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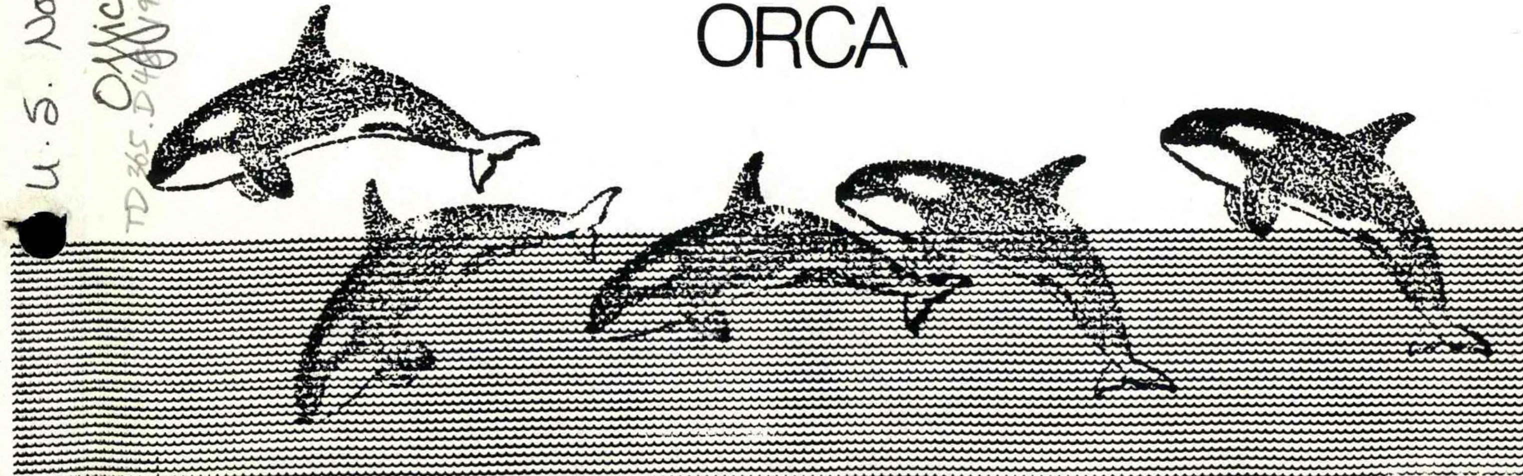


INTRODUCTION

This paper briefly describes the rationale for and the development of a simple water quality pollutant transport model to be used in conjunction with other ocean resource assessment methods to analyze resource use conflicts in the Gulf of Mexico. The overall regional assessment project for the Gulf of Mexico is jointly funded by the Office of Environment and Health, Bureau of Oceans and International Environmental and Scientific Affairs, U.S. Department of State; the National Marine Pollution Program Office, Office of Policy and Planning, National Oceanic and Atmospheric Administration (NOAA); and the Office of Ocean Resources Coordination and Assessment (ORCA), Office of Coastal Zone Management, NOAA. ORCA and the Center for Environmental Assessment Services, Environmental Data and Information Service, NOAA, will jointly develop the model. The regional assessment will be managed by the professional staff of ORCA. The two-year project will be completed during the summer of 1982.

GENERAL BACKGROUND

Many types of resource use conflicts occur in the coastal and ocean zones. Since many of the conflicts can result in significant costs to the natural environment and society, there is growing interest in their early identification and development of strategies to reduce their impacts. Regardless of the specific conflict, certain types of information will always be required for planning and decisionmaking. At least three levels of increasingly complex analysis exist for generating this information. First is a primarily <u>descriptive/qualitative analysis</u> that can be performed by overlaying maps of various types of information. This analysis can identify spatial and temporal relationships among economic activities, physical environments, living environments, the life history of various biological species, and institutional jurisdictions. For some problems this type of descriptive/qualitative analysis may be all that is required, depending on the questions to be answered. However, in most cases, this level of analysis will simply serve to refine the spatial and temporal extent of the problems requiring further analysis. Areas and time periods where conflicts are likely to be more or less important or severe can be identified. An example of this level of analysis is the East Coast Resource Use Mapping project currently being completed by NOAA's Office of Ocean Resources Coordination and Assessment (ORCA).[1]

The second level is simple quantitative analysis. This type of analysis builds on resource mapping analysis methods and utilizes very simple natural systems models, e.g., segmenting relevant coastal/ocean areas into relatively large grid areas (25 or 50 mile grids) and using simple relationships to make "order of magnitude" estimates of ambient pollutant concentrations. This analysis combined with economic analyses of about the same level of complexity can be used to evaluate alternative strategies in a preliminary way. Such analysis further defines and often reduces the dimensions of a problem and provides a preliminary quantitative appraisal of alternative solutions. Again, in some contexts this type of simple quantitative analysis would be all that is required, especially in relation to strategic, macro-level decisions, e.g., such as what would be the ambient water quality effects in the Gulf of Mexico of alternative land-based and ocean-based pollution discharge reduction strategies?

The third and most complex level is detailed regional or site-specific quantitative analysis, e.g., the type of analysis undertaken for individual facility siting studies. Presumably, analysis at levels one and two above would minimize resources invested in very detailed analyses by determining those analyses which are most important in a given problem context. It is neither possible nor necessary to perform complex and detailed analyses for all areas of the coast or ocean.

The study to be carried out in the Gulf of Mexico and the accompanying pollutant transport model described in this paper are characteristic of the second level of analysis described above -- i.e., simple quantitative analysis. The next section briefly describes the Gulf of Mexico study.

The Gulf of Mexico Study

The Gulf of Mexico study is the second in a series of five strategic regional assessment studies of U.S. coastal areas to be carried out by ORCA. The other regional assessments are: 1) the East Coast of the U.S. (nearing completion); 2) the Arctic Alaska region (including the Beaufort, Chukchi, and Bering Seas); 3) the Gulf of Alaska to the Oregon coast; and 4) California, (the latter three have not yet begun). These strategic assessment studies involve integrated analysis and planning for macro-level decisionmaking relating to multiple coastal/ocean resource uses for large regions. It is important to emphasize that the analyses performed and information generated by these studies are not substitutes for the detailed analysis and information required for local site specific or "tactical" decisions.

This study will develop and demonstrate an ocean and coastal resources management framework within which to analyze and evaluate strategies for reducing resource use conflicts in the Gulf of Mexico including the improvement and maintenance of the quality of its waters. The framework will be applicable in a wide range of problem contexts and capable of application with varying degrees of complexity, depending on available expertise, data, resources, and time.

Four analyses will be undertaken: 1) development of an inventory of pollution discharges from all relevant Gulf of Mexico sources, i.e., for all point and nonpoint land-based sources and all stationary and mobile ocean-based sources; 2) development of a series of maps (scale 1:2,000,000 or one inch = approximately 32 miles) which will display the temporal and spatial patterns of living marine resources, and show life history data of selected marine species and their critical habitat, such as wetlands or submerged aquatic vegetation; 3) development of a simple pollutant water quality transport model to analyze the movement of pollution through the Gulf of Mexico (described below); and 4) an analysis of selected resource use conflicts incorporating the results of 1, 2, and 3 above into the management framework.

Rationale for Simple Pollutant Transport Model for the Gulf of Mexico

Development of the capacity to quantify the relative contribution that various pollutant sources (land-based as well as ocean-based) make to ambient pollutant concentrations is important for analyzing ocean resource uses in the Gulf of Mexico. Such capacity would increase significantly the utility of resource use mapping analysis of the Gulf (level one above). Information generated by a pollutant transport model could be used to construct ambient pollutant concentration maps which would then be overlayed with natural resource concentration maps and analyzed. A simple pollutant transport model would enable any number of pollutant source discharge reduction strategies or alternate spatial and temporal patterns of discharges in the Gulf to be analyzed. Examples of problems to be analyzed could include: assessment of the relative impacts of discharges from offshore oil and gas activities, alternative locations for petroleum refineries, petrochemical plants and other major facilities, major port development projects, etc.

Selecting an appropriate modeling approach depends on the problem context, the specific questions to be answered by the analysis, and the nature of the system to be analyzed. Natural systems can be analyzed through a continuum of methods --from relatively simple through extremely complex models. At one end of the continuum are simple statistical models which do not attempt to describe processes, but only establish some causal relationship(s); at the other end are highly complex process models based on the numerical integration of conservation of mass and energy relationships. Between these two extremes a wide range of variably complex methods/models exists, depending on, for example: 1) the number and type of pollutants, constituents, or species (and hence processes and relationships) analyzed; 2) the dimensionality incorporated, e.g., number and size of grids used in segmenting a system, or number of pollution discharge source-receptor combinations included; and 3) the time dimensions of the analysis, e.g., number of time periods, averaging times for computing concentrations (hourly averages, daily averages, seasonal averages, annual averages). Generally, the more complex the modeling undertaken the greater the data requirements and overall costs to implement the model. Eventually a point is reached along the continuum where improvements in accuracy due to increasing model complexity (i.e., including more and more processes and detailed mathematical representations of them) decline and, in fact, may even decrease accuracy.

For the purposes of a strategic assessment in the Gulf of Mexico a model towards the lower end of the continuum is preferred -- at least initially. The model to be developed will serve in the short run as a "first cut" simple quantitative water quality model for use in the strategic resource mapping analysis described above and, in the long run as a starting point to investigate the benefits to be obtained from developing increasingly more complex models of the Gulf (probably to be undertaken by others).

MODEL SPECIFICATION AND DEVELOPMENT

Several approaches for modeling pollutant transport in the Gulf of Mexico are possible, based on the principles of conservation of mass and energy. At least two elements are common to all of these approaches. One, information on the hydrodynamics of the water body to be modeled (i.e., the velocities at which water moves through the system) must be obtained, either from measured data or computed based on geometry and other physical characteristics. Two, the physical processes which govern the movement of material in water must be mathematically represented, so that material transport can be estimated. Depending on the complexity of the approach two other elements may also be included: 1) mathematical representations of the chemical, biochemical, and physico-chemical processes which transform various pollutants as they are transported; and 2) mathematical representations of the biological-ecological processes which translate ambient pollutant concentrations into effects on living species. These two elements are generally included in relatively complex models. The model to be developed here is comprised primarily of only the first two elements, although some simple chemical reaction kinetics are included.

Segmenting the Gulf Into Control Volumes

Common to most conservation of mass and energy approaches, especially those applicable for modeling the entire Gulf, is the requirement that the waterbody to be analyzed be spatially represented as a network of "control volumes" so that mass balance equations can be written to describe the transport of pollutants from one control volume to others and hence throughout the waterbody.

Several schemes for segmenting the Gulf into control volumes are possible. The selection of an appropriate scheme depends on the specific type and set of questions to be answered concerning pollutant transport and the amount and accuracy of the input data on currents, temperature, pollutant discharges, etc., that can be developed with the resources available. Based on the objectives of the overall study of the Gulf (described above) and an assessment of available data, a "two-tier" segmenting approach was selected. The first tier is to divide the Gulf into a 1/4° x 1/4° square grid (approximately 30 mi. by 30 mi.) as shown in Figure 1, which defines approximately 550 control volumes for the Gulf. The pollutant transport equations developed for this grid scheme will roughly describe the movement of pollution throughout the entire Gulf.

The second tier further subdivides selected nearshore regions into smaller square grids or control volumes. These subdivisions are coterminous with the larger grid covering the remainder of the Gulf. Additional resolution is needed in nearshore waters where many important resource use conflicts occur due to relatively heavy concentrations of activities and heavy pollutant loading from land-based sources. The number and location of nearshore regions to be subdivided further will depend on the relative importance of pollution and availability of more refined data in these regions. Figure 2 illustrates the two-tier grid approach for segmenting the Gulf into control volumes. Note that because square grids will be used, some idealization of the coastline will be required to implement this approach.

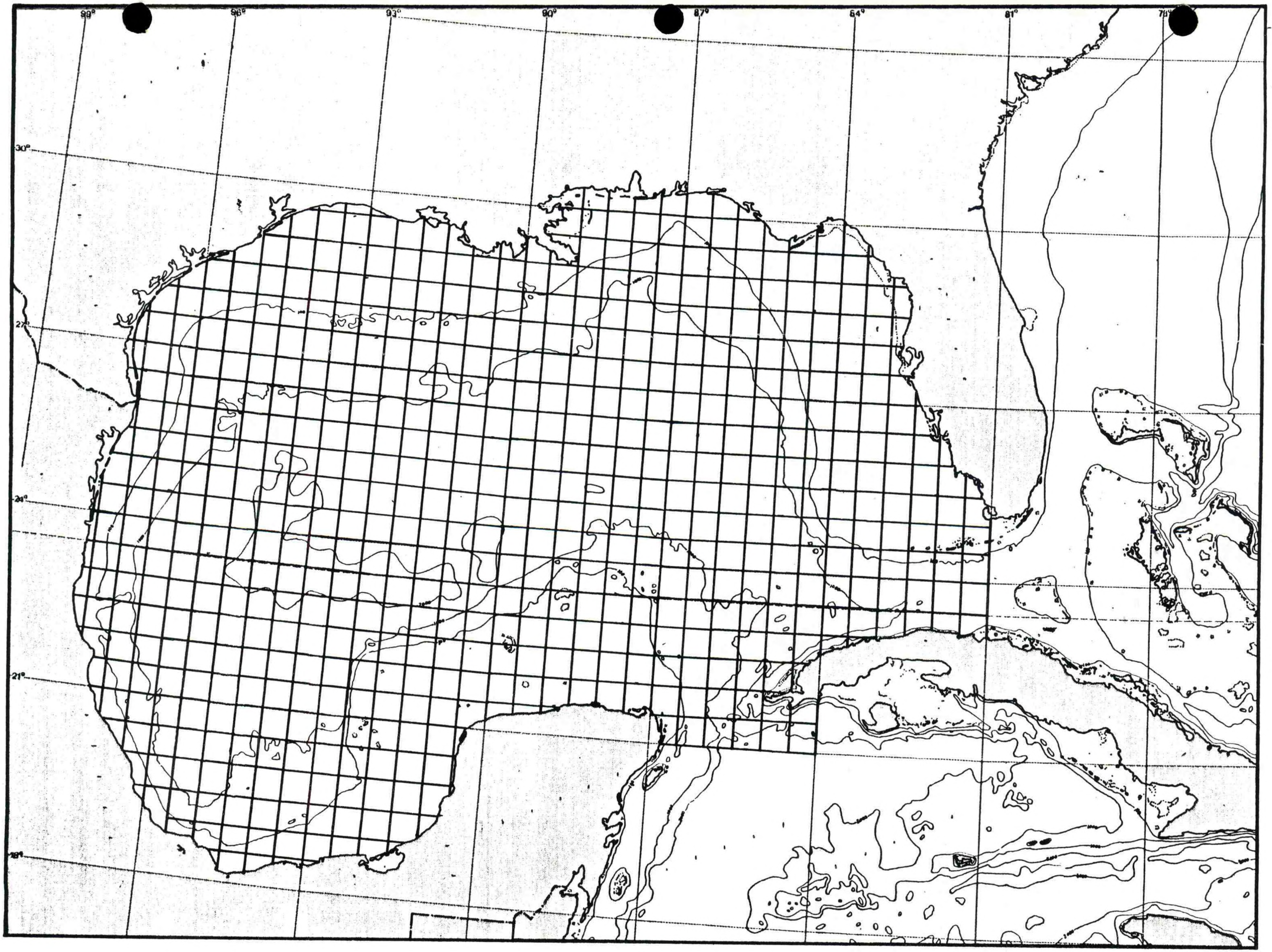


Figure 1. Quarter Degree Square Grid for the Gulf of Mexico

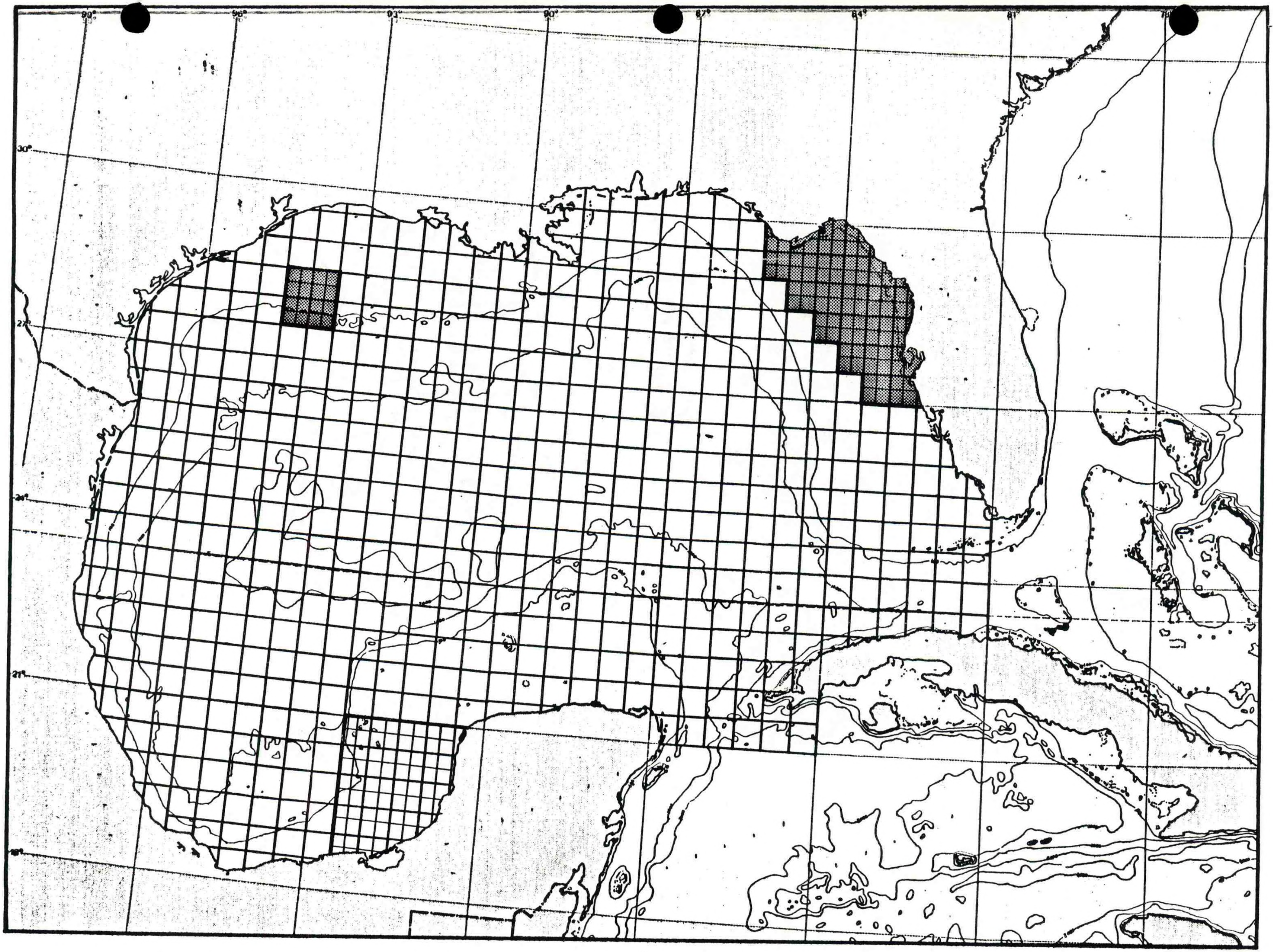


Figure 2. Illustrative Examples of a Two-Tier Approach to Segmenting the Gulf of Mexico

General Structure of Model

The basis for writing the mass balance equations for each control volume will be the well known two-dimensional advection-dispersion mass transport equation,[2] including a first-order reactive term and external sources and sinks of pollutants:

$$\frac{\partial C}{\partial t} = -U_x\frac{\partial C}{\partial x} - U_y\frac{\partial C}{\partial x} + k_x\frac{\partial^2 C}{\partial x^2} + k_y\frac{\partial^2 C}{\partial y^2} - k_d \cdot C \pm S \quad (1)$$

where C = average concentration of pollutant of interest in control volume,

t = time,

x = longitudinal distance,

y = latitudinal distance,

U_x = average current velocity in the x-direction,

U_y = average current velocity in the y-direction,

k_x = coefficient for dispersion in the x-direction,

k_y = coefficient for dispersion in the y-direction,

k_d = first-order decay rate for pollutant of interest, and

S = sum of all external sources, sinks, and interactions among pollutants (when considered).

This equation defines the basic structure of the pollutant transport model to be developed for the Gulf of Mexico. It assumes, and consequently so do the transport equations derived from it, that there is no vertical transport of pollutants within each control volume, and that each control volume is instantaneously and homogeneously mixed. That is, as soon as a pollutant is discharged into a control volume, it is dispersed equally throughout the volume and its concentration is the same everywhere in the volume.

Further, for our purposes, steady state conditions will be assumed (i.e., $\frac{\partial c}{\partial t}$ set equal to zero in equation (1)) and the model will be applied on a seasonal basis for two seasons only -- winter and summer. Winter and summer seasons were selected because they are relatively stable and represent very different meteorologic and hydrologic and oceanographic conditions. The model will estimate the average ambient concentrations of the pollutants of interest in each control volume for each of these two seasons.

In order to fully explain the application of equation (1) to the control volumes into which the Gulf of Mexico has been segmented, several additional points require explanation: 1) How will the requisite hydrodynamic data and parameter inputs be estimated for each control volume?; 2) How will estuaries effect pollutant discharge inputs into nearshore control volumes?; 3) What are the pollutants which will be included in the model?; 4) How will oil and grease be considered?; and 5) What mathematical methods which will be used to solve the model?

Hydrodynamic Data and Parameter Inputs

Based on equation (1) three items of hydrodynamic data are required for each control volume: 1) the direction and magnitude of the average current; 2) depth; and 3) temperature.

The average seasonal current for each control volume will be approximated using data primarily available from the National Oceanographic Data Center. (NDOC).[3] Other data sources will also be used where needed and available. The objective is to use the most representative current data as is possible. Of particular importance will be ship-drift data contained in NODC's Surface Current Data System. This data is based on over 100 years of reported merchant ship positions that indicate the difference between actual and projected ship position and is generally considered to be of high quality.

For control volumes in which these data are unavailable, dynamic topography[4] derived from density observations will be used in conjunction with the geostrophic approximation to indirectly estimate the deep ocean current. The geostrophic approximation states that the horizontal equation of fluid flow can be reduced to a balance between the pressure gradient and the Coriolis force. It is important to note that because all other forces, such as friction, are neglected the approximation is especially inaccurate in shallow nearshore waters. Based on these assumptions fluid flow in two dimensions can be expressed by the following equations:

$$-fv + \frac{1}{\rho}\frac{\partial p}{\partial x} = 0 \qquad (2)$$

$$fu + \frac{1}{\rho}\frac{\partial p}{\partial y} = 0 \qquad (3)$$

where u = average current velocity in the x-direction,

v = average current velocity in the y-direction,

ρ = water density,

$f = 2\, n \sin\phi$, the Coriolis parameter,

n = the earth's rate of rotation,

ϕ = the latitude, and

p = the pressure.

Equations (1) and (2) can also be expressed in terms of dynamic height (D):

$$-fV + \frac{\partial D}{\partial x} = 0 \qquad (4)$$

$$fU + \frac{\partial D}{\partial y} = 0 \qquad (5)$$

where $D = \int_{p_1}^{p_2} \frac{dp}{\rho}$, which is termed the relative dynamic topography between pressure levels p_1 and p_2. Given that values of D can be estimated from temperature and salinity data for each control volume, the relative current between pressure levels p_1 and p_2 can be computed. To estimate an average current for a control volume, p_1 will be assumed to be the pressure at the water surface and p_2 the pressure at a depth of 500 meters. It is further assumed that there is little or no water movement below 500 meters relative to movement on the surface and that the current at 500 meters can be considered to be zero. This assumption is based on an analysis of the NODC mixed layer depth file. Given a current value at p_2 of zero, a current can be estimated at level p_1, i.e., at the surface. The significance of using estimates of average surface currents, rather than a depth averaged current cannot be assessed until the model is developed and the sensitivity of model results to current variations analyzed. When and if they become available, depth averaged currents could be easily put into the model.

As indicated above, the two-dimensional model assumes that vertical transport of pollutants within each control volume is instantaneous and that each volume is homogeneously mixed. Therefore, it is particularly important that the depth of each control volume be specified in a way which makes sense in relation to the natural phenomenon to be modeled (pollutant transport) and the degree of accuracy sought. The depth of each control volume will be defined as either the mean depth (for shallow coastal areas) or mean thermocline depth (average distance from the surface to the point of inflection of the thermocline in each volume). Thermocline depth will be used in volumes in which thermocline depth is significantly less than actual depth. The implicit assumption is that most pollutant transport takes place above the thermocline in the mixing layer and that pollutant transport through the thermocline barrier is of secondary importance. The validity of this assumption depends on a number of factors, e.g., the type and quantity of pollutant, vertical currents, etc, and will be tested when the model is run. The mean thermocline depth specified for each control volume will be based on seasonal estimates of the thermocline/mixed layer depth developed by the Oceanographic Services Branch of NODC for a 1/4° x 1/4° square grid in the Gulf of Mexico. Temperature data required to estimate pollutant reaction and decay rate constants (when included) will be obtained from the same data base.

In addition to the obvious hydrodynamic data, values must be estimated for certain model parameters. These parameters are the dispersion coefficients, k_x and k_y, and the kinetic decay rates, k_d, for the pollutants of interest. The dispersion coefficients represent the rate at which mass (in this case pollutants) is dispersed or spread from one control volume to other volumes due to the eddy motions (turbulent mixing) of the fluid. Dispersion coefficients will be developed from field data, if such data are available.[5] Otherwise they will be estimated as empirical values during the process of model calibration and verification. Kinetic decay rates for pollutants of interest will in most cases also be developed empirically through model calibration and verification.

Estuary Effects on Pollutant Discharges

Most land-based pollution which enters nearshore Gulf of Mexico waters must first pass through estuaries. These estuaries "trap" and/or biochemically decay, to varying degrees, many pollutants before they pass into nearshore waters. The landward boundaries of the control volumes into which the Gulf will be segmented terminate at the mouths of estuaries -- that is, no estuaries will be included in a control volume. Consequently, the amount of pollution discharge reduction which takes place in estuaries must be estimated before land-based pollutant discharges can be passed into nearshore waters. Where available, monitoring data and information from previous studies will be used to estimate the amount of pollutants entering nearshore waters from estuaries. However, for many estuaries monitoring data will not be available. In these cases a simple "blackbox" approach will be used to estimate pollutant transport out of the estuary.

A number of simple black-box type approaches can be used for this purpose. The two most promising approaches are: 1) a residence time approach; and 2) an approach based on the tidal prism and tidal flushing calculation.[6] Given the conditions specified for the modeling analysis, i.e., the large size of control volumes (approximately 30 mi. x 30 mi.) and the assumption of steady state conditions, the residence time approach, the simpler of the two, will be used initally.

Following this approach, the volume of water in an estuary will be estimated from available data, including inflows from pollutant sources, i.e., specifically nonpoint sources, and a mean residence or detention time estimated for the estuary (the average amount of time water entering the estuary system remains in the system before it is discharged into nearshore waters). Mean residence time will be computed as follows:

$$T = \frac{V}{Q} \qquad (6)$$

where T = residence time,

V = mean volume of water in the estuary, and

Q = mean total inflow into the estuary.

Although this equation does not truly represent the residence period of an estuary (the actual period is somewhat shorter), it has been found that an approximate steady state condition is generally reached after the time period T, described by equation (6), has passed. The amount of pollutants discharged from an estuary into nearshore waters is then estimated by computing a "gross" source/sink decay/deposition rate for each pollutant and applying the following formula:

$$DR_0 = (1 - e^{-k_c T}) DR_i \qquad (7)$$

where DR_0 = pollutant discharge rate out of the estuary,

e = naperian base,

k_c = source/sink decay/deposition rate,

T = residence time, and

DR_i = pollutant discharge rate into the estuary.

The source/sink decay/deposition rate for each pollutant will be estimated from available monitoring data and/or modeling studies. The pollutant discharge input estimates to be used in the model are discussed below.

Pollutant Discharge Inputs

Three data bases will be used to estimate pollutant discharges into estuaries and Gulf of Mexico waters: 1) an inventory of land-based pollutant sources in the U.S.; 2) an inventory of land-based pollutant sources in Mexico; and 3) an inventory of mobile ocean-based pollutant sources for the entire Gulf, i.e., pollutant discharges from marine transportation activities. Stationary ocean-based sources, i.e., oil and gas drilling platforms and ocean dumping activites, are also included in 1 and 2.

The inventory of land-based pollutant sources in the U.S. is currently maintained by ORCA.[7] This inventory contains estimates of all point and nonpoint sources of pollutants in "coastal" counties of the Gulf of Mexico. Figure 3 illustrates the U.S. coastal counties in the Gulf of Mexico region. ORCA is in the process of updating this inventory to the most recent base year for which data are available (1977-1978), and expanding it to include additional pollutants and estimates of instream pollutant loads entering estuaries from upstream pollutant sources. The pollutants included at present are: wastewater discharge, biochemical oxygen demand, total suspended solids, total dissolved solids, total phosphorous, oil and grease, fecal coliform bacteria, Kjeldhal nitrogen, and an aggregate category for heavy metals. The current plan is to expand the inventory to include more pollutants which are relevant to the marine environment. For example, halogenated hydrocarbons and specific heavy metals such as lead and cadmium. Some of the pollutants in the inventory at present are of no or only minor importance in the marine environment, for example, total dissolved solids. The number of additional pollutants included will depend on available data and resources.

If feasible an analogous pollutant discharge inventory will be developed for coastal districts of Mexico bordering the Gulf of Mexico. While the inventory to be developed for Mexico will not be as accurate as that for the U.S, much of the experience obtained and some of the information generated, e.g., pollutant discharge relationships for certain types of technology, in developing the U.S. inventory will be transferable to the Mexican context.

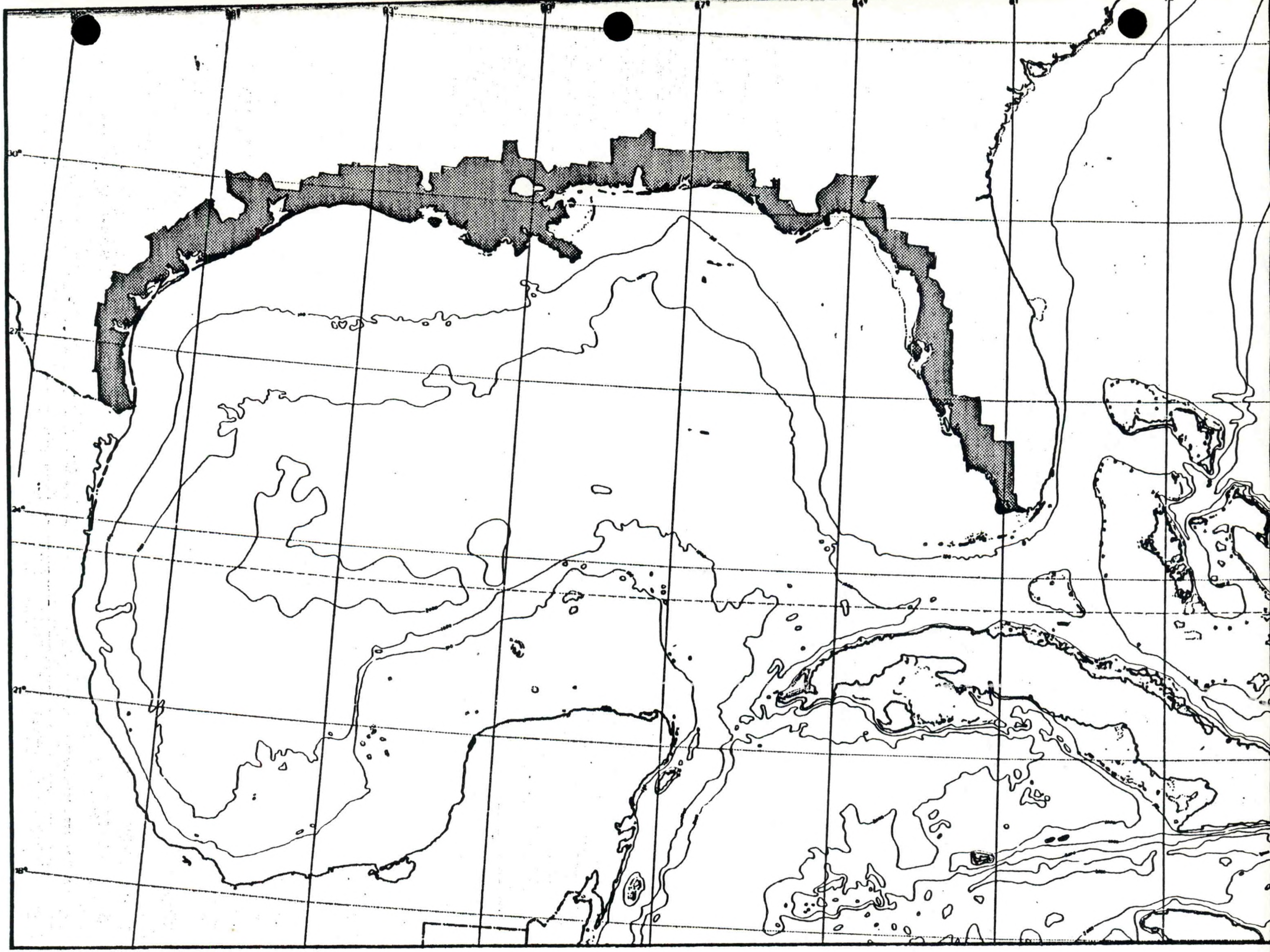


Figure 3. U.S. Coastal Counties in the Gulf of Mexico Region

The inventory of mobil ocean-based pollutant sources is currently under development by ORCA and includes analysis of the following activities: tanker traffic and operations (e.g., lightering), cargo ship traffic, fishing vessel traffic, offshore deepwater port terminal operations, and offshore terminal crew and supply boat operations. For vessels, the inventory will contain the type of vessels, by season, traveling into, through, or out of each grid area (control volume), estimates of the amount of oil and other pollutants discharged (either intentionally or accidentally) by these vessels during normal operations, and estimates of the amount and probability of oil spilled in each grid area by season due to ship casualties. For offshore deepwater port terminals the inventory will contain estimates of the amount of oil and other pollutants discharged in each grid area by season due to normal operations.

The actual constituents to be included in the pollutant transport model will be those pollutants for which adequate data can be obtained for calibration.

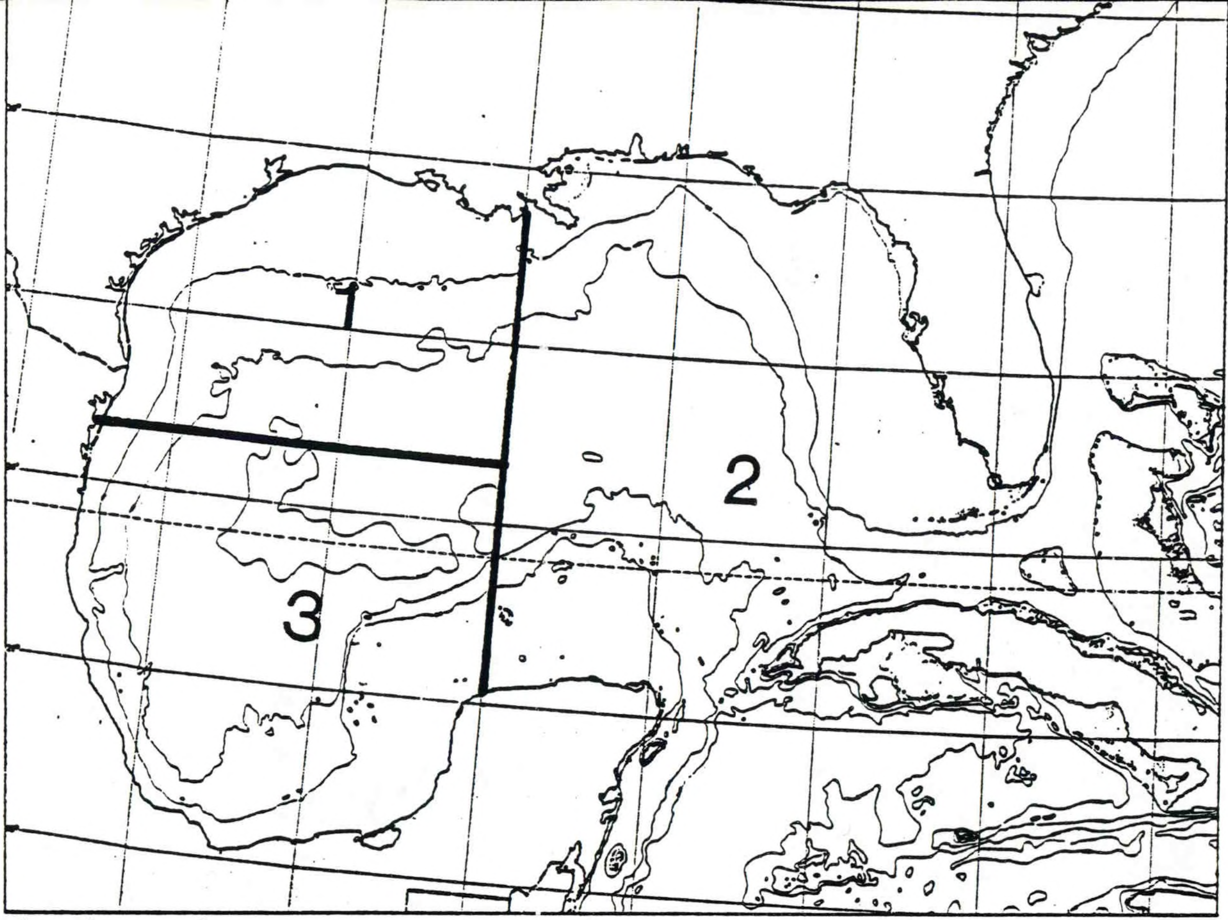
Modeling Oil Pollutant Transport

Oil pollutants interact with water much differently than other pollutants. While most other pollutants undergo varying degrees of dispersion throughout the water column, oil undergoes very little. A major portion of oil pollutants discharged onto the water surface remains on the surface and are dispersed along the surface as a function of wind and current and other factors. Oil which remains on the surface is termed the insoluble fraction; the small amount which dissolves and undergoes some dispersion in the water column is termed the soluble fraction.

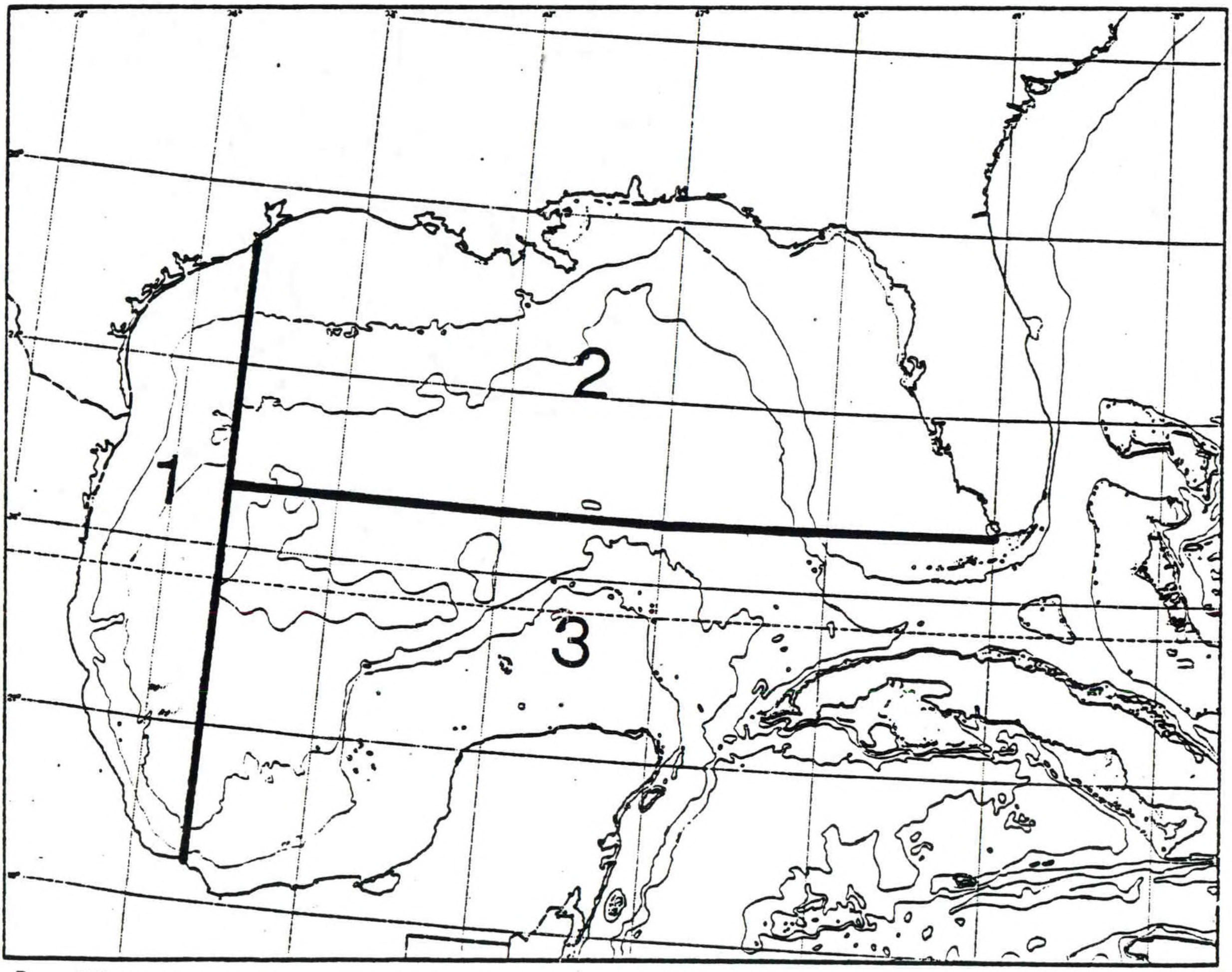
Note that a distinction will be made between oil which is discharged on the surface and oil discharged below the surface; for example, oil discharged at the ocean floor due to a well rupture. Because insufficient knowledge exists to effectively model the movement of oil discharged significantly below the surface, only the movement of surface discharges of oil, and its soluble fraction, will be included in the pollutant transport model.

Given the pollutant transport model as specified above, in particular the assumptions regarding complete, instantaneous, and homogeneous mixing, it is clear that an alternative approach must be formulated to model the movement of surface oil discharges. The basic approach is to consider the soluble and insoluble fractions separately, although transport of the soluble fraction will depend on that of the insoluble fraction.

To estimate the surface dispersion of the insoluble fraction of oil discharged into each grid area, a surface oil spill trajectory model will be used. It will be assumed that all oil discharged into a grid area is discharged at its center. Since we are concerned only with steady state seasonal conditions it is assumed that general climatological conditions can be used to specify the meteorologic and hydrologic factors which affect the movement of oil on the surface -- factors which are required inputs to the trajectory model. Three of these meteorological regions exist in the Gulf of Mexico for each season of interest.[8] Geographically these regimes are defined as shown in Figure 4. Within each meteorological region, four, possibly five background current regimes can be defined. The trajectory model will simulate the surface dispersion of a hypothetical oil spill for each combination of meteorological/current regimes in each season. Each of the 550 grid areas will then be assigned one set of conditions, and therefore one surface spill trajectory, for each season. These spill trajectories or plumes will then be used to scale the amount of oil discharged into a grid area which is transported along the surface into other grid areas.[9] To provide an indication of



A. Summer Season



B. Winter Season

Figure 4. Meteorological Regions of the Gulf of Mexico

surface oil pollution, the volume of oil estimated to be on the surface in each grid area in each season will be divided by the surface area of the grid.

It is important to note that it is not clear at this time which of the available oil spill trajectory models will be used, and that, regardless of the model selected, it is likely that some modifications will have to be made to adapt the model to climatological conditions. Most existing models are not designed to operate with climatologic data. If none of the existing models can be appropriately modified, a conservation of mass approach will be used to develop a surface oil transport model based on NOAA's Climatological Model For Oil Spill Contingency Planning.[10]

The soluble fraction of oil will be derived from the insoluble fraction by assuming a "leaching" rate at which the insoluble fraction lying on the surface dissolves over time. Therefore, the amount of oil dissolved in the water column in each grid area will be proportional to the amount of oil on the surface. The oil leaching rate will be determined from available literature. Once computed, the soluble fraction will then be input into each grid area and assumed to be mixed over some specified depth (a large portion of dissolved oil generally remains in the upper 10 or 15 meters) and transported by the pollutant transport model just as any other constituent, i.e., through advection and dispersion.

Solution Method

Based on equation (1) a system of equations will be developed for the 550 control volumes into which the Gulf of Mexico will be segmented. The system will be solved using implicit finite difference techniques. Equation (1) will be solved for each control volume using forward-difference, backward-difference, and central difference approximations. This method appropriately represents the spatial partial differentials in the equation. Equations (8) and (9) show typical central difference expressions for first and second order terms:

$$\frac{\partial C}{\partial x} = \frac{1}{2\Delta x}\left[C_{i+1} - C_{i-1}\right] \tag{8}$$

$$\frac{\partial^2 C}{\partial x^2} = \frac{1}{\Delta x^2}\left[C_{i+1} - 2C_i + C_{i-1}\right] \tag{9}$$

where C = concentration of pollutant,

x = dimension of the grid area in the x-direction, and

i = the ith grid area.

Substituting finite difference approximations, such as equations (8) and (9), into the system of equations based on equation (1) results in a vector equation of the form:

$$[A][\bar{C}] = [\bar{B}] \tag{10}$$

where A = is an n x n square matrix

C = a column vector of unknowns containing n elements

B = a column vector of n known elements, and

n = the number of control volumes

Because the [A] matrix will not be a dense matrix (it will consist of only five non-zero elements per row), a "sparse matrix" solution routine will be used to solve the set of equations defined by equation (10). Utilization of a sparse matrix solution routine will greatly reduce computer storage requirements. To solve for steady conditions, $\frac{\partial C}{\partial t}$ in equation (1) will be set equal to zero in the formulation of the finite difference expressions, and the system of equations then solved sequentially for each pollutant.

CONCLUDING COMMENTS

Developing a natural system model is an exercise in uncertainty. The essence of the processes at work in the natural system can never be completely captured. Regardless of how complex a model is and how carefully it attempts to represent relevant natural processes, model results will always contain a high degree of uncertainty. Although models will always be imperfect abstractions of reality, they are still very useful tools in explaining certain behavior of natural systems. Careful thought must be given to determining the most meaningful way in which to use the results of a given model in the specific problem context to which it is applied.

Developing a pollutant transport model for the Gulf of Mexico amplifies the general concern of uncertainty in natural system models, primarily because of the Gulf's immense size and the many localized processes which are at work throughout its many subregions. The crux of the problem of pollutant transport modeling of the Gulf is whether or not the scale and level of detail of modeling will enable pollutant concentration estimates to be made which can be meaningfully used in the overall analysis specified at the outset of this paper, that is, in making a preliminary identification of resource use conflicts by overlaying maps of living natural resources with maps of pollutant concentrations estimated from the model and an initial evaluation of management strategies for resolving these conflicts. The hope is that this will be the case, although a final evaluation will not be possible until the model is thoroughly tested.

Aside from its direct use in the Gulf of Mexico project, developing the model will produce other potential benefits with respect to improving coastal and ocean resource management -- both in the short- and long-run. Developing and using the model will: 1) illustrate an important aspect of the analysis framework that is required to generate the information necessary for resource management decisionmaking in coastal and ocean areas; 2) stimulate the collection and integration of information not previously collected or integrated into a single framework; 3) identify major data gaps and priorities for future research, both in terms of data to be developed and specific areas requiring additional detailed analysis; and 4) serve as a basis for developing a more refined pollutant transport model commensurate with the information needs of more detailed regional assessments.

FOOTNOTES AND REFERENCES

1. The East Coast Resource Use Mapping project was initiated in June 1979 through an Interagency Agreement between the Council on Environmental Quality and the Office of Ocean Resources Coordination and Assessment (ORCA), Office of Coastal Zone Management (OCZM), National Oceanic and Atmospheric Administration (NOAA). The project is intended to identify possible resource conflicts and compatabilities in the coastal and ocean zone of the Eastern United States. The principal investigators for the project are G. Carleton Ray of the University of Virginia (formerly at The Johns Hopkins University), James A. Dobbin of James Dobbin Associates Limited, Toronto, Canada, and Charles N. Ehler and Daniel J. Basta of the Office of Ocean Resources Coordination and Assessment, OCZM, NOAA.

2. For additional explanation see: 1) Fischer, H.B. 1967. "The Mechanics of Dispersion in Natural Streams," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers vol. 93, no. HY6 (November) pp.187-216; 2) Thoman, R.V. 1972. Systems Analysis and Water Quality Management (New York, Environmental Research and Applications, Inc.); and 3) Tracor, Inc. 1971. Estuarine Modeling: An Assessment, prepared for the Water Quality Office, Environmental Protection Agency (Washington, D.C., GPO, February).

3. The National Oceanographic Data Center (NODC) is a component of the Environmental Data and Information Center of NOAA. NODC is the U.S. Government's repository for worldwide oceanographic data.

4. Additional discussion on dynamic topography can be found in G. Neumann and Pierson, W.M. 1968. Principles of Oceanography (Englewood Cliffs, N.J., Prentice-Hall).

5. For example, dispersion coefficients can be estimated from information provided in: Okuba, A. 1962. A Review of Theoretical Models of Turbulent Diffusion in the Sea, TR 30, prepared for the Maryland Chesapeake Bay Institute of The Johns Hopkins University.

6. For a succinct discussion of this approach see: Section 4.2 "Simple Tidal Flushing Calculations for Shallow Enclosed Bays," A Study of the Environmental Benefits of Proposed BATEA and NSPS Effluent Limitations for the Offshore Segment of the Oil and Gas Extraction Point Source Category, 1977, prepared for the Office of Water Planning and Standards, Environmental Protection Agency, (Washington, D.C. GPO, May).

7. ORCA's current data base, The National Ocean Coastal County Pollution Discharge Inventory, was developed by Resources for the Future, Inc.

8. Meterologic regions were defined based on wind-rose data obtained from monthly "pilot" charts developed by the Naval Oceanographic Office.

9. It is important to note that most current oil spill models do not explicitly include the quantity of oil spilled in determining plume trajectory.

10. Bishop, J.M. 1980. A Climatological Oil Spill Planning Guide - No. 1. The New York Bight, Environmental Data and Information Service, National Oceanic and Atmospheric Administration.