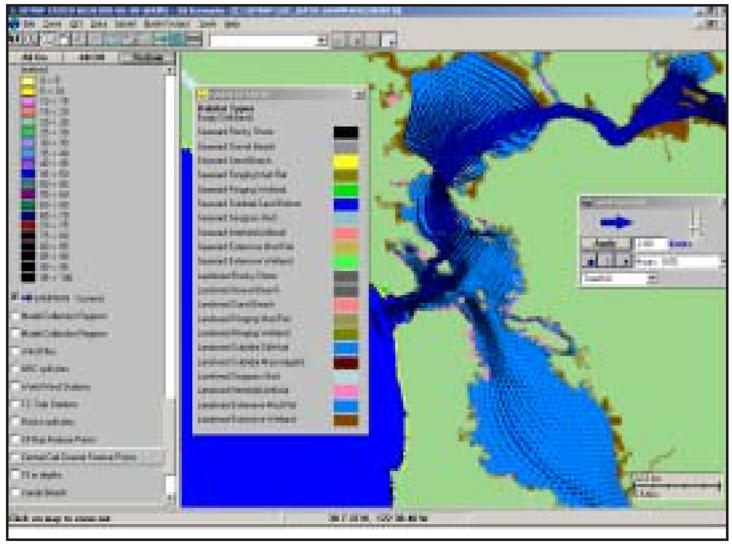
SIMAP

Integrated Oil Spill Impact Model System

APPLIED SCIENCE ASSOCIATES



Overview

SIMAP is a computer modeling software application that estimates physical fates and biological effects of releases of oil. A related model system, CHEMMAP models hazardous chemicals. In SIMAP, both the physical fates and biological effects models are threedimensional. There is also a two-dimensional oil spill model for quick trajectories and screening of scenarios and a three-dimensional stochastic model for risk assessment and contingency planning applications. The models are coupled to a geographic information system (GIS), which contains environmental and biological data, and also to databases of physical-chemical properties and biological abundance, containing necessary inputs for the models. The PC-based system operates on Windows 95(+) or Windows NT with userfriendly graphical inputs for running the models, editing data and viewing model output. The model has been applied to a variety of marine and freshwater environments for use in response and contingency planning, risk assessment, and training.

Introduction

There is an increasing need for *quantitative* and *objective* assessments of environmental impacts resulting from releases of toxic substances. Assessments are required for accidental spills, for chronic releases, for continuing contamination from historical dumping, and for planning and management decisionmaking (i.e., “what if” and “so what” analyses). Spill response should be managed to minimize biological and other environmental impacts.
While there is clearly a role for site-specific field assessments of potential impacts, this can be time-consuming and expensive. The high degree of natural variability in both time and space can make pollutant-induced changes difficult or impossible to

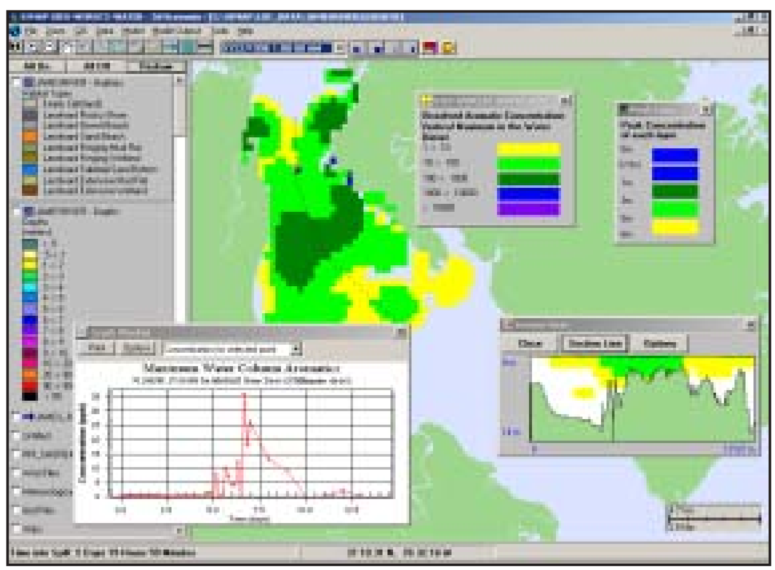
observe and assess quantitatively by field data collections. Numerical models are powerful tools in environmental impact assessment. A model represents a set of assumptions (or best estimates of impacts) which are stated quantitatively and may be tested, modified and re-tested using laboratory and field observations. The consequences of various spill and response situations can be explored using numerical models. An integrated model system such as SIMAP may be used to quantify environmental impacts of real events, of hypothetical spills and of response management scenarios.

SIMAP contains several major components:

- The physical fates model estimates surface distribution and subsurface concentrations of the spilled oil and its components over time.
- The biological effects model estimates impacts resulting from a spill scenario on fish, shellfish, wildlife, and for each of a series of habitats (environments) affected by the spill.
- The probability of impact from an oil discharge is quantified using the three-dimensional stochastic model.
- Currents that transport contaminant(s) and organisms are entered using the graphical user interface or generated using a (separate) hydrodynamic model. Alternatively, existing current data sets may be imported.
- Environmental, chemical, and biological databases supply required information to the model for computation of fates and effects.
- The user supplies information about the spill (time, place, oil type, and amount spilled) and some limited environmental conditions at the time (such as temperature and wind data).

Physical Fates Model

The physical fates model estimates distribution (as mass and concentrations) of contaminant on the water surface, on shorelines, in



the water column, and in sediments. The model is threedimensional, using a latitudelongitude grid for environmental data and projecting model results into that grid. A geographical information system (GIS) database supplies values for water depth, sediment type, ecological habitat, shoreline type, and ice cover throughout the gridded domain. The chemical (oil property) database supplies physical and chemical parameters required by the model. The user supplies a wind time series specific to the time and location of the spill.

The model estimates surface spreading, slick transport, entrainment into the water column, and evaporation, to determine trajectory and fate at the surface. Surface slicks interact with shorelines, depositing and releasing material according to shoreline type. In general, some fraction of any contaminant spilled will exist in both water column and sediments. In the water column, horizontal and vertical transport by currents and turbulent (random) dispersion are simulated. A contaminant in the water column is partially adsorbed to particles and partially dissolved. Partitioning between these states is assumed to be in constant proportions (i.e., is based on equilibrium partitioning theory). The contaminant fraction adsorbed to suspended particulate matter is assumed to settle at a rate typical for the type of sediment. Contaminants at the bottom are mixed by benthic animals into underlying sediments according to a simple bioturbation algorithm. Degradation of water column and sediment contaminant are estimated assuming a constant rate of "decay" in each environment.

The model is designed to simulate fates of crude oils, and petroleum products. Crude oil and petroleum products are actually complex mixtures of hydrocarbons. For modeling purposes, crude oils and petroleum products are represented by seven pseudo-components: three aromatic fractions considered toxic to organisms, three non-aromatic volatile and relatively insoluble fractions, and a nonvolatile insoluble (residual) fraction. Each has representative volatility and solubility characteristics for that component.

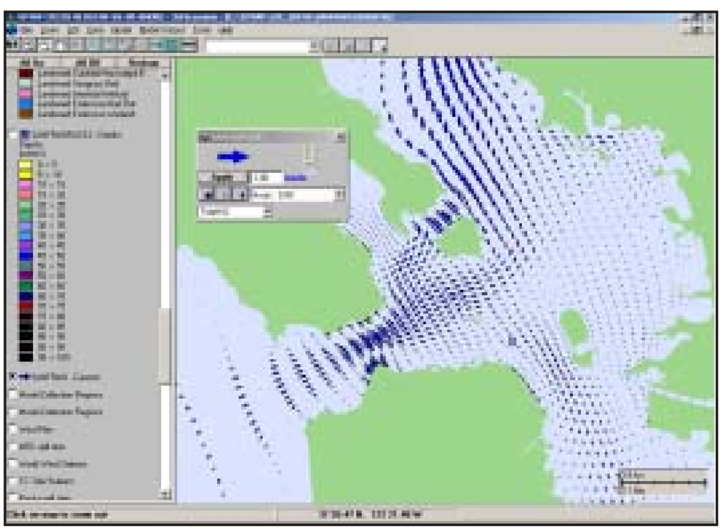
The physical fates model computes dissolved concentrations in the water column and sediments, and the area of water and shoreline covered by surface slicks in space and time. These results may be viewed and evaluated using the graphical user's interface. The information is also passed to the biological effects model, which then calculates biological effects of those concentrations and areas of coverage.

Hydrodynamics

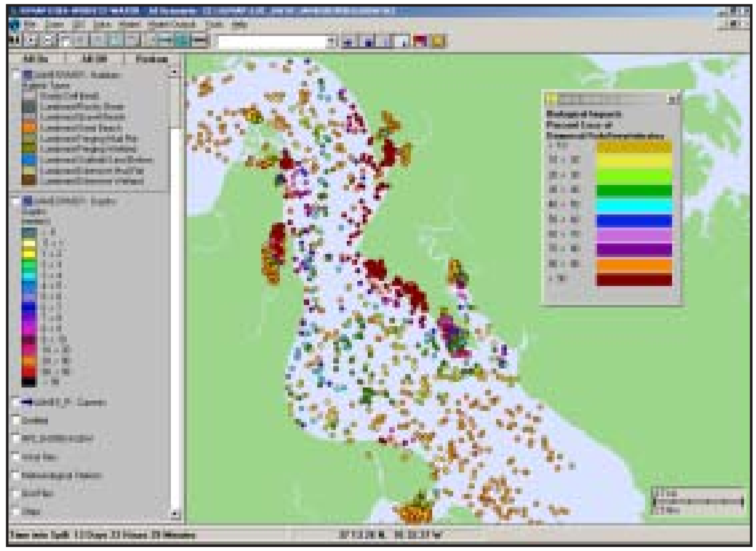
The transport of oil is dependent on inputs of high quality current (hydrodynamic) data for the area of interest. The data may be empirical (from direct observations) or calculated by a hydrodynamic model based on physical forcing and laws. The user may import current data in ASCII files or other standardized formats, or "paint" in current vectors using graphical tools.

ASA has developed several hydrodynamic models of varying complexity and applicability, including two- and three-dimensional applications that generate data sets that are either cyclic or varying in time. Model grids may be rectilinear or boundary-fitted (which better conforms to estuarine and river shorelines). Forcing may include tidal, pressure gradient, and winddriven motion of water. ASA's hydrodynamic models provide standardized current data sets, which are seamlessly read by the SIMAP physical fates and biological effects models.

In coastal and marine applications, the hydrodynamic modeling includes and is often dominated by tidal currents, whereas for freshwater, either gradient or wind-driven flow is dominant. Currents in rivers are typically computed for mean flow conditions, and stored in the database. These flows are generally twodimensional, varying across and along the river channel, but not with depth. They may be scaled up or down, depending on mean seasonal flow velocities.



These water currents are in turn used to calculate transport of contaminants in and on the water. The user also supplies a wind time series, which is used in SIMAP to predict the wind- and wave-driven surface drift of oil and contaminants.



Biological Effects Model

The biological effects model uses habitatspecific and seasonallyvarying estimates of fish, shellfish, bird, mammal and reptile abundances, and productivity of plant and animal communities at the base of the food chain, to determine biological effects resulting from the spill. Alternatively, the model may calculate the portion of a stock or population affected.

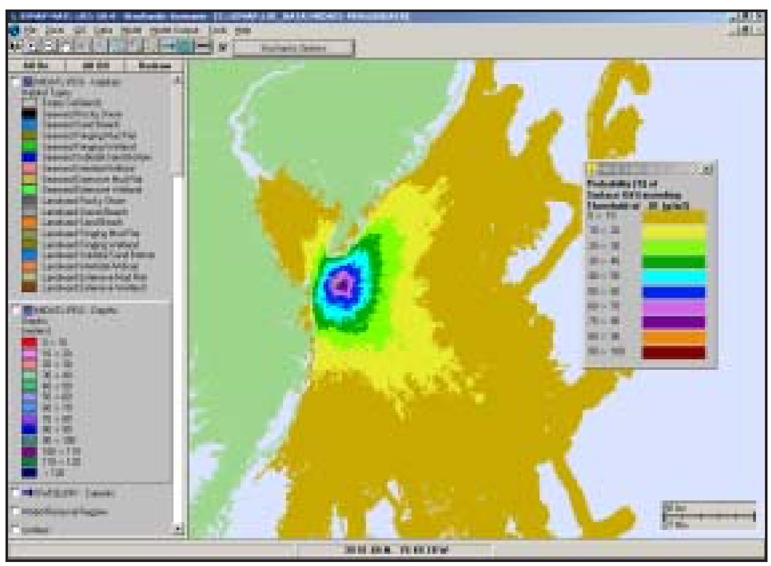
A rectangular grid of habitats represents the area potentially affected by the spill, with each grid cell coded for habitat type. Habitats include deepwater, nearshore, wetland and shoreline environments. The habitat grid matches the grid set up for the physical fates model using the GIS database. A contiguous grouping of habitat grid cells with the same habitat code represents an ecosystem in the biological submodel. Fish, birds, mammals and rates of lower trophic level productivity are assumed constant and evenly distributed across an ecosystem within each of four seasons. Fish, birds and mammals are assumed to move at random within each ecosystem during a single season (after that they may move on). Fish eggs, larvae, and juveniles (i.e., youngoftheyear) are assumed constant and evenly distributed across each ecosystem within each month of an annual cycle. Planktonic stages (eggs and larvae in the water column) are moved with the currents.

In the model, surface slicks (e.g., oil and petroleum products) interact with wildlife (birds, mammals, reptiles). A portion of wildlife in the area swept by the slick are assumed to die based on probability of encounter with the slick and mortality once oiled. Estimates for these probabilities are derived from information on behavior and field observations of mortality under similar circumstances.

Fish and their eggs and larvae are affected by dissolved contaminant concentration (in the water or sediment). Mortality is calculated using laboratory acute toxicity test data (LC50, concentration lethal to 50% of test individuals) corrected for temperature and time of exposure, and assuming a lognormal relationship between percent mortality and dissolved concentration. For oil and petroleum products, LC50s for the most toxic component, dissolved aromatics, are used. Movements of biota, either active or by current transport, are accounted for in determining time and concentration of exposure. Organisms killed are integrated over space and time by habitat type to calculate a total kill. Lost production of plants and animals at the base of the food chain is also computed. Lost production of fish, shellfish, birds and mammals due to reduction or contamination of food supply is estimated using a simple food web model.

In addition to the direct kill and food web losses of eggs and larvae, fish youngoftheyear may be lost via habitat disruption. This is included in the model for wetland and other nursery habitats destroyed by lethal concentrations or oiling. Losses are related to the habitat loss. Thus, recovery of spawning and nursery habitat in wetlands follows recovery of plant biomass and production.

The biological effects model computes reduction of fish and shellfish catch in the present and future years using standard fisheries models. Lost catch includes losses due to mortality of adults, juveniles and larvae due to the spill. Relatively high natural mortality rates of fish eggs and larvae are considered in the model, since a high number killed



at the time of the spill would have died anyway. Young oftheyear (eggs, larvae, and juveniles less than one year old) of each fish species category are tracked as percents of the one-year-old population. Youngoftheyear and older age classes are not assumed to inhabit the same environment concurrently, and their losses are calculated separately.

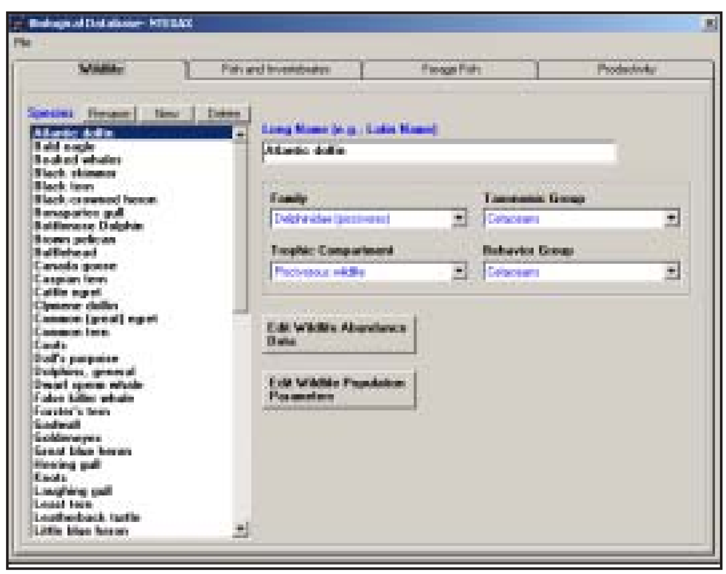
Using similar models, the numbers of birds and mammals missing and not hunted in present and future years are also calculated. For all fish and wildlife, population losses are the number not left alive in present and future years as the result of the spill, after constant natural mortality (and hunting mortality) is subtracted.

Three-Dimensional Stochastic Model

The probability of impact from an oil discharge is quantified using ASA's three-dimensional stochastic model in SIMAP. Long-term historical wind and current data are assembled for the area of interest. The model is run many times, randomizing the start date and time within a specified range of months of the year. The spill volume may be held constant or randomized from 0% to 100% of the worst-case amount each run. An effects endpoint is selected, which provides a threshold above which probabilities are to be reported.

Model output includes maps of oil:
(1) mass on the water surface,
(2) mass on shorelines,
(3) dissolved concentration in the water column,
(4) concentration of submerged particles in the water column, and
(5) mass in the sediments.

Five statistics are produced for each location (cell) in the model grid:
(1) probability of (any) amount exceeding the threshold,
(2) time when amount first exceeds threshold,



(3) mean expected maximum mass or concentration (i.e., mean of all runs),
(4) worst case (maximum possible) amount (i.e., maximum of all runs), and run date and time for worst case.

For each of the model runs, the peak exposure in time and the dosage (the sum of concentration times time exposed) are computed. The outputs include exposure maps and statistics: mean standard deviation, minimum and maximum for both exposure and dosage.

Environmental,Chemical and Biological databases

The physical and biological models require environmental, chemical and biological data as inputs. One of ASA's strengths is the ability to synthesize data from disparate sources. The data come from many sources including government and private data services, field studies and research. Modeling techniques are used to fill in "holes" in the observational data, thus allowing complete specification of needed data.

The environmental database is geographical, including data of the following types: coastline, bathymetry, shoreline type, ecological habitat type, and temporally varying ice coverage and temperature. This information is stored in the simplified geographic information system (GIS). The system provides storage and easy access for data over large geographic areas that is compatible with the large and complex models in real-time applications. The data system also has a user-friendly interface to allow viewing and editing of data via pull-down menus and mouse-driven selections.

The chemical database includes physical-chemical parameters for a wide variety of oils and petroleum products. Data have been compiled by ASA from existing, but diffuse, sources.

The default toxicological database contains LC50 (lethal concentration to 50% of test organisms) and EC50 (effective concentration to reduce to 50% of control rate) data for the low molecular weight aromatic components of oils and petroleum products. The data were derived from existing sources, including EPA's AQUIRE database. Data were standardized for temperature, pH, and salinity; and then averaged by species groups.

A biological database may be set up for any area of the world. For the U.S., ASA has developed a biological database containing seasonal or monthly mean abundance by species and habitat type for each biological "province" or biogeographic region of the U.S. These data have been compiled for 77 coastal and marine, 11 Great Lakes, and 10 inland waters biological provinces. Typical provinces are large estuaries, sounds, bays, sections of oceanic shelf, each of the Great Lakes, and biogeographic zones of the inland portion of the country.

In setting up a biological database for a region or province, data are compiled for up to 96 fish or shellfish and 46 wildlife (bird, mammal and reptile) species categories. Depending on availability of information, abundances are averaged by habitat type or total population estimates are distributed among habitats according to life history and behavior. For fish and shellfish young-of-the-year (i.e., eggs and larvae), total populations of individuals needed to replenish adult populations are estimated from the biological population model. These young-of-the-year are then distributed in habitats according to life history and development to calculate their abundances on a monthly basis.

Also compiled are estimates of lower trophic level production rates by season and habitat type. All of these data are compiled into standardized formats, with separate (equivalent format) data files for each biological province.

System Features

The model system is developed for an IBM compatible PC running Windows 95 (or higher) or Windows NT. The system is delivered with environmental data tools and an interactive GIS that allows the user to view and enter data, run the model, and view model output. Geographical data and model output are mapped and animated on the color screen and may be printed. Tabular information may also be viewed. Colored icons on a map indicate locations of site-specific information (such as critical habitats or response equipment).

SIMAP for Windows has a variety of features that include:

- Direct support for MapInfo GIS data.
- Direct support for ArcView GIS data.
- Support for raster based nautical charts.

- Ability to manually or automatically import GPS data (vessel/buoy tracking).
- Data stored in Microsoft Access databases for easy editing, import/export, and maintenance.
- Links to video images, photographic images, and external documents such as Microsoft Word or Microsoft Excel documents.
- Export of model results to dBase files for use in Excel, ArcView, MapInfo and other commercial applications.
- Improved reporting and annotation for paper output
- 2-D Trajectory and Fates Model
- 3-D Trajectory and Fates Model
- Biological Impacts Model
- 3-D Stochastic Model
- Ability to access different geographic locations from a global database stored on CD-ROM
- Biological abundance database
- Tool to edit biological data
- Tool to create wind time series
- Tool to add/edit oil database
- Easy addition of overflight polygons for model update.

Usefulness of Modeling Approach

The model system may be used to quantify physical fates and biological effects resulting from release of pollutants into aquatic environments for many purposes. SIMAP may be run under varying scenarios for contingency planning and risk assessment. The results of different management strategies may be investigated, and the relative impacts of various spills may be used to focus response efforts. The model system may be used to educate the public about potential impacts of postulated spills, and it is ideally suited for drill exercises.

The SIMAP client list includes the following:

- Minerals Management Service, US
- PEMEX
- Alyeska Pipeline Company
- National Power, UK, Ltd.
- AGIP, Italy
- Florida Power & Light
- INTEVEP, Venezuela
- Chevron
- ExxonMobil