reflecting current habitat conditions for each evaluation species; future habitat conditions for each evaluation species. HSI data collection includes (1) species-specific habitat use information such as general information (e.g., geographic distribution); age, growth, and food requirements; water quality, depth, and flow; species-specific habitat requirements; reproductive information; (2) species-specific life history information for each life stage, (i.e., spawning/embryo, fry, juvenile, and adult); (3) suitability indices for each habitat variable.
Ease of Use:	
Strengths and Weaknesses:	It measures the impact of water and land use changes on habitat. Requires extensive input data on species specific habitat.

Other Notes:	

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	HES: Habitat Evaluation System
Developed by:	U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180, 601-634-5276
Distributed by:	Same as above
Primary Purpose:	A community-based evaluation technique used to assess the impacts of development projects for two aquatic habitats (streams and lakes) and five terrestrial habitat evaluations (wooded swamps, upland forest, bottomland hardwood forest, open lands, and terrestrial wildlife value of aquatic habitats).
Applications and Experience:	HES has been used in major ecosystems in the Lower Mississippi Valley Region. With revisions to curves, weights, and other variables, it can be applied to may other areas of the United States.
Overview of Characteristics:	HES assumes that presence, abundance, and diversity of animal populations in a habitat are determined by biotic and abiotic factors that can be readily quantified. HES determines the quality of a particular habitat type through the use of functional curves that relate habitat quality and carrying capacity to these factors. HES uses general habitat characteristics that indicate quality for aquatic and terrestrial wildlife communities as a whole. Six steps are involved in an HES: (1) obtaining habitat type and land use acreage; (2) deriving Habitat Quality Index (HQI) scores; (3) deriving Habitat Unit Values (HUVs); (4) projecting HUVs for future with and without-project conditions; (5) using HUVs to assess impacts of project alternatives; (6) determining mitigation requirements, if any. For complex projects with several habitat types, computer software is available for making HES computations for steps 1-5. Inputs to this software are the data for land use or habitat size and HQI scores. Applications: ▪ Evaluating the effects of projects on the quantity and quality of wildlife habitats in he Lower Mississippi Valley Region of the United States. ▪ Aiding in the selection between project alternatives.
Applicability for Assessing Ecological Impacts of Withdrawals:	HES evaluates ecological impacts through aquatic and terrestrial habitats as a response to water quality. It can be used for further development on ecological impact assessment.
Data Requirements:	▪ Baseline data on habitat types and land uses in the project area ▪ Size (acreage) of each habitat type and land use for existing and future conditions ▪ Measurements of key variables (e.g., percent understory, number of large trees, number of mast trees, species associations, number of snags) identified for each habitat and land use type for existing conditions ▪ Projected measurements of same key variables for future conditions
Ease of Use:	
Strengths and Weaknesses:	HES determines the habitat quality as response to conditions of aquatic systems. It desire some scores which are subjective and reserved for a specific system for use.
Other Notes:	

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☑ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	HSPF: Hydrological Simulation Program – FORTRAN Modified version provided with BASINS named WinHSPF and NPSM.
Developed by:	Model Distribution Coordinator, Center for Exposure Assessment Modeling (CEAM), USEPA, 960 college Station Road, Athens, GA 30605-2700, 706-355-8400
Distributed by:	Same as above. Also distributed with BASINS
Primary Purpose:	Calculate surface and subsurface pollutant transport from complex watersheds to receiving waters.
Applications and Experience:	HSPF is being used by the Chesapeake Bay Program to model total watershed contributions of flow, sediment, nutrients, and associated constituents to the tidal region of the Bay (Donigian *et al.*, 1990; Donigian and Patwardhan, 1992). Moore *et al.* (1992) describe an application to model BMP effects on a Tennessee watershed. Scheckenberger and Kennedy (1994) discuss how HSPF may be used in subwatershed planning. Ball *et al.* (1993) describe an application of HSPF in Australia. Lumb *et al.* (1990) describe an interactive program for data management and analysis that can be effectively used with HSPF. Lumb and Kittle (1993) have presented an expert system that can be used for calibration and application of HSPF. Model can be applied for evaluating the surface and subsurface pollutant transport to receiving water with subsequent simulation of instream transport and transformations, watershed hydrology and water quality for both conventional and toxic organic pollutants, and BMPs and development of design criteria.
Overview of Characteristics:	**Model Components:** Watershed hydrology assessment, Surface water quality analysis (conventional and toxic organic pollutants), Soil/groundwater contaminant runoff processes with instream hydraulic and sediment-chemical interactions (saturated and unsaturated zones), Pollutant decay and transformation **Method/Technique:** A lumped parameter watershed model is used to simulate diffuse loads from pervious and impervious land types. A linked water quality model simulates the instream process. Hydrolysis, oxidation, photolysis, biodegradation, volatilization, and sorption are used to describe the transfer and reaction processes of pollutant fate and transport. First-order kinetic processes are employed to model sorption. Three sediment types (sand, silt, and clay) and a single organic chemical, as well as transformation products of that chemical, can be simulated. Detailed agrichemical modules are used to estimate diffuse loads from different land use types. Calibration is required for model application. Because of the modular approach, detail of application can be varied depending on data availability and modeling needs. **Type of Modeling:** ▪ Water quantity ▪ Pollutant load and water quality in complex watersheds ▪ Continuous and storm event simulation ▪ Single, continuous, intermittent, multiple, and diffuse source/release ▪ Screening, intermediate, and detailed applications ▪ BMP evaluation and design criteria
Applicability for Assessing Ecological Impacts of Withdrawals:	HSPF model can be applied to calculate surface and subsurface pollutant transport in receiving water with subsequent simulation of instream processes. With it's applicability to watershed hydrology, it can be used to evaluate the ecological impacts due to presence of toxic organic pollutants at storm events as well as under unsteady flow conditions.
Data Requirements:	▪ Continuous rainfall records ▪ Continuous records of evapotranspiration, temperature, and solar intensity ▪ A large number of parameters need to be specified (some default values are available)
Ease of Use:	Not user-friendly. Requires experienced person for model handling and application. However, USEPA and USGS have created several utilities, and data processing programs that make using HSPF easier. Examples include, BASINS, WinHSPF, WDMUtil, and GenScn.
Strengths and Weaknesses:	Nonpoint source loading and hydrodynamic results are automatically linked to the HSPF water quality submodel. Highly applicable for watershed assessments. The model evaluates time series of water quantity and quality at any point in a watershed. However, HSPF needs extensive hydrologic data for calibration and verification. The model is appropriate for well-mixed rivers and reservoirs and requires trained staff for model application.

Other Notes:	Model and information is available for FTP form at: ftp://ftp.epa.gov/epa_ceam/wwwhtml/software.htm http://www.epa.gov/ednnrmrl/tools/model/hspf.htm, Manual - Bicknell *et al*. 1996.

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Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	IFIM: The Instream Flow Incremental Methodology
Developed by:	Riverine and Wetlands Ecosystem Branch, National Biological Service, 4512 McMurray Avenue, Fort Collins, CO 80525-2400, 303-226-9337
Distributed by:	Same as above
Primary Purpose:	A conceptual framework that consists of a collection of analytical procedures and computer models used to assess riverine habitats.
Applications and Experience:	IFIM, and its components, can be applied as guideline to solve problems regarding the hydraulic disturbance of a riverine ecosystem. Used extensively by the U.S. Fish and Wildlife Service and state fisheries management agencies.
Overview of Characteristics:	IFIM attempts to determine the effects of any of a number of hydraulic modifications on aquatic habitat through a complete process that steps through the description of the river system and available habitat and incrementally changes one or more variables describing the system to reflect a management option, and determining the available habitat for this new system. Each option is then evaluated and a management strategy is selected. IFIM considers changes to both microhabitat (the distribution of structural and hydraulic features that form the living space for an organism) and macrohabitat (channel characteristics, temperature, and water quality). PHABSIM is a collection of computer programs that form the key microhabitat simulation component of IFIM. IFIM is a general problem solving approach employing systems analysis techniques, PHABSIM is a specific model designed to calculate an index to the amount of microhabitat available for different life stages at different flow levels. Relying on the assumption that aquatic species will react to hydraulic changes in stream by selecting the most favorable conditions, PHABSIM uses a combination of standard, one-dimensional steady-flow, open-channel hydraulic models and habitat models to describe the Weighted Usable Area (a measure of habitat) under a variety of channel configurations and flow management conditions. TSLIB uses a set of computer programs to create monthly or daily habitat time-series and habitat-duration curves using the habitat-discharge relationships produced by PHABSIM. It can calculate basic statistics for monthly data, generate flow-duration habitat curves for designated months, and create monthly or annual habitat time series for four to seven life stages of selected species.
Applicability for Assessing Ecological Impacts of Withdrawals:	IFIM considers the fluctuations in river flow and evaluates it's effect on aquatic species. As a part of IFIM, PHABSIM, has been used extensively to describe biological effects of flow regulations on species. The available area of habitat can be quantified for the range of modeled discharges.
Data Requirements:	Detailed data are required for both physical characteristics (e.g., depth, velocity, stream channel characteristics, riparian cover) and biological characteristics (e.g., life history and habitat preference information for the species of concern) of the stream.
Ease of Use:	
Strengths and Weaknesses:	IFIM provides quantitative assessment of the changes in a given aquatic species' habitat with changes in hydrologic conditions. PHABSIM provides an index to the microhabitat availability; it is not a measure of the habitat actually used by aquatic organism. The typical application of PHABSIM assumes relatively steady flow conditions such that depths and velocities are comparably stable for the chosen time step. PHABSIM does not predict the effects of flow on channel change. Finally, the field data and computer analysis requirements can be relatively
Other Notes:	Information on IFIM and PHABSIM is available at the USGS website at http://www.mesc.nbs.gov/rsm/IFIM_5phases.html http://webmesc.mesc.nbs.gov/rsm/PHABSIM

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☑ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	LBRM - GLERL Large Basin Runoff Model
Developed by:	The Great Lakes Environmental Research Laboratory
Distributed by:	Same as above: http://www.glerl.noaa.gov/wr/LBRMFiles.html
Primary Purpose:	To estimate basin runoff to the Great Lakes and other large-basin applications for use in long term routing determinations, water resource operation decisions, operational hydrology studies, and long-term forecasting.
Applications and Experience:	The GLERL developed, calibrated and verified conceptual model based techniques for simulating hydrologic processes in the Laurentian Great Lakes, including Georgian Bay and Lake St. Clair. GLERL integrated the models into a system to estimate lake levels, whole-lake heat storage, and water and energy balances for forecats and for assessment of impacts associated with climate change. The model is applied to 121 basins in the Great Lakes area and the integrated response used in simulation studies and in forecasting of water levels on the lakes.
Overview of Characteristics:	It is an interdependent tank-cascade model that uses a mass balance coupled with linear reservoir concepts. It is physically based and uses climatological considerations and designed for weekly or monthly volumes of runoff. The model consists of water and heat balances. Analytical solutions are presented in favor of numerical solutions to bypass associated numerical error. For application of model to a very large drainage basin such as that associated with a Great Lake, the basin is divided into watersheds with areas of between 120-20,000 km^2 (there are 121 watersheds in the entire Great Lakes basin); most between 1,000 – 5,000 km^2. The meteorological data from stations about and in watershed are combined through Thiessen weighting to produce areally-averaged daily time series of precipitation and minimum and maximum air temperatures for each watershed. Flow records of all most-downstream flow stations are combined by aggregating and extrapolating the ungaged areas to estimate the daily runoff from each watershed. LBRM is calibrated with 30 years of daily weighted watershed climatologic data.
Applicability for Assessing Ecological Impacts of Withdrawals:	Applications of the model to the Great Lakes watershed can be used for determining the flow fluctuations in the system. The estimates of runoff volumes from large basins are useful in determining the ecological impacts of water withdrawals.
Data Requirements:	Daily precipitation, daily minimum and maximum air temperatures, wind speed, humidity, and insolation, and daily basin outflows. In addition model parameters and initial conditions are also required.
Ease of Use:	
Strengths and Weaknesses:	▪ The mathematical features of this interdependent tank-cascade model may be described by continuous equations; none of the complexities associated with inter-tank flow rate dependence on partial fillings are introduced. ▪ Since the solution is analytically tractable, large time steps may be employed without introducing numerical errors. ▪ Comparisons with other runoff models and climatology show that the LBRM does a good job for estimates of runoff volumes from large basins.
Other Notes:	Croley, T. E., II, 2002. Large basin runoff model. Mathematical Models in Watershed Hydrology, Vol. 1, Chapter 17, (V. Singh, D. Frevert, and S. Meyer, Eds.), Water Resources Publications, Littleton, Colorado, 717-768 (in press). Croley, T. E., II, Quinn, F. H., Kunkel, K.E., and Changnon, S. A. 1989. Climate Transposition Effects on the Great Lakes Hydrological Cycle. NOAA Technical Memorandum ERL GLERL-89.

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☑ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	MIKE 21 – Generalized Modeling Package-2-D-Hydrodynamics
Developed by:	Danish Hydraulic Institute
Distributed by:	Same as above.
Primary Purpose:	Simulate hydraulics, sediment transport and water quality in estuaries, rivers, lakes, estuaries, bays, coastal areas and seas, irrigation systems and similar bodies.
Applications and Experience:	MIKE 21 is constructed in a modular manner around the four main application areas: ▪ Coastal Hydraulics and Oceanography ▪ Environmental Hydraulics ▪ Sediment Processes and ▪ Waves The MIKE series of models represents a continuous development since the early 1970s by the Danish Hydraulic Institute. The system has been applied in hundreds of applications and is presently used as the basis for countrywide river models in Bangladesh.
Overview of Characteristics:	The system consists of 5 main modules: 1) A hydrological module that computes the rainfall-runoff from rural catchments; 2) A hydrodynamic module that computes discharges and water level variations in rivers and flood plains. The module solves the full dynamic, diffusive or kinematic wave equations as appropriate; 3) A sediment transport module that simulates sediment transport, dune formation, bed level changes and hydraulic resistance; 4) a transport-dispersion module that includes a special description for cohesive sediments; and 5) a water quality module that simulates chemical and biological processes. **Constituents Modeled:** ▪ Hydrodynamics, ▪ D.O., BOD, ▪ nutrients, ▪ phytoplankton, ▪ temperature, ▪ bacteria, ▪ toxics
Applicability for Assessing Ecological Impacts of Withdrawals:	Mike 21 model computes the fluctuations in discharge and water level variations in sediment quality subjected to various pollution sources. The result can be used to evaluate ecological impacts of withdrawals for various water bodies.
Data Requirements:	The input data for a MIKE simulation consists of organizational input, initial values, boundary and topographical data.
Ease of Use:	User-friendly model interface, although extensive modeling experience is required.
Strengths and Weaknesses:	The model is proprietary in nature, which will constrain its widespread use and acceptance.
Other Notes:	http://www.dhisoftware.com/mike21/

Category of Model:	☐ Hydrologic/Watershed ☑ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	MODFLOW - Modular Three-Dimensional Ground-Water Flow Model Visual MODFLOW - integrated groundwater modeling environment for MODFLOW, MODPATH and MT3D is the most commonly used version.
Developed by:	Michael G. McDonald and Arlen W. Harbaugh
Distributed by:	Available at USGS website at http://water.usgs.gov/nrp/gwsoftware/modflow2000/modflow2000.html http://www.scisoftware.com/products/visual_modflow_details/visual_modflow_details.html http://www.flowpath.com/software/visualmodflow/visualmodflow.html
Primary Purpose:	A three-dimensional finite-difference ground-water flow model to simulate systems for water supply, containment remediation and mine dewatering.
Applications and Experience:	MODFLOW is the recognized standard model used by courts, regulatory agencies, universities, consultants and industry.
Overview of Characteristics:	The modular structure of MODFLOW consists of a Main Program and a series of highly-independent subroutines called modules. The modules are grouped in packages. Each package deals with a specific feature of the hydrologic system which is to be simulated such as flow from rivers or flow into drains or with a specific method of solving linear equations which describe the flow system such as the Strongly Implicit Procedure or Preconditioned Conjugate Gradient. The division of MODFLOW into modules permits the user to examine specific hydrologic features of the model independently. This also facilitates development of additional capabilities because new modules or packages can be added to the program without modifying the existing ones. The input/output system of MODFLOW was designed for optimal flexibility. In MODFLOW, the ground-water flow equation is solved using the finite-difference approximation. The flow region is subdivided into blocks in which the medium properties are assumed to be uniform. In plan view the blocks are made from a grid of mutually perpendicular lines that may be variably spaced. Model layers can have varying thickness. A flow equation is written for each block, called a cell. Several solvers are provided for solving the resulting matrix problem; the user can choose the best solver for the particular problem. Flow-rate and cumulative-volume balances from each type of inflow and outflow are computed for each time step. Ground-water flow within the aquifer is simulated in MODFLOW using a block-centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of both. Flows from external stresses such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through riverbeds can also be simulated. The Visual MODFLOW interface has been specifically designed to increase modeling productivity and decrease the complexities typically associated with building three-dimensional groundwater flow and contaminant transport models. The interface is divided into three separate modules, the Input Module, the Run Module, and the Output Module. It allows switching between these modules to build or modify the model input parameters, run the simulations, and display the results (in plan view or full-screen cross section). New Version of Visual MODFLOW includes RT3D, MT3DMS and WinPEST. Visual MODFLOW is the most complete and easy-to-use modeling environment for practical applications in three-dimensional groundwater flow and contaminant transport simulations.
Applicability for Assessing Ecological Impacts of Withdrawals:	MODFLOW estimates the flow of water through groundwater and MODFLOW SURFACT is an integration of flow and transport modules. Integration of groundwater and surface-water modeling can be used to assess the effect of water withdrawals. It can help in assessing the ecological impacts caused by withdrawals by incorporating the surface-water and groundwater interactions.
Data Requirements:	A large amount of information and a complete description of the flow system is required to make the most efficient use of MODFLOW. In situations where only rough estimates of the flow system are needed, the input requirements of MODFLOW may not justify its use. To use MODFLOW, the region to be simulated must be divided into cells with a rectilinear grid resulting in layers, rows and columns. Files must then be prepared that contain spatial orientation of geologic units, topography, hydraulic parameters (hydraulic conductivity, transmissivity, specific yield, etc.), boundary conditions (location of impermeable boundaries and constant heads), and stresses (pumping wells, recharge from precipitation, rivers, drains, etc.).

Ease of Use:	• The Visual MODFLOW interface has been specifically designed to increase modeling productivity and decrease the complexities typically associated with building three-dimensional groundwater flow and contaminant transport models. • MODFLOW is a complex model requiring extensive knowledge on the hydraulics and groundwater systems.
Strengths and Weaknesses:	▪ It has a modular structure that allows it to be easily modified to adapt the code for a particular application. ▪ Because of its ability to simulate a wide variety of systems, its extensive publicly available documentation, and its rigorous USGS peer review, MODFLOW has become a popular model. ▪ MODFLOW is most appropriate in those situations where a relatively precise understanding of the flow system is needed to make a decision.
Other Notes:	Information available at: http://water.usgs.gov/nrp/gwsoftware/modflow2000/ http://www.epa.gov/ada/csmos/models/modflow.html http://www.ground-water-models.com/products/modflow_overview/modflow_overview.html http://www.scisoftware.com/products/visual_modflow_details/visual_modflow_details.html

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☒ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	Ontario Flow Assessment Techniques (OFAT) Version 1.0
Developed by:	N.E. Science and Information, Ontario Ministry of Natural Resources
Distributed by:	N.E. Science and Information, Ontario Ministry of Natural Resources
Primary Purpose:	Primary purpose of OFAT project is to develop a useful tool that effectively and efficiently manages spatial watershed databases, characterizes watersheds, and performs hydrologic analyses to support decisions related to water resources planning and management in Ontario. Currently, OFAT can automatically estimate various flow statistics for watersheds anywhere in Ontario. These flow statistics include low flows (e.g., $7Q_2$, $7Q_{10}$, $7Q_{20}$, etc.), flood flows (e.g., Q_2, Q_{10}, Q_{25}, Q_{100}, etc.), mean annual flows, minimum instream flow requirements, and bankfull flows. OFAT has been created by automating a number of existing regional hydrologic models for Ontario, as well as other empirical relationships pertaining to flow estimation, with the support of GIS to provide various physiographic and climatic inputs.
Applications and Experience:	OFAT has been used by various MNR offices to support Water Management Planning (WMP) and Waterpower Project for watersheds in different geographic areas in Ontario. OFAT has also currently been used by MOEE offices to support their programs.
Overview of Characteristics:	OFAT contains the following three main processes: 1. Delineate a watershed using Digital Elevation Models (DEMs) 2. Calculate physiographic and climatic parameters pertaining to the delineated watershed as well as summarize/mapping/charting environment-related GIS databases within the watershed 3. Execute various regional hydrologic models and report/export the modelling results
Applicability for Assessing Ecological Impacts of Withdrawals:	• Water management/planning - Use OFAT in conjunction with other models to assist in deriving water allocation strategies (e.g., determining minimum flow requirements for fish habitat protection, recreation use, water-taking permit, or water quality; hydropower peaking/ramping rate impact assessment; relations of flow scenario to water levels, etc.) • Fish habitat rehabilitation - Use products/outputs from OFAT to assist in developing design criteria to protect or enhance fish habitat (e.g., fish spawning habitat enhancements via natural channel design). • River/valley segment classification systems - OFAT would provide the hydrological component of systems presently being developed for classification of aquatic communities within rivers and streams in Ontario. • Environmental assessment - OFAT can be used to assist in evaluating fish habitat based on stream behaviour and characteristics when conducting environmental assessment for proposed instream development projects. • Outputs of OFAT (e.g., delineated watershed, physiographic and climate parameters, flow statistics, GIS layers, etc.) can be input into other ecological modelling tools for further modelling purposes.
Data Requirements:	Data required to run OFAT can be distributed by any of 13 major basins in Ontario (e.g., the Lake Superior Basin, Lake Huron Basin, Moose River Basin, etc.) through CDs or DVDs, including provincial DEM-related databases (e.g., DEM, flow direction, flow accumulation grids, etc.) at different cell resolutions, provincial climate databases (e.g., mean annual snowfall/precipitation, lake evaporation, etc.), provincial landscape databases (e.g., land cover, surficial geology, soil, etc.), etc.
Ease of Use:	OFAT is a user-friendly, interactive GIS-based software which can be run under MS Windows 95/98/2000/XP platforms. Detailed OFAT User's Manual is also available.
Strengths and Weaknesses:	Strengths: (1) derive various flow information (e.g., low flow, floods, etc.) in the same run, (2) easy to use (3) province-wide application, (4) contain a number of existing regional hydrologic models in one package so that users easily compare modelling results obtained from different models, (5) all the data have already been organized in the context of watershed, and (6) the batch run option allow users to run as many watersheds as they want in the same run. Weaknesses: (1) ArcView 3.2a and Spatial Analyst Extension software are required to run OFAT, and (2) currently, OFAT provides flow statistics rather than complete hydrograph.
Other Notes:	Development of OFAT version 2.0 is currently underway by using VB/VBA programming language with ArcGIS 8.x ArcObjects. Version 2.0 will incorporate more flow information/statistics for both ungauged and gauged sites in Ontario, including flow duration curves, low flow and flood frequency analyses, daily flow hydrographs, etc.

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	PVA: Population Viability Analyses
Developed by:	
Distributed by:	Applied Biomathematics, Inc., 100 North Country Road, Setauket, NY 11733-1345, 800-735-4350, (Fax) 516-751-3435
Primary Purpose:	Examines how expected time to extinction changes with the effects of demographic, genetic, or environmental variability on population stability for aquatic or terrestrial populations.
Applications and Experience:	Used extensively for ecological risk analysis and wildlife population research. A commercially available form of a PVA is RAMAS. RAMAS operates on IBM PC- and compatibles in DOS. PVAs have been used mostly in a generalized sense to determine how a population will respond to environmental changes.
Overview of Characteristics:	The accurate projection of population growth requires a knowledge of the age structure of the population and the survival and fecundity of individuals of each age. This is often achieved using a life table (or matrix) approach in which the demographic parameters include annual rates of survival, growth or change among defined life history stages, and fecundity. Life tables set out the fecundities and probabilities of survival for each age class of individuals in a population and use an "accounting' formulation to calculate future population size on the basis of current size and rates of growth, death, and birth. PVAs also incorporate uncertainty due to unknown or unpredictable events by modeling variation in population parameters and estimating probabilities of extinction over specified periods of time, instead of using a single estimate for an unspecified time.
Applicability for Assessing Ecological Impacts of Withdrawals:	PVA provides quantified analysis of the stability of a specified population following a change in environment, population structure, or behavior. These factors are a function of water quality and quantity.
Data Requirements:	Age structure of the population, survival, and fecundity of each age or life stage.
Ease of Use:	RAMAS GIS has an interactive, user-friendly menu system.
Strengths and Weaknesses:	PVAs can provide risk assessors and other scientists with simulations of the impact of a stressor (that has been translated into demographic parameters) to examine how expected time to extinction changes with the environment, population structure or behavior. PVAs have been used to determine how a population will respond to environmental changes, rather than specifically to assess risk from alternative management scenarios.
Other Notes:	Information and software available at http://www.ramas.com/ramas.htm#gis

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	QUAL2E: The Enhanced Stream Water Quality Model
Developed by:	Model Distribution Coordinator, Center for Exposure Assessment Modeling (CEAM), USEPA, 960 College Station Road, Athens, GA 20605-2700. Models are available for FTP from: ftp://ftp.epa.gov/epa_ceam/wwwhtml/ceamhome.htm and Windows at http://www.epa.gov/ost/tools Documentation for QUAL2E is also available at http://www.epa.gov/ord/webpubs/qua12e/
Distributed by:	Same as above
Primary Purpose:	Water quality management, planning, and wasteload allocation tool applicable for conventional pollutants.
Applications and Experience:	The QUAL series of models has a two-decade history in water quality management and wasteload allocation studies. Paschal and Mueller (1991) used QUAL2E to evaluate the effects of wastewater effluent on the South Platte River from Chatfield reservoir through Denver, Colorado. Cubilo *et al.* (1991) applied QUAL2D to the major rivers of the Comunidad de Madrid in Spain. Little and Williams (1992) describe a nonlinear regression programming model for calibrating QUAL2E. Johnson and Mercer (1994) report a QUAL2E application to the Chicago waterway and Upper Illinois River waterway to predict DO and other constituents in the DO cycle in response to various water pollution controls.
Overview of Characteristics:	**Model Processes:** ▪ Temperature, Salinity, BOD-DO, Nitrogen cycle, Phosphorus cycle ▪ Chlorophyll *a* (is modeled as the indicator of planktonic algae biomass; benthic algae is not considered) ▪ Conservative constituent, Nonconservative constituent ▪ First-order kinetics of constituents ▪ Uncertainty analysis **Method/Techniques:** The QUAL2E model permits simulation of several water quality constituents in a branching stream system using an implicit backward-difference, finite-difference solution to the one-dimensional advective-dispersive equation. The stream is conceptually represented as a system of reaches of variable length, each of which is subdivided into computational elements that have the same length in all reaches. A mass and heat balance is applied for every element. Mass may be gained or lost from elements by transport processes, external sources and sinks, or internal sources and sinks. The UNCAS component allows quick implementation of uncertainty analysis using sensitivity analysis, first-order error analysis, or Monte Carlo simulation. Model can be used for water quality/eutrophication, far-field, stream/river, 1-D, branching, steady flow, steady-state/quasidynamic, and advective/dispersive transport.
Applicability for Assessing Ecological Impacts of Withdrawals:	QUAL2E can be used for addressing the issues related to conventional pollutants under steady flow conditions.
Data Requirements:	The stream is represented by a network of headwaters, reaches, and junctions. Twenty-six physical, chemical, and biological properties have to be specified for a reach.
Ease of Use:	The QUAL2E Windows interface was developed to make the model more user friendly. It provides input screens to facilitate preparing model inputs and executing the model. It also has help screens and provides graphical viewing of input data and model results.
Strengths and Weaknesses:	▪ It is widely used and accepted for various solutions of environmental problems. It is alos a water quality planning tool to aid in developing total maximum daily loads (TMDLs). It is linked into EPA's BASINS modeling system. ▪ Steady-state model, best suited for low-flow analysis and not wet weather related events. ▪ Requires significant site-specific data for its proper application. ▪ Considers only steady flow; Only time-varying forcing functions are the climatologic variables that primarily affect diurnal temperature and dissolved oxygen.
Other Notes:	EPA, 1995. QUAL-2E: The Enhanced Stream Water Quality Model. Model Documentation and User's Manual. EPA-823-B-95-003 Information available at: http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	RATECON – Rate Constant Model for Chemical Dynamics
Developed by:	Donald Mackay
Distributed by:	Trent University
Primary Purpose:	To understand the relative importance of various fate processes and for estimating the lake's time response to loading reductions.
Applications and Experience:	Applied to evaluate PCB fate and transport in Lake Ontario. The model can be applied in steady-state or unsteady-state forms.
Overview of Characteristics:	The model considers three compartments: ▪ the atmosphere, ▪ a single well-mixed water column ▪ a well-mixed surficial sediment layer. The sources of contaminant include land-based discharges and atmospheric deposition. Processes of chemical degradation in the water column and sediment, outflow, sediment-water exchange, and sediment burial are quantified. A simple aquatic food chain model is also included. The model calculates the contaminant concentration in water and sediment. These concentrations are then used as input to the food chain model to compute concentration in the various organisms.
Applicability for Assessing Ecological Impacts of Withdrawals:	RATECON model simulate the time response of a lake from different loading scenarios, which may be due to changes in water quantity. The results from this model can be used to assess the impact of chemicals on biota.
Data Requirements:	Lake specific input data (area, volume, water flow rates, water temperature, rainfall rate, sedimentation and resuspension rates, composition and active depth of the sediments), loadings, properties of chemicals, rate constants for various processes
Ease of Use:	Easy to use, but interpretation requires knowledge of fugacity concepts.
Strengths and Weaknesses:	▪ Mass balance model that can be used to determine the fate of chemicals in the Great Lakes basin and elsewhere. ▪ Rate constant approach used in the model allows for the uniform and complete treatment of all processes. ▪ Concept of rate constants can be easily understood by diverse users.
Other Notes:	Mackay, D., Sang, S., Vhalos, P., Gobas, F., Diamond, M., and Dolan, D. 1994. A rate constant model of Chemical Dynamics in a Lake Ecosystem: PCBs in Lake Ontario. J. Great Lakes Res. 20(4): 625-642.

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☑ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	RMA-2V
Developed by:	Army Corps of Engineers, Waterways Experiment Station, Coastal And Hydraulics Laboratory 3909 Halls Ferry Road, Vicksburg, Mississippi 39180 http://ripple.wes.army.mil/software/tabs/models.htp
Distributed by:	Same as above.
Primary Purpose:	Computes flow velocities and water surface elevations on a vertically averaged two-dimensional mesh. It also computes the dynamic boundary between wet and dry regions in the model. Flow separations and eddy currents are accurately modeled.
Applications and Experience:	It is suitable for solving many problems involving hydraulic behavior of river, reservoirs, wetland, estuaries and bays. Its output can be used by RMA4 to model contaminant migration and sediment transport problems. RMA-2V is part of the SMS modeling system and has been used extensively by the Army Corps of Engineers and their consultants. This model has also been used by the USGS for such projects as the modeling of in-channel habitats in the Ozark Highlands of Missouri, and by the USEPA in New York's Hudson River Study.
Overview of Characteristics:	RMA-2V is a vertically averaged two-dimensional finite element hydrodynamic analysis model. The governing equations provide for the conservation of mass, conservation of momentum in both the x and y direction, and turbulence closure. Constituents modeled: Flow velocities and water-surface elevations. Outputs: Discharge and water level at specific grid points.
Applicability for Assessing Ecological Impacts of Withdrawals:	This model can be used to predict the change in amount of underwater habitat area due to a lowering of the surface water resulting from water withdrawals. It can also be used to predict the change in bed scour resulting from a decreased water depth and an increased flow velocity. This increase scour can lead to degradation of sediment habitat. Additionally, this model can assist in physical habitat inventory classification based on Froude number and depth as was done in the USGS project in the Ozarks listed above. (For more details on this project see: http://smig.usgs.gov/SMIG/features_0999/ratcliff.html)
Data Requirements:	Initial values, boundary data, roughness coefficients, continuous topographical data for model area.
Ease of Use:	Implemented as part of the user friendly, graphical SMS (Surface Water Modeling System) model interface. Some training is required for operation and implementation of the SMS user interface as well as manipulation of the extensive set of model results.
Strengths and Weaknesses:	▪ RMA-2V is not intended to be used for near field problems where flow-structure interactions (like vortices, vibrations, or vertical accelerations) are of interest. ▪ RMA-2V is a vertically averaged and therefore vertical extremes in hydraulic characteristics, such as velocity will not be predicted.
Other Notes:	U.S. Army Corps of Engineers Waterways Experiment Station, 1997. *Users Guide to RMA2-WES*. Version 4.3. Hydraulic Laboratory, Vicksburg, MS.

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	SAGEM- Saginaw Bay Ecosystem Model
Developed by:	J. V. DePinto, V. J. Bierman, Jr., J. Kaur, T. J. Feist
Distributed by:	
Primary Purpose:	Simulate time-varying concentrations of water quality constituents by coupling eutrophication, contaminant fate and transport, benthic, zebra mussel bioenergetics, and bioaccumulation models.
Applications and Experience:	The model was used to simulate the effect of zebra mussels on fate and transport of Polychlorinated Biphenyls (PCBs) in Saginaw Bay. The water quality component of the model was used to establish the target phosphorus loading to Saginaw Bay as part of the 1978 Great Lakes Water Quality Agreement.
Overview of Characteristics:	The model consists of a set of deterministic differential equations for each state variable in the form of dynamic mass balances. The state variables in the model are: ▪ Nitrogen, Phosphorus, Silicon in the water column and sediments ▪ Biomass of phytoplankton (5 groups), zooplankton (2 groups), zebra mussels (3 cohorts) ▪ Benthic green algae ▪ PCBs in water column, sediemnts ▪ PCBs in phytoplankton, zooplankton and zebra mussels ▪ Abiotic and detritus solids **Method/Techniques:** The fundamental governing principle for the model is conservation of mass in space and time. Each state variable is described by the two-dimensional advective-diffusion equation. The solution method used in the model consists of a finite difference approximation to the derivatives of advective-diffusion equation. The method is a control volume approach. The model uses Runga-Kutta method to solve the equations.
Applicability for Assessing Ecological Impacts of Withdrawals:	It predicts time-varying concentrations of water quality and contaminant concentrations in water, sediments, and species and water quality component is modular. The coupled modeling framework can be sued to simulate the ecological impacts of conditions imposed by water quality and water quantity, which could be affected by exotic species introduction.
Data Requirements:	System specific data, forcing functions (loadings for nutrients and contaminants, solar radiation, temperature, wind data), boundary and initial conditions, zebra mussel densities, process-related parameters, chemical-specific parameters.
Ease of Use:	Require significant technical expertise in eutrophication, contaminant transport, bioaccumation, and bioenergetics of mussels to use the model effectively.
Strengths and Weaknesses:	▪ The model simulates the effect of exotic species on energy and contaminant transport. ▪ SAGEM quatifies the spatial distribution of contaminants in the water column. ▪ The model is temporally dynamic and spatially segmented in horizontal (& assumes vertically well-mixed). ▪ Although the model has full capabilities to simulate state-of-the-art water quality kinetics and fate and transport of contaminants, it is potentially limited by available data for calibration and verification. ▪ The model does not compute hydrodynamics. Flows, diffusion coefficients, and volumes must be
Other Notes:	Information on model components: Bierman, V. J., Jr. and Mcllroy, L. M. 1986. User Manual for two-dimensional Multi-class Phytoplankton Model with Internal Nutrient Pool Kinetics. EPA/600/3-86/061. Limno-Tech, Inc. (LTI) 1995. A Preliminary Ecosystem Modeling Study of Zebra Mussels (Dreissena polymorpha) in Saginaw Bay, Lake Huron. Report to U.S. Environmental Protection Agency, Large Lake Research Station, Grosse Ile, MI. Limno-Tech, Inc. (LTI) 1997. Application of a Coupled Primary Productivity-Exotic Species Model for Saginaw Bay, Lake Huron. Report to Office of Research and Development, National Health and Environmental Effects Lab., Mid-Continent Ecology Division-Duluth, Large Lake Research Station, Grosse Ile, MI. Kaur, J. 2002. Development of a coupled Plankton-Zebra mussel- PCB Aquatic Ecoystem Model: Application to Saginaw Bay, Ph.D. Dissertation, University at Buffalo, Buffalo, NY.

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	SALMOD – Salmonid Population Model
Developed by:	
Distributed by:	USGS, Fort Collins, Colorado
Primary Purpose:	Simulate the dynamics of freshwater salmonid populations, both anadromous and resident.
Applications and Experience:	SALMOD has been applied to a fall chinook population in a portion of the Trinity River, California. An application on the Klamath River, California, is planned. There is a trial underway with rainbow and brown trout on the Poudre River, Colorado. Among the uses are 1) determination of the population consequences of alternative flow (and temperature) regimes, 2) understanding of the relative magnitude of mortality in determining the timing and degree of habitat "bottlenecks", and 3) designing flow regimes to mitigate those bottlenecks.
Overview of Characteristics:	**Model Processes:** SALMOD represents the freshwater population dynamics of two life history variants: (1) an anadromous fish species that returns to the stream as an adult to spawn or (2) a resident population of salmonids. The focus is on biological processes that affect the early lifestages of the species. The model simulates (1) spawning, (2) egg development and growth, (3) movement, induced by freshets, time of year, or living space constraints, and (4) various types of mortality. SALMOD employs a weekly time step for one or more biological years. Biological years typically (but not always) start with the first week of spawning. All rate parameters (e.g., growth, mortality) and physical state variables (e.g., streamflow, water temperature) are represented by mean weekly values. Spatial resolution is consistent with the mesohabitat inventory approach, in which the study area is classified and mapped as discrete mesohabitat types, intermediate between micro- and macrohabitat, that tend to behave similarly in response to discharge fluctuations.
Applicability for Assessing Ecological Impacts of Withdrawals:	In SALMOD, habitat quality and capacity are characterized by the hydraulic and thermal properties of individual mesohabitats. It can be used to track populations of spatially distinct cohorts as a function of water temperature.
Data Requirements:	Temperature, flow, species rate parameters
Ease of Use:	Model processes are implemented such that the user has the ability to easily program the model to create the dynamics thought to animate the population.
Strengths and Weaknesses:	• SALMOD is best explained by describing its fundamental structure in terms of temporal, spatial, and biological resolutions. • SALMOD considers a linear stream, with no tributaries or branches.
Other Notes:	http://www.mesc.nbs.gov/rsm/more_salmod.html Manual available at: ftp://ftp.mesc.usgs.gov/webdl/salmodoc.pdf

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☑ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	SMPTOX4: Simplified Method Program - Variable-Complexity Stream Toxics model
Developed by:	Limno-Tech., Inc.
Distributed by:	Model Distribution Coordinator, Center for Exposure Assessment Modeling (CEAM), USEPA, 960 College Station Road, Athens, GA 20605-2700.
Primary Purpose:	SMPTOX4 provides a technique for calculating water column and stream bed toxic substance concentrations resulting from point source discharges into streams and rivers. It predicts pollutant concentrations in dissolved and particulate phases for water column and bed sediments, and total suspended solids.
Applications and Experience:	The users manual presents an example application using data from investigations on the Flint river, Michigan, in EPA's guidance manual for stream toxics modeling (USEPA, 1984). SMPTOX4 can be applied to streams and rivers.
Overview of Characteristics:	**Method/Techniques:** SMPTOX4 is a steady-state, one-dimensional analytical model for predicting suspended solids, and dissolved and particulate toxicant concentrations in the water column and streambed resulting from point source discharges into streams and rivers, based on an EPA-recommended technique (USEPA, 1980). Three levels of complexity are available within the model. At the simplest level, only total toxic pollutants can be predicted. The next level can be used to predict toxic water column concentrations but interactions with bed sediments are not considered. The third level allows prediction of pollutant concentrations in dissolved and particulate phases for the water column and bed sediments, as well as the total suspended solids concentrations. Operating within a Windows environment, SMPTOX4 allows quick data input and easy access to graphical output, sensitivity analysis, and uncertainty analysis. SMPTOX4 also contains a database of chemical properties for may chemicals of concern. **Application:** ▪ Streams/Rivers in one dimension ▪ Steady flow ▪ Steady-state predictions ▪ Advective and dispersive transport ▪ Considers benthic exchange ▪ Capability to simultaneously model multiple chemicals **Model Processes:** ▪ First-order decay ▪ Equilibrium sorption ▪ Sediment processes may be input
Applicability for Assessing Ecological Impacts of Withdrawals:	The model can be used to simulate the contaminant concentrations in streams and rivers. It is applicable for assessing the effect of pollutants under steady flow conditions.
Data Requirements:	Flow, total pollutant and suspended solids concentrations, geomorphic parameters physical/chemical coefficients and rates. Observed pollutant concentrations may be input for use during model calibration.
Ease of Use:	SMPTOX4 provides a user-friendly microcomputer program for performing toxics modeling. It contains a full screen editor to facilitate the entry and modification of inputs. Separate simulation routines are provided for model calibration, waste load allocation, and sensitivity analysis.
Strengths and Weaknesses:	▪ The model provides-steady state predictions for point sources only, and cannot simulate nonpoint source loadings. ▪ The model does not consider daughter products. ▪ Process kinetics are not simulated
Other Notes:	EPA, 1995. SMPTOX4. User's manual. Office of Water. Washington, D.C.

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	SNTEMP/SSTEMP: Stream Network/Stream Segment Temperature Models
Developed by:	
Distributed by:	Riverine and Wetlands Ecosystem Branch, National biological Service, 4512 McMurray Avenue, Fort Collins, CO 80525-3400, 303-226-9319
Primary Purpose:	Simulate mean daily water temperature for a stream segment for a single time period (SSTEMP) or for a stream network with multiple tributaries for multiple time periods (SNTEMP). Estimate minimum and maximum water temperatures from equations utilizing the stream characteristics.
Applications and Experience:	Used extensively by the U.S. Fish and Wildlife Service and state fisheries management agencies.
Overview of Characteristics:	SNTEMP and SSTEMP and computer models that estimate how the temperature of a stream changes with altered conditions of flow, riparian shade, and meteorologic conditions. They calculate the heat flux components for the stream segment and then transport that heat downstream. Both models assume that (1) water in the system is instantaneously and thoroughly mixed at all times; (2) all stream geometry (e.g., slope, shade, friction coefficient) is characterized by mean conditions' (3) distribution of lateral inflow is uniformly apportioned throughout the segment length; and (4) solar radiation and the other meteorological and hydrological parameters are 24-hour means. The programs also handle the special case of a dam with steady-state release at the up-stream end of the segment. The companion programs SHADE and SOLAR can be used in tandem with SNTEMP/SSTEMP to calculate percent shade, solar radiation, and day length. SNTEMP and SSTEMP are typically used in deciding whether regulatory requirements are being met for fisheries in rivers and streams. Is a logical next step for factoring temperature consequences of altered streamflow into management decisions.
Applicability for Assessing Ecological Impacts of Withdrawals:	The SNTEMP/SSTEMP models can estimate stream temperature changes (that can be linked to fish health) flowing the changes in climate and stream hydrology. These models can be used for evaluating the temperature effects caused due to water withdrawals.
Data Requirements:	Twenty input parameters are required that describe the stream geometry (e.g., segment length, elevation, roughness, shading), hydrology (e.g., segment inflow and outflow, dam locations) and meteorology (e.g., air temperature, relative humidity, solar radiation).
Ease of Use:	SNTEMP and SSTEMP operate on IBM PCs and compatibles in DOS, and are written in FORTRAN. New version developed for the Windows 9x and NT operating environments combines all of the previous DOS SSTEMP utilities (Temperature, Solar, and Shade) and adds several new features including Windows Help, automated sensitivity analysis, and graphic displays.
Strengths and Weaknesses:	Evaluates minimum, mean, and maximum daily water temperature in a stream. Models are applicable only for thoroughly mixed stream systems along with uniform lateral distribution of inflow.
Other Notes:	SNTEMP and SSTEMP are available at http://www.mesc.nbs.gov/rsm/rsm_software.html

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☑ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	SPARROW – SPAtially Referenced Regression On Watershed attributes
Developed by:	Alexander, R. B., Elliot, A. H., Shankar, U., and McBride, G. B.
Distributed by:	http://water.usgs.gov/nawqa/sparrow/
Primary Purpose:	SPARROW relates in-stream water-quality measurements to spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and stream transport.
Applications and Experience:	Model has been applied to (http://water.usgs.gov/nawqa/sparrow/) ▪ assess the atmospheric contributions of total nitrogen (TN) in riverine exports to coastal and estuarine ecosystems in the United States, to a selected set of 40 major coastal watersheds. ▪ **evaluate the Effect of Stream Channel Size on the Delivery of Nitrogen to the Gulf of Mexico** ▪ estimate Total nitrogen and total phosphorus transport (i.e., export) and point and nonpoint source contributions for hydrologic cataloging units in the conterminous United States ▪ **Nutrients in the Chesapeake Bay Watershed:** • Spatially Referenced Regression Modeling of Nutrient Loading in the Chesapeake Bay Watershed • Application of Spatially Referenced Regression Modeling for the Evaluation of Total Nitrogen Loading in the Chesapeake Bay Watershed ▪ Public Drinking-Water Supplies: • A National Model for Assessing the Susceptibility of Surface-Water Supplies to Source-Area Contamination
Overview of Characteristics:	The model empirically estimates the origin and fate of contaminants in streams, and quantifies uncertainties in these estimates based on model coefficient error and unexplained variability in the observed data.
Applicability for Assessing Ecological Impacts of Withdrawals:	SPARROW model evaluates nutrients in surface water that is an important parameter for assessing biota. The model can be used to assess the impact of nutrients as a result of changes in water quality and quantity, which could be due to water withdrawals.
Data Requirements:	Watershed data, water resources data
Ease of Use:	
Strengths and Weaknesses:	• Spatially referenced regression modeling is a statistical technique that uses spatial information to provide nutrient load predictions that are more spatially detailed than those provided by other large-scale watershed models. • Model development, calibration and validation need comprehensive data sets. • Model requires refined spatial data for nutrients.
Other Notes:	SPARROW related publications can be found at: http://water.usgs.gov/nawqa/sparrow/intro/pubs.html

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☑ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	SWAT: Soil and Water Assessment Tool
Developed by:	Blacklands Research Center, Texas A & M University
Distributed by:	http://www.brc.tamus.edu/swat/index.html
Primary Purpose:	SWAT is a river basin scale model developed to quantify the impact of land management practices on water, sediment and agricultural chemical yields in large, complex watersheds with varying soils, land use and management conditions over long periods of time.
Applications and Experience:	SWAT has been used: ▪ to determine flow and chemistry variables for development of ecological indicators in stream ecosystems in Minnesota/Michigan, ▪ in the Great Salt Plains Reservoir (Oklahoma/Kansas) ▪ to quantify the impact of changes in soil use on hydrosedimentologic characteristics of the Joanes river. An impact assessment was also performed in the coastal zone by means of a qualitative approach based on air photo historic series analysis, stream data from field tests and in-situ inspection. (Joanes River Watershed, Brazil), ▪ Hydrologic Unit Modeling of United States (HUMUS), and ▪ Coastal Watershed Assessment (Gulf of Maine). County-level NRI data and SSURGO has been used in SWAT simulations of 5 watersheds (Johnson County, Iowa), Natural Resources Inventory & Analysis Institute, USDA NRCS.
Overview of Characteristics:	Subbasin components of SWAT can be placed into eight major divisions – hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. ▪ SWAT is physically based. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT using this input data. ▪ It uses readily available inputs. SWAT can be used to study more specialized processes such as bacteria transport, the minimum data required to make a run are commonly available from government agencies. ▪ SWAT is computationally efficient. Simulation of very large basins or a variety of management strategies can be performed without excessive investment of time or money. ▪ It enables users to study long-term impacts. Many of the problems currently addressed by users involve the gradual buildup of pollutants and the impact on downstream water bodies. SWAT simulates – surface runoff, runoff volume, peak runoff rate, percolation, lateral subsurface flow, groundwater flow, evapotranspiration, soil and plant evaporation, snowmelt, and transmission losses. SWAT uses a command structure for routing runoff and chemicals through a watershed. Commands are included for routing flows through streams and reservoirs, adding flows, and inputting measured data or point sources. Using a routing commend language, the model can simulate a basin subdivided into grid cells or subwatersheds. Using the transfer command, water can be transferred from any reach or reservoir to any other reach or reservoir within the basin. The user can specify the fraction of flow to divert, the minimum flow remaining in the channel or reservoir, or a daily amount to divert. The user can also apply water directly to a subbasin for irrigation.
Applicability for Assessing Ecological Impacts of Withdrawals:	SWAT is a watershed-scale model used to predict the effects of management decisions on water quality and quantity, sediment, nutrient, and pesticide yields on large and small river basins. The transport of pollutants on water and sediment from varying soils, land use and management conditions over long periods of time will assist in evaluating the ecological impacts of water withdrawals.
Data Requirements:	Watershed attributes, Subbasin data, reservoir/lake data, climatic data, weather data (precipitation, air temperature, solar radiation, wind speed, and relative humidity), soils, crops, pesticides and nutrients.
Ease of Use:	Interfaces for the model have been developed in Windows (Visual Basic), GRASS, and ArcView. Some expertise on the part of the user is required.
Strengths and Weaknesses:	• It is a complex model, and requires many inputs. • SWAT is a continuous time model, i.e. a long-term yield model. The model is not designed to simulate detailed, single-event and flood routing. • It is included in the new EPA 'Better Assessment Science Integrating point and Nonpoint Sources' (BASINS) CD (Refer BASINS model review sheet).
Other Notes:	

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☑ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☐ Surface Water Quality
Name and Acronym:	WAM: Watershed Assessment Model
Developed by:	Soil and Water Engineering Technology, Inc.
Distributed by:	Same as above.
Primary Purpose:	A GIS based model that allows engineers and land use planners to interactively simulate and assess the environmental effects of various land use changes and associated land use practices.
Applications and Experience:	WAM was originally developed for the entire Suwannee River Water Management District (SRWMD - 19,400 km2 of northern Florida) and is currently being customized for the St. Johns River Water Management District (SJRWMD) in northeast Florida to accommodate their special regional characteristics.
Overview of Characteristics:	The modeling approach is to overlay land use and soil ARC/INFO Grid coverages (one hectare cell size) to locate every unique soil/land use combination within a watershed. The surface and ground water discharges and their total suspended solids (TSS), nitrogen and phosphorus contents from every cell are then simulated using a land use specific cell model. The USDA GLEAMS model is used for non-wetland and non-urban areas. Wetland and urban areas are handled with separate models. The individual cell discharges are then routed through the watershed based on the GIS hydrography coverage. Two separate versions of WAM are available for predicting either very detailed hourly discharges (WAM-D) or long-term annual average responses (WAM-A). The WAM-D simulates water depths and flows throughout the stream network, but it requires much more data and longer run-times than WAM-A. WAM-A is normally preferred unless the actual time series of constituent loads and flow to a receiving water body is needed for assessments. WAM also provides a simple indexing model for the spatial assessment of BOD, toxins, and coliform bacteria sources, as well as the pollutant assimilative capacity and wildlife diversity of wetlands within a watershed.
Applicability for Assessing Ecological Impacts of Withdrawals:	WAM provides water quality assessments – by spatial assessment using impact indices and by utilizing hydrologic and contaminant transport modeling. The model also assessing the wetland habitat based on relative areal influences of surrounding land uses on wetland habit. The model can be used to assess water quantity, quality, wetland's habitat, and flood proneness.
Data Requirements:	Watershed characteristic data, model parameters
Ease of Use:	• A menu driven interface allows the user to easily view the input, output data and control the model environment. • Graphical land use editing and management assignment tools allow the user to modify land uses for comparisons to existing conditions.
Strengths and Weaknesses:	WAM results provide rank/index, which is a good comparative tool for assessing the spatial importance of the land use, soils, wetlands, depressions and hydrography within a given watershed and across different watersheds. The simulated results provide precise load estimates for the individual watershed impact parameters; rather, they provide a relative index of the potential environmental impacts. WAM can be used to determine and rank current areas under environmental stress, estimate future impacts of land use management decisions and set achievable load reduction goals.
Other Notes:	Information available at: http://www.swet.com/index.htm

Models with Prospective Relevance to Ecological Impact Assessment

Category of Model:	☑ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	WARMF: Watershed Analysis Risk Management Framework
Developed by:	Systech Engineering, Inc. under the sponsorship of Electric Power Research Institute
Distributed by:	Proprietary
Primary Purpose:	• Guide stakeholders through the consensus building process and provides scientific information for making informed decisions on a watershed management plan • Help stakeholders determine TMDLs for point and nonpoint source loads • Simulate hydrology, nonpoint loading, and water quality of a watershed • Predict changes in water quality due to point and nonpoint source control, land use changes, and best management practices
Applications and Experience:	The WARMF model has been applied to • Catawba River, North and South Carolina • Chartiers Creek, Pennsylvania • Cheat River, West Virginia • Hockanum River, Connecticut • Holston River, Virginia and Tennessee • Blue River, Colorado • Mica Creek, Idaho • Oostanaula Creek, Tennessee • Truckee River, California and Nevada
Overview of Characteristics:	**Model Processes:** ▪ Water, mass and heat balances, ▪ Weathering, ▪ Pyrite oxidation (acid mine), ▪ Advection, ▪ Erosion, ▪ Sedimentation, ▪ Decay, ▪ Nutrient cycling, ▪ Productivity, and ▪ Adsorption/desorption. **Type of Constituents:** TDS, suspended sediments, temperature, pathogens, pesticides, BOD/DO, N, P, Algae, Al, Zn, Mn, pH. Equilibrium Watershed Analysis Risk Management Framework (WARMF) is a tool designed to support the watershed approach. The purpose of the watershed approach is to develop a water quality management plan that will improve the water quality of a river basin, to the extent that all waterway locations can serve their intended uses (e.g. water supply, swimmable water, fish habitat, recreation, and aesthetics). The plan must consider all factors that contribute to the deterioration of water quality. They may include land use (e.g. urbanization), farming practices, point source discharges, and flow diversions. The watershed approach requires the calculation of total maximum daily load of pollutants. Two methods, top-down and bottom-up, have been proposed. In the top-down approach, the TMDL for the entire river basin is determined first. The basinwide TMDL is then allocated to individual point and nonpoint dischargers. In WARMF, however, we recognize that the waste discharge is confined to the waterway. Each section of the waterway can have its own water quality problem, requiring a TMDL determination. Therefore, WARMF uses a bottom-up approach, in which TMDL calculations are made for a series of control points from the upstream to the downstream of a river basin. A road map is provided for the step-by-step calculation.
Applicability for Assessing Ecological Impacts of Withdrawals:	The model is suitable for water quantity and quality analysis involving various types of withdrawals and environmental conditions.

Data Requirements:	The model requires meteorology, air quality, point source, reservoir release, and flow diversion data. It also needs observed flow and water quality data.
Ease of Use:	• WARMF integrates all models and databases in a Windows-based graphical user interface (GUI). By pointing and clicking, the stakeholders can specify a management plan, run the model, and see the results, literally, at their finger tips. The outputs are displayed in colored maps and graphs, and/or tables. • WARMF requires expertise on the part of the user.
Strengths and Weaknesses:	• The water quality, in scientific terms of constituent concentrations, is translated to the easy-to-understand terms of whether the water can serve its beneficial uses. • A decision support system (DSS) is better suited than a decision model for the development of a consensus. • The model simulates so many processes with so many kinetic coefficients that it is difficult to perform sensitivity analyses or Monte Carlo simulations. • The river segment cannot be influenced by tides. • The site-specific coefficients are not measured. The uncertainty of using the default (literature) values is not known. • Lumped parameter approach does not allow the analysis with parcel-by-parcel detail.
Other Notes:	Information available at: http://www.systechengineering.com/warmf.html

Category of Model:	☐ Hydrologic/Watershed ☐ Groundwater ☐ Ecological Effects ☐ Hydrodynamic/Hydraulic ☑ Surface Water Quality
Name and Acronym:	WASP5: Water Quality Analysis Simulation Program New Version: WASP6
Developed by:	Model Distribution Coordinator, Center for Exposure Assessment Modeling (CEAM), USEPA, 960 College Station Road, Athens, GA 30605-2700, 706-355-8400 Ftp from: Ftp://ftp.epa.gov/epa_ceam/wwwhtrnl/ceamhome.htm WASP6: http://www.epa.gov/region4/water/tmdl/tools/wasp.htm
Distributed by:	Same as above
Primary Purpose:	Simulate the fate and transport of conventional and toxic pollutants in surface waters.
Applications and Experience:	WASP is a general, finite-segment based water quality model that had its origins in the Manhattan College environmental engineering program in the late 60's. Over the years it has been refined and upgraded largely through extensive applications to Great Lakes problems. Among the notable Great Lakes application are the Lake Erie eutrophication model by Di Toro and Connolly (1980), the Lake Ontario eutrophication model by Thomann (Thomann *et al.* 1975, 1979), and the Lake Michigan eutrophication model by Rodgers (Rodgers and Salisbury, 1981). Out of these applications came a PC-based version of WASP, known as WASP5, supported by EPA (Ambrose *et al.* 1993). A considerably revised version of the WASP5 model was used as the modeling framework for the development and application of the GBOCS/GBTOX model by Bierman *et al.* (1992), which was the first toxic chemical mass balance model that used multiple organic carbon state variables as sorbents for the hydrophobic organic chemicals in the model. WASP5 has been used in a wide range of regulatory and water quality management applications for rivers, lakes, and estuaries. Lang and Fontaine (1990) describe an application to predict the transport and fate of organic contaminants in Lake St. Clair, Michigan. Cheng *et al.* (1994) describe the development and application of a GIS-based modeling framework using a watershed loading model and WASP. Lu *et al.* (1994) used the model to simulate the transport and fate of DO, BOD, and organic nitrogen in untreated wastewater discharges in Weeks Bay, Alabama. Lung and Larson (1995) used EUTRO5 to evaluate phosphorus loading reduction scenarios for the Upper Mississippi River and Lake Pepin. Cockrum and Warwick (1995) used WASP to characterize the impact of agricultural activities on instream water quality in a periphyton dominated stream. Tetra Tech (1995) describes a full three-dimensional application of EUTRO5 in conjunction with the EFDC hydrodynamic model to assess-the effectiveness of options for total nitrogen removal from a wastewater treatment plant. **Application:** ▪ May be applied to most waterbodies in one, two, or three dimensions ▪ Can be linked with simulated hydrodynamics
Overview of Characteristics:	**Model Processes:** ▪ Temperature, Salinity, Bacteria, DO-BOD ▪ Nitrogen cycle, Phosphorus cycle, ▪ Phytoplankton ▪ First-order decay, daughter products ▪ Process kinetics, Equilibrium sorption, Net resuspension/deposition **Methods/Techniques:** WASP5 is a general-purpose modeling system for assessing the fate and transport of conventional and toxic pollutants in surface waterbodies. The model simulates time varying processes of advection and dispersion, considering point and diffuse mass loading, and boundary exchange. WASP5 includes two submodels for water quality/eutrophication and toxics, referred to as EUTRO5 and TOXI5, respectively. In EUTRO5, the transport and transformation of up to eight state variables in the water column and sediment bed may be simulated. In TOXI5, the transport and transformation of one to three chemicals and one to three types of particulate material can be simulated.
Applicability for Assessing Ecological Impacts of Withdrawals:	WASP5 is applicable for assessing the effect of water quality on fate and transport of pollutants.

Data Requirements:	The body of water to be simulated must be divided into a series of completely mixed computational segments. Loads, boundary concentrations, and initial concentrations must be specified for each state variable. Forcing functions must be specified for time and spatially variable parameters. In TOXI5, up to 12 spatially variable environmental variables, such as pH and light extinction, may be specified as needed. In addition, up to 17 time-variable functions may be used to study diurnal or seasonal effects on pollutant behavior. In EUTRO5, up to 16 spatially variable environmental parameters, 60 rate constants, and 14 time-variable functions can be specified.
Ease of Use:	• Extensive modeling experience required. • WASP6 has user-friendly input and output interfaces.
Strengths and Weaknesses:	▪ It provides the flexibility to describe almost any water quality constituent of concern, along with its widespread use and acceptance. ▪ Limited hydrodynamic capabilities with the 1-D RIVMOD-H and DYNHYD5 models ▪ There is a potential for instability or numerical dispersion in the user specified computational network. ▪ Zooplankton dynamics are not simulated in EUTRO5 although their effect may be described by user specified forcing functions that vary in space and time. ▪ Intermediate-level method for computation of sediment oxygen demand and benthic nutrient fluxes.
Other Notes:	Ambrose, R.B., Wool, T.A., and Martin, J.L., 1993. The Water Quality Analysis Simulation Program WASP5, Part A: Model Documentation, Version 5.10, US Environmental Protection Agency, Env. Research Lab., Athens Georgia Ambrose, R.B., Wool, T.A., and Martin, J.L., 1993. The Water Quality Analysis Simulation Program WASP5, Part B: The WASP5 Input Dataset, Version 5.10, US Environmental Protection Agency, Env. Research Lab., Athens Georgia. Bierman, V.J., Jr., DePinto, J.V., Young, T.C., Rodgers, P.W., Martin, S.C., Raghunathan, R., and Hinz, S.C. 1992. Development and Validation of an Integrated Exposure Model for Toxic Chemicals in Green Bay, Lake Michigan. US Environmental Protection Agency, Grosse Ile, MI, Cooperative Agreement CR-814885. Di Toro, D.M. and Connolly, J.P. 1980. Mathematical Models of Water Quality in Large Lakes, Part 2: lake Erie. US Environmental Protection Agency, Environmental Research Laboratory, Duluth, Minnesota, EPA-600/3-80-065. Rodgers, P.W. and Salisbury, D.K. 1981. Water Quality Modeling of Lake Michigan and Consideration of the Anamalous Ice Cover of 1976-1977. J. Great Lakes Res. 7(4):467-480. Thomann, R.V., Di Toro, D.M., Winfield, R.P., and O'Connor, D.J., 1975. Mathematical Modeling of Phytoplankton in Lake Ontario. 1. Model Development and Verification, NERC, ORD, USEPA, Corvallis, OR, 177 pp. EPA-660/3-75-005. Thomann, R.V., Winfield, R.P., and Segna, J.J. 1979. Verification Analysis of Lake Ontario and Rochester Embayment Three-Dimensional Eutrophication Models, ERL, ORD, USEPA, Duluth, MN, 135 pp. EPA-600/3-79-094. Information available at: http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home http://www.epa.gov/ednnrmrl/tools/model/wasp5.htm http://www.epa.gov/region4/water/tmdl/tools/wasp.htm

Appendix B

List of Relevant Models

Table B-1. Hydrodynamic/Hydraulic Models

Model	Description	Steady State/ Dynamic	Dimension	Supporting Agency/ Developer
ALIS*	Aquatic Landscape Inventory System (ALIS) and associated database	Steady State	2-D	OMNR
CE-QUAL-RIV1*	Hydrodynamic & Water Quality Model for Streams	Dynamic	1-D	USACOE
CE-QUAL-W2*	2D Laterally-Averaged Water Quality Model	Dynamic	2-D vertical	USACOE
CH3D-WES*	Curvilinear Hydrodynamics in Three Dimensions - Waterways Experiment Station	Dynamic	3-D	USACOE
CORMIX	A Mixing-Zone Model	Steady State	3-D	USEPA
DYNHYD5	Link-Node Tidal Hydrodynamic Model	Dynamic	1-D	USEPA/CEAM
ECOMSED	Hydrodynamic and Sediment Transport Model	Dynamic	3-D	HydroQual, Inc.
EFDC*: Environmental Fluid Dynamics Code	Hydrodynamics and transport model	Dynamic	1-D to 3-D	Tetra-Tech/Virginia Institute of Marine Sciences
HEC-2/HEC-RAS*	River Analysis System	Steady State	1-D (HEC-2)	USCOE/ HEC
HEM1D/HEM2D/HEM3D	Hydrodynamic Eutrophication Model	Dynamic	1-D to 3-D	Virginia Institute of Marine Science
HSCTM-2D	Hydrodynamic and Sediment and Contaminant Transport Model	Dynamic	2-D lateral	USEPA/CEAM
MIKE-11/ MIKE-21/ MIKE-3*	Generalized Modeling Package-1D/ 2D/3D - Hydrodynamics	Dynamic	1-, 2-, and 3-D	Danish Hydraulic Institute
OFAT*	Ontario Flow Assessment Techniques (OFAT) Version 1.0	Steady State	2-D	OMNR
POM	Princeton Ocean Model	Dynamic	3-D	Princeton University
RIVMOD-H	River Hydrodynamic Model	Dynamic	1-D	USEPA/CEAM
RMA-2V*	Hydrodynamic analysis model	Dynamic	2-D lateral	WES
UNET	1-D Unsteady Flow through a Full Network of Open Channels	Dynamic	1-D	USACOE

*Indicates that model is reviewed in more detail in Appendix A.

Table B-2. Hydrology/Watershed Models

Model	Description	Supporting Agency/ Developer
AGNPS	Agricultural Nonpoint Source Pollution Model	USDA
ANSWERS	Event based agricultural area run off/erosion model	University of Georgia
ATLSS*	Across trophic level system simulation for the freshwater wetlands of the everglades and big Cypress swamp	Coordinated through USGS
BASINS*	Better Assessment Science Integrating point and Nonpoint Sources (NPSM – Dynamic, QUAL2E – Steady state)	USEPA/CEAM
CREAMS/ GLEAMS	Field scale run off/erosion model	USDA
ELM*	Everglades Landscape Model	SFMD (H. Carl Fitz)
GAWSER	Object-Oriented Guelph All-Weather Storm Event Runoff Model	John A. Hinckley, Jr. (USCOE)
GWLF	Generalized Watershed Loading Functions	EPA/CEAM
HSPF*: Hydrological Simulation Program – FORTRAN	Capable of simulating mixed-land-use watersheds (urban and rural) (1-D, Dynamic)	USEPA/CEAM
LBRM *	GLERL Large Basin Runoff Model	GLERL/NOAA
SLAMM	Source Loading and Management Model	University of Alabama
SPARROW*	Spatially Referenced Regression On Watershed attributes	USGS
SWAT*	Soil and Water Assessment Tool	USDA
SWMM	Storm Water Management Model	USEPA/CEAM
WAM*	Watershed Assessment Model	SWET
WARMF*	Watershed Analysis Risk Management Framework	Systech Engineering, Inc. under the sponsorship of EPRI
WATFLOOD	The WATFLOOD Hydrologic Model	Nick Kouwen (Univ. of Waterloo, Ontario, Canada)

*Indicates that model is reviewed in more detail in Appendix A.

Table B-3. Surface Water Quality Models

Model	Description	Steady State/ Dynamic	Dimension	Supporting Agency/ Developer
AQUATOX*	Ecosystem Model	Dynamic	2-D	USEPA
CE-QUAL-ICM*	3-D Time variable integrated compartment eutrophication model	Dynamic	3-D	USCOE
CE-QUAL-RIV1*	Hydrodynamic and water quality model for streams	Dynamic	1-D	USCOE
CE-QUAL-W2*	2-D laterally averaged hydrodynamic and water quality model	Dynamic	1-D, 2-D	USCOE
ECOFATE*	Ecosystem model	Dynamic	2-D	Simon Fraser University, Canada (Frank P. Gobas)
EUTROMOD*	Receiving water model	Steady-state	1-D	NALMS
GBTOX/GBOCS*	Green Bay Toxics Model	Dynamic	3-D	USEPA
HUDTOX	Contaminant Fate and Transport Model	Dynamic	3-D	USEPA
MIKE11-WQ MIKE21-WQ MIKE3WQ*	Generalized Modeling Package-1D(/2D/3D) Water Quality Module	Dynamic	1-D to 3-D	Danish Hydraulic Institute
QUAL2E*	Steady-state, 1-D stream water quality model	Steady-State	1-D	USEPA/CEAM
QWASI	Quantitative Water Air Sediment Interaction Model			Trent University, Canada (Donald Mackay)
RATECON*	Rate Constant Model for Chemical Dynamics	Dynamic	1-D	Trent University, Canada (Donald Mackay)
SAGEM*	Saginaw Bay Ecosystem Model	Dynamic	3-D	USEPA
SMPTOX4*	Simplified Method Program – Variable-Complexity Stream Toxics Model	Steady-state	1-D	USEPA/CEAM
WAQ-DELFTS3D	3-D time variable water quality model	Dynamic	3-D	WL Delft Hydraulics
WARMF*	Watershed Analysis Risk Management Framework			Systech Engineering, Inc. (w/ EPRI)
WASP5*	Water Quality Analysis Simulation Program	Dynamic	1-D to 3-D	USEPA
WASTOX	Water Quality Analysis Simulation of TOXics	Dynamic	1-D to 3-D	USEPA/CEAM

*Indicates that model is reviewed in more detail in Appendix A.

Table B-4. Groundwater Models

Model	Description	Source
AQTESOLV	Aquifer Test Design and Analysis Computer Software	HydroSOLVE Inc.
Bioplume III	Transport of Dissolved Hydrocarbons under the influence of oxygen-limited biodegradation	Scientific Software Group
Bioscreen	Simulates remediation through natural attenuation of dissolved hydrocarbons	USEPA
Chemflo	Simulates Water and Chemical Movement in Unsaturated Soils	Scientific Software Group
FLONET/TRANS	FLONET Computes potentials, streamlines and ground-water velocities in a vertical section through a confined or unconfined aquifer. FLOTRANS computes heads, velocities and contaminant concentrations in a vertical section through a confined or unconfined aquifer. It has advective-dispersive solute transport capability	IGWMC Colorado School of Mines
GEOPACK	Geostatistical Software for Conducting Analysis of the Spatial Variability of One or More Random Functions	Scientific Software Group
GMS*	Sophisticated Groundwater Modeling Environment for MODFLOW, MODPATH, MT3D, RT3D, FEMWATER, SEAM3D, SEEP2D, PEST, UTCHEM, and UCODE (1-D to 3-D)	Scientific Software Group
HSSM-DOS	Hydrocarbon Spill Screening Model (HSSM)	USEPA/CEAM
MODFLOW/ Visual_MODFLOW*	Three-Dimensional Finite-Difference Ground-Water Flow Model	USGS/ Scientific Software Group/ Waterloo Hydrogeologic, Inc.
MOFAT	Multiplephase Flow and Multi-component Transport Model (Dynamic, 2-D)	USEPA
MT3D99	A Modular 3D Solute Transport Model	Scientific Software Group
RETC	Analyzes Soil Water Retention and Hydraulic Conductivity Functions of Unsaturated Soils	Scientific Software Group
RITZ	Regulatory and Investigative Treatment Zone Model	Scientific Software Group
VLEACH	One-Dimensional Finite-Difference Vadose Zone Leaching Model	Scientific Software Group/USEPA
WhAEM	Wellhead Analytic Element Model (WhAEM2000)	USEPA/CEAM
WHPA	Wellhead Protection Area Model (Steady-state, 2-D)	Scientific Software Group
WinTran	Groundwater Flow and Finite-Element Contaminant Transport Model	Scientific Software Group

*Indicates that model is reviewed in more detail in Appendix A.

Table B-5. Ecological Effects Models

Model	Description	Supporting Agency/ Developer
ATLSS*	Across trophic level system simulation for the freshwater wetlands of the everglades and big Cypress swamp	Coordinated through USGS
ECOFATE *	Model to investigate whether existing or planned chemical emissions can be expected to pose an ecological or human health risk,	Simon Fraser University (Frank P. Gobas)
ELM*	Everglades Landscape Model	SFWMD (H. Carl Fitz)
EXAMS II*	A fate and exposure model for assessing toxics in receiving waters	USEPA/CEAM
FGETS*: Food and gill exchange of toxic substances	Fish bioaccumulation simulation modeling for laboratory and field condition	USEPA/CEAM
HEP/HS*: Habitat Evaluation Procedures/Habitat Suitability Indices	Species based-evaluation method that determines the quality and quantity of available habitat and measures the impact of land or water use changes on that habitat	USEPA/CEAM
HES*: Habitat Evaluation System	Community-based evaluation technique to assess the impacts of development projects for aquatic and terrestrial habitat evaluations	USEPA/CEAM
HGM: Hydrogeomorphic Assessment	Used for determining the integrity of physical, chemical, and biological functions of wetlands as they compare to reference conditions	USEPA/CEAM
IFIM*: Instream Flow Incremental Methodology • PHABSIM: Software that combines Fish-habitat preference models and discharge-habitat models • TSLIB: Time-Series library	Collection of analytical procedures and computer models used to assess riverine habitats • Describes the weighted Usable Area (a measure of habitat) under a variety of channel configurations and flow management conditions • Creates habitat time series and habitat-duration curves using habitat discharge relationships produced by PHABSIM	USEPA/CEAM
MNSTREM: Minnesota Stream Temperature Model	Simulates dynamic stream temperatures averaged over one to six hours	USEPA/CEAM
PVA*: Population Viability Analyses	Population dynamics modeling for aquatic and terrestrial populations	USEPA/CEAM
RBPs: Rapid Bioassessment Protocols	Techniques to characterize the biological integrity of streams and rivers	USEPA/CEAM
SAGEM*	Saginaw Bay Ecosystem Model	USEPA
SNTEMP*: Stream Network TEMPerature Model SSTEMP: Stream Segment for a Single Time Period	• Models that simulate mean daily water temperature for a stream segment for a single time period • Models that simulate mean daily water temperature for a stream network with multiple tributaries for multiple time periods	USEPA/CEAM
WET II: Wetland Evaluation Technique, version 2.0	A community-based habitat evaluation approach that can provide a broad overview of potential project impacts on wetland habitat functions	USEPA/CEAM

*Indicates that model is reviewed in more detail in Appendix A.

GLOSSARY

EPRI	Electric Power Research Institute
NALMS	North American Lake Management Society
OMNR	Ontario Ministry of Natural Resources
SFWMD	South Florida Water Management District
SWET	Soil and Water Engineering Technology
USDA	US Department of Agriculture
USEPA/CEAM	U.S. Environmental Protection Agency/Center for Exposure Assessment Modeling
USGS	U.S. Geological Survey
WES	Waterways Experiment Station