NOAA TECHNICAL MEMORANDUM

NMFS-SEFSC-330

ESTUARINE ASSESSMENT AND CONTAMINANT PROBLEM IDENTIFICATION

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Summary of a Workshop

held in Biloxi, Mississippi

April 23-25, 1991

July 1993

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
Beaufort Laboratory
Beaufort, North Carolina 28516

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July 1993

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NOTICE

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PREFACE

Gulf of Mexico estuaries are a productive resource, but they are susceptible to the impacts of natural phenomena and human activities. Human activities can result in increased inputs of toxic substances, such as pesticides and other contaminants that may cause adverse effects to the Gulf estuarine ecosystem. Therefore, a need exists to be aware of the current status and future trends of the occurrence and effects of these contaminants, which requires acceptable assessment protocols. Many State, Federal, and private assessment and monitoring efforts are presently underway, but most of these efforts are designed to meet specific goals (e.g., effluents, water column, sediments, or benthic organisms), are not conducive to integrated assessments, and do not necessarily address Gulf-wide ecological regulatory concerns. Although additional monitoring may be essential to address those concerns, enhanced coordination among existing programs will increase the likelihood that more inclusive ecological assessments will be generated. This would result in a more efficient use of the limited financial resources. Finally, enhanced coordination and integrated approaches are likely to improve local assessment and monitoring programs while providing comparable Gulf-wide information simultaneously.

A 1987 document, "Surface Water Monitoring: A Framework for Change," produced by the U.S. Environmental Protection Agency's (U.S. EPA) Office of Water, has led to several advances in U.S. EPA water programs. These include a policy on the use of community bio-assessments, guidance on rapid bio-assessment protocols, and expanded emphasis on bio-criteria. Although many of the successes to date focused on freshwater, the document also recommended the development of assessment protocols for estuarine and coastal ecosystems. A recent U.S. EPA Science Advisory Board report to the U.S. EPA Administrator discussed the need to improve ecological assessment methods for marine ecosystems.

Over the past year at training workshops on stream bio-assessment protocols, the U.S. EPA Office of Water Regulations and

Standards discovered great interest from some States in the development of analogous methods for coastal waters. As a result, the Office of Wetlands, Oceans, and Watersheds initiated a study to assess the level of interest in all the coastal States and to collect information on existing programs and methods with potential as coastal assessment protocols. The study indicated a high level of interest, and in addition, several States were already in various stages of planning and development of bio-assessment protocols and interested in working with the U.S. EPA. The study also identified some assessment methods and analysis frameworks that have potential; chief among these was a variant of the Index of Biotic Integrity, now being used for freshwater streams.

Stephen J. Glomb from U.S. EPA's Ocean and Coastal Protection Division of the Office of Wetlands, Oceans and Watersheds presented the keynote speech entitled, "Community Bioassessment Protocols for Use in Estuarine and Coastal Waters." He stated that the U.S. EPA is now assigning ecological assessment, including estuaries, a higher priority. Comprehensive ecological assessments in estuarine and coastal systems will need to integrate information over several levels of organization, from organismal bio-markers through measures of community structure and function. Much of the current focus of the U.S. EPA Office of Water is on community level assessments that can integrate information on stresses over time. The set of environmental problems faced by our estuaries and coasts is diverse - toxic contamination, pathogens, eutrophication, loss of habitat, species decline - as is the set of causative factors. Because of that, there is no single test that will provide all the answers; a variety of biological assessment protocols will be necessary. Once these are identified and we know what and how to assess, the U.S. EPA will work to translate information from bio-assessments into the criteria and standards program.

The U.S. EPA's goal is to help States develop narrative bio-criteria by the end of 1993. Numeric bio-criteria would follow when the science has progressed enough to go from qualitative to quantitative statements about biological integrity. Bio-criteria should be useful to help solve many management problems, starting with problem identification and priority setting before potentially moving into the regulatory realm. At this point, bio-criteria development is much more advanced for freshwater streams than it is for estuaries.

In his keynote speech, Mr. Glomb mentioned the importance of documenting and understanding natural (seasonal and geographical) variability to properly assess toxicant or man-induced changes observed in the environment. He viewed this workshop as a first step in determining the types of problems to be encountered when evaluating the effects of contaminants on estuaries and near coastal areas.

In response to the need for more holistic and integrated assessment processes and protocols, a workshop on Estuarine Assessment and Contaminant Problem Identification was held in Biloxi, Mississippi, April 23 - 25, 1991. The workshop concept evolved through the U.S. EPA's Gulf of Mexico Program (Toxic Substances & Pesticides Subcommittee) and involved scientists and managers from throughout the Gulf of Mexico area. The following steering committee was formed to develop the workshop:

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The workshop addressed a broad array of assessment processes and approaches, with a focus on endpoints and biological indicators of contaminant stress at the individual, population, community, and ecosystem levels. All areas evaluated were applicable to estuary-wide assessments. It was decided that a demonstration site to test the resulting approach will be selected in a Gulf of Mexico estuary during the next year.

In support of the workshop effort, we thank the following personnel of the Gulf Coast Research Laboratory, University of Southern Mississippi, Ocean Springs, MS for their meticulous care in recording workshop discussions: Don Barnes, Sue Barnes, Annette Barrett, Dr. Tom Lytle, Julie Miller, Debbie Murphy, Ken Stuck, Mary Tussey, Jenny Weber, and Marie Wright. We are also appreciative of Dr. William Walker for coordinating the logistics and accommodations for the workshop. Maureen Stubbs (Computer Sciences Corporation) typed the manuscript. Al Alonzo (T.G.S. Technologies) and Steven Castille (National Wetlands Research Center) performed the final editing for the manuscript. The financial support, without which the workshop could not have been convened, was provided by the University of Southern Mississippi (Gulf Coast Research Laboratory), U.S. Fish and Wildlife Service (National Wetlands Research Center, Lafayette, LA), and the U.S. Environmental Protection Agency (Environmental Monitoring and Assessment Program, Gulf Breeze, FL, Gulf of Mexico Program, Stennis Space Center, MS, and Office of Wetlands, Oceans, and Watersheds, Washington, DC).

Foster L. Mayer
Stephen J. Glomb

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CHAPTER I
INTRODUCTION

F.L. Mayer

Estuarine ecosystems are subject to a complex and dynamic array of physical, chemical, and biological interactions. We have only limited understanding of how toxic stressors influence these interactions and how perturbations at one level of organization are expressed at other levels. We have a limited capability to compare or predict effects from one species to another, and have only simple qualitative approaches for dealing with population, community, or ecosystem comparisons. We must extend assessments from single-species approaches for site-specific and media-specific (e.g., effluent, water column, sediment) situations to a fundamental, quantitative understanding of exposure-response relationships for larger ecological units such as estuaries.

Bio-assessments must be based on validated cause-effect relationships and must enable the scientific community to predict from one system to another to provide consistent, rational guidance for national regulatory actions. The biogeographical distributions of discrete species and populations (e.g., Gulf of Mexico, North Atlantic, and Pacific coastal regions) and the influence of seasonal factors (e.g., temperature, salinity, and nutrients) probably will require regulatory actions to be based upon the unique or site-specific characteristics of each region. Researchers and managers must develop prudent, reliable, technically correct, and cost-effective approaches to compare and predict the effects of various stressors at all levels of biological organization in estuarine ecosystems of varying complexity and size within defined biogeographic regions.

To achieve a more holistic, integrated, and ecological-based approach to bio-assessment, comparative toxicology should be used to define those species at risk and the stressors of concern in marine ecosystems. Existing comparative toxicological data on individual species alone only provide baseline estimates regarding the acceptable degrees of environmental stress. We may use these data to predict environmental impacts through the construction of models and empirical exposure-response relationships. Currently, our available tools range from simple and informal attempts to more complex relationships and mathematical expressions intended to represent an ecosystem. The complex approaches to cause-effect relationships are not reliable or sophisticated enough to provide comprehensive and quantitative inputs for ecological assessments of even relatively simple situations, much less, multiple exposures of estuarine ecosystems to complex pollutant mixtures on a local, regional, or national scale. Also, few approaches have been validated (field verified) and uncertainties quantified.

Credible bio-assessments require quantitative data and understanding about the stressor(s), the receptor(s), ambient environmental factors, and interactions among these ecological components. Research has demonstrated that (1) genetically similar organisms will more likely respond similarly to a stressor than different organisms, (2) organisms will respond more similarly to stressors of similar physical, structural, and/or chemical characteristics than to stressors of differing characteristics, and (3) environmental factors will influence the exposure-response relationship of similar organisms for a stressor more similarly than they would affect different organisms subjected to that same stress. Because of the large number of potential interactions, we must use and expand this minimal data set and identify useful and dependable approaches in developing environmental bio-assessment procedures.

Considering the aforementioned ecological and toxicological concepts and complexities, the question becomes one of whether a pragmatic and simplified assessment protocol can be developed that will dependably identify contaminant problems and assess estuarine health. This was the overall challenge presented to the participants of the workshop along with the following goals:

A. To define, through consensus, a set of ecological assessment procedures to:

1. Describe, at a screening level, the condition

(physical, chemical,and biological) of Gulf Coast estuaries;

2. Identify and characterize ecological problems caused by contaminants; and

3. Determine the causes of observed problems, focusing on pesticides and toxic contaminants.

B. To establish selection criteria for demonstration sites in the Gulf of Mexico to field test the applicability and predictive capability of the procedures.

The general plan of the workshop was to address the major areas of assessment in three working groups, with the efforts being coordinated and integrated through plenary sessions. Each group met separately to address specific goals, objectives, questions, and issues as follow.

Group I - APPROACHES FOR EVALUATING ESTUARINE ECOSYSTEM CONDITION

Goal - To develop a set of recommended environmental data and indices that should be considered in order to assess contaminant stresses on an estuarine system.

The charge to this group was to develop approaches for evaluating the health of an estuarine system. Methods and effectiveness of problem identification were to be evaluated according to the following questions:

- What kinds of data (chemical, biological, and hydrological) are needed in order to characterize contaminant stresses on an estuary? What kinds of data can be used to identify non-contaminant stresses (e.g., habitat loss, over-fishing)?

- What historical data should be compiled for examination? How can baseline conditions be established?

- How can the data be analyzed/presented to determine if an area is healthy? What uses should be considered? What criteria are applicable? What indices or indicators can be utilized?

- What criteria will be used to determine if an environmental problem exists?

- What are the levels of complexity necessary to complete an adequate environmental assessment (e.g., qualitative versus quantitative data; trophic analyses, etc.)?

Group II - CATEGORIZING AND RANKING CONTAMINATED SITES WITHIN ESTUARINE ECOSYSTEMS

Goal - To rank contaminant problems within an estuary relative to magnitude, duration, probability of recovery, and others.

This group was to develop a strategy for categorizing and ranking contaminated sites within an estuary or coastal area. Discussions were to focus on issues with which a resource manager would be faced when ranking problems and allocating funds for contaminated areas. Issues and questions for discussion included:

- What criteria should be used to rank contaminant problems?
  - Different influences are applied to a resource manager to rank contaminant problems, including scientific/technical data, user groups (commercial and recreational), politics, and economics.
  - Within each force, a hierarchy of issues may exist. For example, scientific/technical data can be ranked based on real or potential threats to organisms, the ecosystem, or human health. Bioavailability, persistence, and remedial actions contribute to the ranking process. Sociologically, different user groups may desire different standards and ultimate management.
- What mechanism(s) can be utilized to develop a ranking (categorization) system?
  - How can the above criteria be utilized to rank differing ecosystems (or different contaminant problems within a given ecosystem) for prioritization? Do all criteria have to be considered for an initial ranking?
  - Should one categorize (qualitative), rank (quantitative), or categorize and then rank within category?
  - How should an ecosystem be categorized? One may consider an immediate threat to organisms, ecosystems, or human health; an area not meeting the fishable/swimmable goals of the Clean Water Act; long-term effects on productivity or disease of organisms or ecosystems; or loss of commercial or recreational revenue.
  - Is qualitative ranking possible based on meeting or not meeting uses versus slightly impacted, impacted, and greatly impacted?
  - Is ranking or characterizing on a point system possible?

- o Is it possible to conduct a preliminary characterization of a site with limited funds, and if a site ranks high enough, conduct an extensive characterization? What information would be required?

Group III - ESTABLISHING CAUSAL RELATIONSHIPS

Goal - To define a set of ecological assessment procedures to establish a causal relationship between a perturbed estuarine site and environmental contamination.

The group was to develop a strategy for establishing direct causal relationships based on site ranking (see Group II) and any additional testing that might be necessary. Discussions were to focus on the two elements of any causal relationship -- cause and effect. The following questions were to be addressed:

Causes

- o Which environmental medium is contaminated (i.e., water, sediment, or biota) and to what degree?
- o What is the qualitative nature of this contamination (i.e., single or multiple classes of contaminants)?
- o Could non-contaminant reasons explain the observed environmental perturbations (i.e., episodic hypoxia)?

Effects

- o What assessment endpoint(s) should be measured?
- o Which available measurement endpoints are reliable, technically sound, and logistically feasible?

Establishing a Causal Relationship

- o What models and/or experimental designs allow the establishment of direct causal relationships?
- o What interpretive guidance is necessary for these designs to have managerial utility?

An effort was made to have equal representation of technical discipline and experience in each of the three groups. The list of participants and their respective affiliations follow.

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Since the overall document provides a process rather than detailed techniques, reference publications were infrequently cited. However, a general bibliography, containing those publications most frequently relied upon by participants during workshop deliberations, was included as a final section of the document.

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CHAPTER II

APPROACHES FOR EVALUATING ESTUARINE ECOSYSTEM CONDITION

P.B. Dorn, J.R. Clark, J.D. Allen, L. Anderson-Carnahan, B. Cain, J.C. Carlton, R.S. Carr, J. Fournie, G.R. Gaston, J.S. Moody, F.J. Reilly, Jr., P. Roques, T.C. Sauer, and J. Webb.

The goal was addressed in three steps: (1) stating several assumptions concerning environmental assessments, (2) structuring an assessment process, and (3) developing an assessment strategy that involved three tiers for sequentially assessing selected endpoints of impact. We listed several assumptions considered critical for assessing contaminant stress. For example, it was agreed that persons making environmental assessments were normally working with a constrained budget, a designated (usually short) time frame, and limited personnel, and that best professional judgment must be utilized throughout the assessment process.

The scientific design of an assessment must include spatial, temporal, and historic considerations, and must take advantage of the wealth of scientific information available in the literature and from other sources. The process must involve developing specific, testable, hypotheses as opposed to unorganized sampling and analysis at all levels of biological organization. It was recognized that no one scheme would prevail for all estuaries and that site-specific modifications would be required for any generic scheme or schemes that may be developed. Finally, the members of the group agreed that a tiered approach is required to meet the constraints listed above.

Stresses on an estuary may originate from natural causes such as physical/chemical alterations, ranging from local to widespread, and contaminant stresses resulting from point and non-point sources with exposures being continuous, semi-continuous, or single occurrence. The group's efforts focused toward assessing the impacts from single contaminants and the interaction of contaminants with other factors.

Assessment Process

An assessment process was developed to identify contaminant problems. The process included consideration of sources, exposure (concentration over time), bio-availability, and effects.

These components are interactive, including the potential for many feedback loops. They may be approached from "top down" or from "bottom up". Information at all levels must be obtained on a temporal and spatial basis. The consensus of the group was that one must have a "no" or "none" answer for each of the components of the proposed assessment process to conclusively classify an estuary as having no contaminant problem.

Sources

Much of the data for contaminants can be obtained by thoroughly searching the available historical data bases and by utilizing other sources of existing data, such as the National Pollution Discharge Elimination System (NPDES), Toxic Release Inventories, Environmental Monitoring and Assessment Program, and NOAA's National Status and Trends Program. Other sources that should be considered include land use such as agriculture, municipal, and recreational development; inadvertent releases and spills; and atmospheric deposition. Global inputs of specific contaminants may be more significant than local ones and should be considered in all assessments.

Exposure

A thorough assessment of the ambient contaminant concentration is required to identify the exposure component. Ambient contaminant concentrations should be measured in the water column, sediments, and atmosphere (biological aspects are discussed below in the bioavailability section). Also, physical/chemical characteristics of these components must be known in order to interpret the presence of the contaminant in terms of an environmental effect. Variation in exposures over short-term (hours or days) and long-term (weeks or months) intervals are important aspects in determining the level of investigation necessary to detect problems. Differentiating contemporary exposure problems from historical problems also is an important aspect of problem identification. The following are some specific measurements that are needed for the exposure component:

- Water Column -- Physicochemical (solids, temperature, dissolved oxygen, salinity, total organic carbon, pH), nutrients, human pathogens, organics/inorganics
- Sediment (including pore water) -- Nutrients, human pathogens, organics/inorganics, radionuclides
- Atmosphere -- Depositional material

Ambient concentrations can often be related to chemical bioavailability through use of empirical models.

Bioavailability

Once ambient levels of a contaminant are established, it is necessary to determine how much of the contaminant is biologically available. Thus, bioavailability of the contaminant becomes an important link in the assessment process and is closely related to the effects component. The concentration of a contaminant (residues) in the tissues of an organism is, of course, a reflection of the contaminant bioavailability. Normally, knowledge of levels of concentration in organisms alone is not sufficient to assess the impacts to organisms and systems. It is also necessary to know the mechanisms of bio-accumulation (from food, water or sediment) and residence time.

The group discussed bioavailability phenomena in terms of tissue residues, which indicate contamination of a specific resource or simply indicate pollution has occurred, and physiological bio-markers, which also indicate an exposure has occurred. In addition, residues may reflect various problems such as exceeding human health guidelines in fish and shellfish. Tissue residues in the top predators of the food web can indicate levels of "actionable" chemicals with respect to human health. Bivalves are especially useful as indicators of the levels of radionuclides, metals, and bio-active (virus, bacteria) materials. Bio-markers are physiological responses of organisms that indicate exposure to a contaminant. The field of bio-markers is considered a developing state-of-the art assessment tool and involves such physiological responses as mixed function oxidases, metallo-proteins, DNA adducts, and bile metabolites. Populational significance of some bio-markers is known, while that for many bio-markers is unknown.

Effects

The effects of contaminants on estuaries can be evaluated in the field and in the laboratory. For example, adverse effects on fish may be reflected in the field by fish kills, population shifts, changes in size-class frequency and abundance, reproductive condition, incidence of disease, and indirectly, through catch-per-unit effort and species composition of the catch. Invertebrate community assessments may include interpretation of feeding guilds, dominant feeding strategies, and assessments of community physiological characteristics. Laboratory evaluations can be conducted on behavior, toxicity, carcinogenicity, growth, and reproduction using receiving waters and site sediments.

Assessment Strategy

The members of the group agreed that the assessment to determine if an environmental problem exists in an estuary can be most efficiently approached through tiered observations on the components of the assessment process: sources, exposure, bioavailability, and effects. The first tier represents the least amount of information required to identify an environmental problem. The second and third tiers add more information to each of the components of the risk assessment process.

Figure 1 illustrates the strategic approach that the group developed to identify contaminant impacts in estuaries.

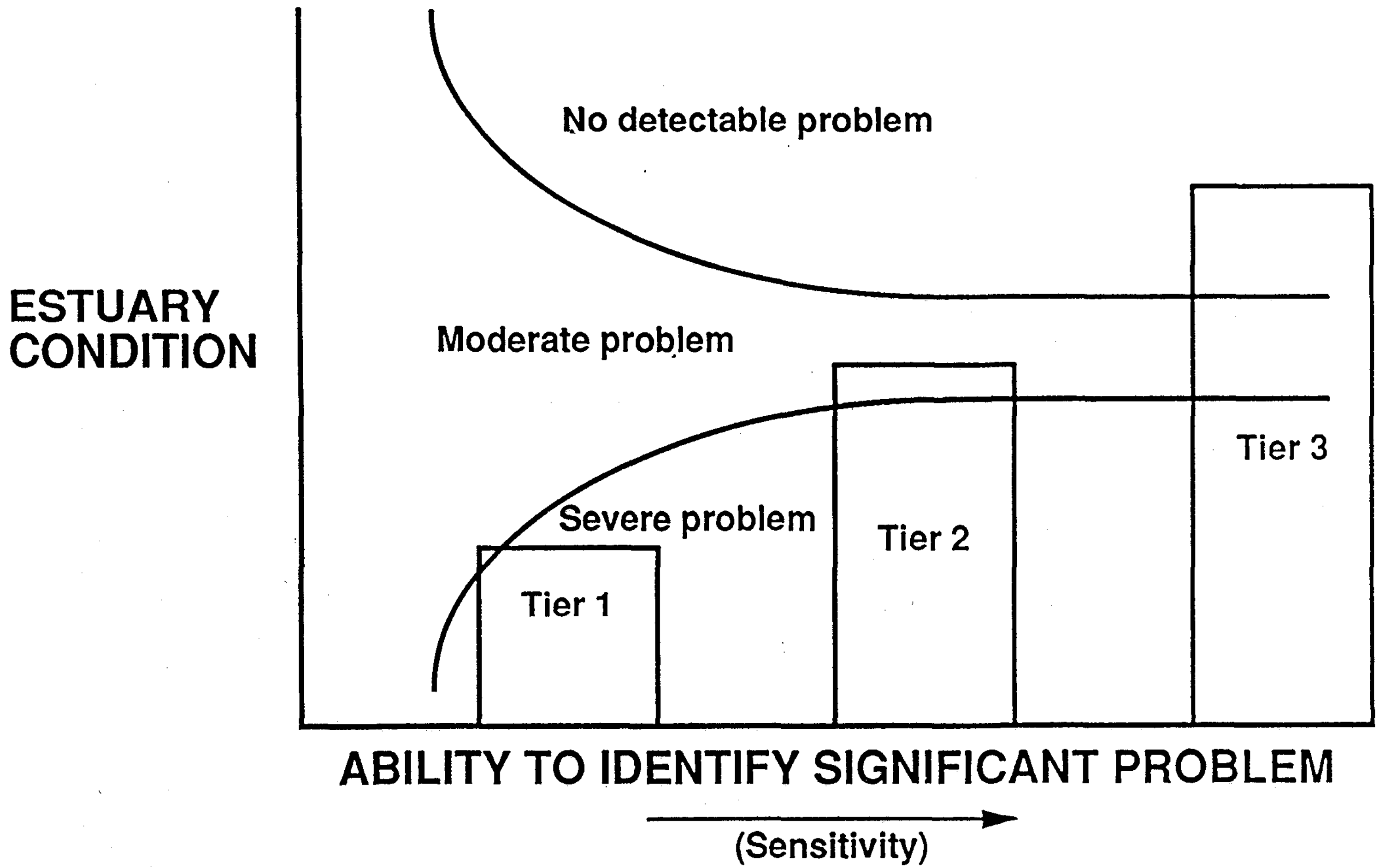

Fig. 1. Strategic approach to identification of contaminant effects in estuaries.

Classification of the estuary is determined through three tiers of testing. It is less difficult to identify a problem than to demonstrate that no problem exists. We focused on methods of determining if a contaminant problem exists. The tiers represent increasing levels of complexity in testing activities. As one progresses from the first to the third tier of testing, the cost of experimentation increases greatly, whereas the uncertainty is expected to decrease because of an increase in the amount of data available. However, field data can be very difficult to interpret.

The first and second tiers of the assessment strategy are shown in Tables 1 and 2. Tier 1 is designed to answer the question, "What is the minimum data set required to determine that yes, an environmental contamination problem exists?" The criteria must be of reasonable complexity and amenable to evaluation through existing scientific techniques that are acceptable for these purposes by the scientific community. This is reflected in the choice of parameters. Effects will be assessed by examining fish liver tissue for pathology, testing the toxicity of sediments to sensitive benthic organisms, and characterizing the structure of benthic communities.

Procedures for determining the presence of pre-neoplastic and neoplastic tumors in livers of fish are well documented. The presence of tumors in even a small number of fish from a specific site is evidence that a problem has occurred (Baumann et al. 1987, Couch and Harshbarger 1990, Harshbarger and Clark 1990, Myers et al. 1990). This is a direct assessment that can then be followed by more extensive analysis, if required.

Sediments from a depositional zone found to be lethal to sensitive test organisms provide sufficient evidence to believe that a contamination problem exists at that site. A comprehensive analysis of benthic community structure characterizing the kinds of animals present, their feeding strategies, numbers of individuals, and life histories may also yield needed information (Gaston and Nasci 1988, Gaston et al. 1988). No single standard will represent a benthic effect, but a knowledgeable benthic ecologist can judge

Table 1. Tier 1 Assessment

Decision Criteria for Contaminant Impact	Parameter
Effects	
Liver pathology	Pre-neoplastic and neoplastic liver lesions in fish and other contaminant related lesions
Sediment toxicity	Sublethal endpoints with sensitive species
Benthic community	Diversity and other community indices (0.5 μm sieves) use best professional judgment to ascertain impact.
Bioavailability	
Residues in top predators and shellfish	Human health oriented (exceeds guidelines for contaminants of concern)
Exposure	
Available data	Integrate with other data i.e., posted fishery advisory
Sediment physical and chemical data	Exceed sediment quality criteria when available
Sources	
Available information and site characteristics	Clean Water Act, sections 304(l) and 305(b); NPDES permit data, designated uses, temperature, salinity, dissolved oxygen, and flushing characteristics

Table 2. Tier 2 Assessment

- Expand pathological examination.
- Conduct additional laboratory and field toxicity tests including plants.
- Characterize spatial and temporal aspects of Tier 1 data.
- Expand residue analysis beyond human health objectives and include analyses from sources.
- Utilize bio-markers for specific contaminants of concern.

whether a contaminant effect is reflected in the communities analyzed. Knowledge of contaminant concentrations in the sediment combined with toxicity test results and benthic community evaluations provide significant insight for contaminant impact assessments (Chapman 1986, Long et al. 1990).

Other key assessment information includes collection and evaluation of contaminant residues in bivalves and top predators (bioavailability) for both ecological and human health concerns. Additionally, data on physical/chemical properties of sediment and residue levels in relation to sediment quality standards or criteria are needed, which requires information on the flushing characteristics and dynamics of the site in question. The group members believed that a "positive" in any one of these sets of data indicates a potential contamination problem in the estuary. Furthermore, if none of the data show adverse effects, further monitoring is probably not required.

This is not to say that other data would not be helpful in an assessment. Tier 2 (Table 2) is an expansion of the endpoints in Tier 1. For example, pathological examinations could include other organs, gross pathologies, and possibly other organisms. Tier 3 is a comprehensive assessment that could include many other system, community and population endpoints, and would probably contain other site-specific tests. For purposes of this workshop, participants did not address methods for separating natural variability in assessment parameters from changes caused by contaminants. They did, however, acknowledge that natural variability must be addressed on a case by case basis.

Issues of Concern

- Best professional judgment must be utilized throughout the assessment process.
- A tiered approach is required for efficient use of resources.
- High-quality biological and chemical analyses, as well as professional interpretation of data, are assumed.

- No one assessment scheme will be applicable to all estuaries (no magic bullets).

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CHAPTER III
CATEGORIZING AND RANKING CONTAMINATED SITES WITHIN ESTUARINE ECOSYSTEMS

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Decision Support System

The group (Group II) approached their goal by establishing a decision support system consisting of three tiers of effort, developing lists of contaminants of concern, developing a strategy for categorizing and ranking contaminated sites within an estuary, and ranking these contaminants in relation to specific estuarine characteristics. In addition, the group developed and ranked a list of criteria for selecting estuaries for pilot studies to apply and verify the relationships submitted by this workshop.

The first order of business was to develop a tier system to identify the problem. A decision support system was developed that consisted of three tiers of effort: (1) initial, which would involve screening and analysis of indicators; (2) intermediate, a more definitive level; and (3) final, the diagnostic tier. These tiers are related to ranking problems in estuaries as none detectable, moderate, or severe (Fig. 2).

The focus of an investigation moves from a broad-based screen in Tier 1 to more narrow diagnostic tests in Tier 2 (A). The complexity of analyses increases from Tier 1 to Tier 2 and so do costs, resources, and numbers of personnel to complete the analyses (B).

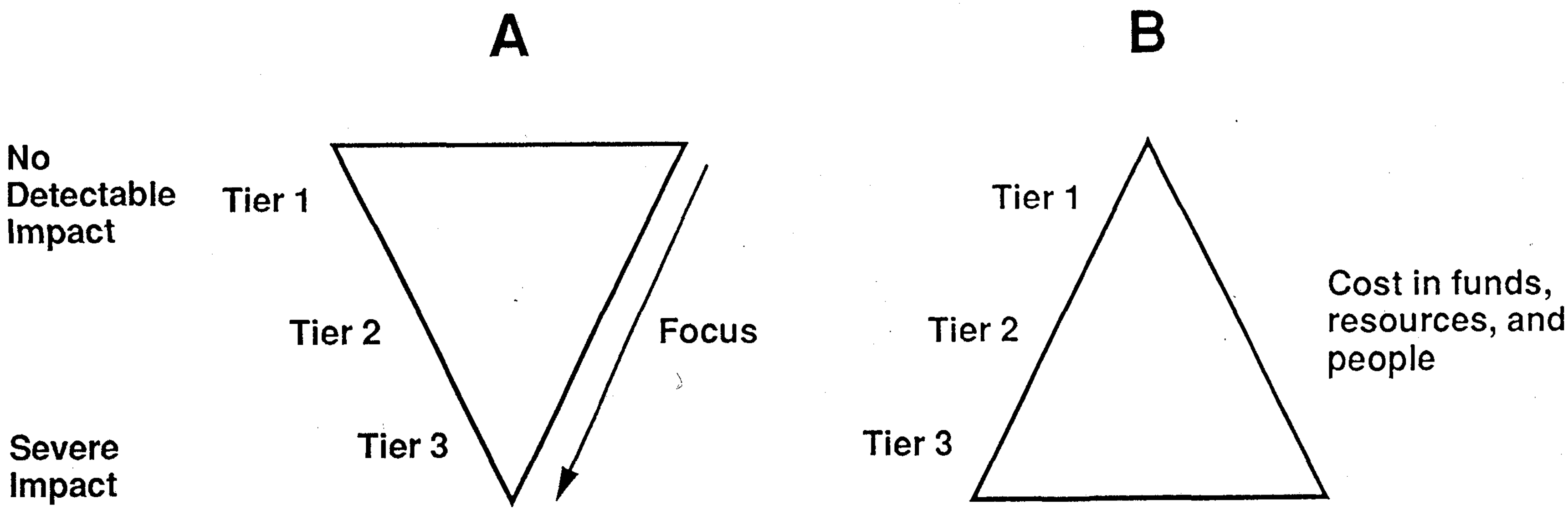

Fig. 2. Relation between tier complexity and effort involved.

The concept of the tier approach is to obtain as much information as necessary with as little cost in resources as possible through a sequential approach to gathering information. The initial tier (Table 3) is flexible. A "windshield" survey technique can be used where a visual observation may be sufficient to detect an odor, foam, floating debris, etc; or, if necessary, one can proceed directly to a more complex tier. Often a review of the literature pertinent to the site will reveal historic problems or insight into a recent problem and yield information on endangered species and public perception issues. Fishery advisories issued by the States are especially helpful in this regard. At this level, preliminary findings on temporal and spatial problems and the hydrology of the site can be obtained. It may be possible during this preliminary assessment to obtain samples of organisms and sediments, and return them to the laboratory. Specimens from a fish kill are especially helpful as are those demonstrating gross pathology. Experienced personnel can obtain useful information on the organic carbon content of the sediments through visual observations of the samples. The presence of hydrocarbons in the sediment often can be determined by a simple "smell test" because of the characteristic odors of this class of chemicals. Clay and sand relationships of the sediment may be important and can be determined relatively easily. Screening level toxicity tests may be conducted in the laboratory on sediments and aquatic organisms to determine the impact of specific contaminants or, more likely, mixtures of contaminants. The initial tier of tests can probably be conducted for minimal cost, but would depend to a great extent on the best professional judgment of those making the assessment.

The intermediate tier (Tier 2) is based on information obtained from the Tier 1. The intermediate tier is concerned with both human health and ecological issues (Table 3). Information on residues of contaminants in tissues of organisms consumed as seafood would be used (in part) to establish fishery advisories. Residue data would not be exclusively used for human health issues

Table 3. Tiered Approach to Identify and Characterize Estuarine Problems

Initial Tier (Tier 1): Screening Level

Site evaluation	Appearance, odor, debris, foam, slimes, habitats and water quality measurements of pH, temperature, dissolved oxygen, salinity, and turbidity.
Site information	Literature review and synthesis advisories, National Pollution Discharge Elimination System (NPDES and other permits), land use/aerial photos, population/watershed, hydrology, creel surveys, public perception of use, and presence of endangered species.
Biota	Presence/absence, unhealthy specimens
Sediment	Organic carbon, clay/sand
Bioassays	Screening level

Intermediate Tier (Tier 2): Definitive Level

Human health

Analysis of residues in edible tissues of estuarine organisms

Advisories

Ecological

Biota - Laboratory
Short-term < 14 days
Toxicity testing - water and sediments

Estuarine characterization
Hydrology
Flushing, sediment

Gross pathology and preliminary histopathology

Sediment /water /tissue chemistry
(analyzed for human health purposes also)

Field information
Population
Community

In-situ biological testing

Pathogens

Magnitude of problem
  Spatial and temporal exposure

Final Tier (Tier 3): Diagnostic (Confirmatory) Level

Toxicity Identification Evaluation (TIE) approach--
extracts, chelation, sequestering

Extensive laboratory tests

Ecological/ecosystem information/habitat assessment modeling

Exposure/*in situ*

Geographical information systems (GIS)

Bio-markers of effect/exposure indicative of problem source

Risk assessment - Human/wildlife

Advisory decision

but could also apply to ecological concerns as well. The manner in which the residue data was measured (a fish fillet versus whole fish tissue, or liver residue versus whole fish versus a fillet) may vary depending upon the purpose of the analysis.

Definitive laboratory (and field if possible) toxicity tests, both aqueous and solid phase (sediment), would be conducted. The duration of these toxicity tests would be 14 days or less as specified in standard testing schemes (Long et al. 1990). A more extensive estuarine characterization phase would include more finite information on hydrology, flushing rates, sediment type, etc. Gross pathology and preliminary histopathology of indicator organisms would be conducted to evaluate external parasites, tumors, and other aberrant features. Additional chemical measurement of the water, sediments, and biota would be required. A variety of field data on populations and communities, particularly on benthic communities, would be collected. For example, by gathering more samples than can be used in the initial benthic investigations, the excess samples can be subsequently processed for more detailed analyses that could include diversity indices.

The third or diagnostic tier (Table 3) is designed to determine the source of the contamination problem and to provide information on the manner in which to best handle the problem. This tier includes such diagnostic approaches as employed in toxicity identification evaluations (TIE's) required by the U.S. Environmental Protection Agency and State regulatory agencies (U.S. EPA 1989a, 1989b, 1991). TIE's involve sequential isolation of various parts of a waste stream or effluent that are subjected to toxicity tests and chemical analyses to identify the source and magnitude of the toxicity. In addition, extensive laboratory tests and examinations can be conducted to determine the impact of contaminants on the health, growth, and reproduction of appropriate organisms. _In situ_ exposure of animals with caged indigenous or other appropriate species may be appropriate at this point.

Models can be applied to extrapolate information from individuals and populations to communities and ecosystem levels of biological organization. Habitat assessment techniques to determine the "integrity" of various habitats can be applied. This tier of assessment also would involve extensive benthic surveys that would include submerged aquatic vegetation. On a broader scale, geographical information systems (GIS), which are well designed and based on quality input data, can be used to evaluate habitats within the estuary as well as to provide information on watershed or larger land use areas that may influence the estuary under study.

Ranking

The group ranked contaminants of concern by first developing a list of contaminants and a list of estuarine characteristics that could affect the route, rates, reservoirs and effects of the contaminants (Table 4). Each contaminant was generally ranked among estuarine characteristics (L = low, M = medium, and H = high) by a participant knowledgeable on that contaminant. The participant would present his/her rationale for the ranking, the group would discuss the recommendation, and a group consensus would then be formulated. Overall rankings of estuarine characteristics and ratings of contaminants were achieved by totaling the values (H = 1, M = 2, and L = 3) and ordering those totals (lowest total = 1).

Contaminants are listed as anthropogenic, natural, and human health-related pathogens. This is not an all-inclusive list but it does contain the most commonly found estuarine contaminants and represents broad classes of contaminants based on the knowledge and experience of the participants in this group.

An estuary is considered susceptible if it is located in a highly populated watershed and is subject to accumulating run-off or if it receives point source discharges from sewage treatment or industrial facilities. The potential for and sources of repopulation are an indication of the capacity of a system to recover from a perturbation. This capacity depends in part on

Table 4. Contaminants of concern ranked by estuarine characteristics.

Contaminants	Suscept-ability	Sources of repopulat-ion (recovery)	Hydrology, river domination	Watershed, population	Freshwater interface, inflows	Localized vs widespread	Endangered, threatened species	Fragile or unique habitants	Historic	Chemical Character-istics	Human per-ception	Species of interest	Subsistence (fisheries)	Rating
• Anthropogenic														
Organics														
Acids	M	M	H	L	M	L	L	L	L	H	L	L	L	17
Bases/Dyes	L	L	L	L	L	L	L	L	L	H	L	L	L	19
Hydrocarbon	M/H	M	M/H	M	M	H	H/M	H	H	M/H	H	H	M/H	3
PCB's	H	H	H	H	H	H	H	L	H	H	H	H	H	1
Dioxin	L	L	H	H	H	H	L	L	L	H/M	H	H	H	8
Pesticides	M/H	M/H	M/H	H	H	M	M	H	H	H	H	H	H	2
Phenols	M	M/H	M	L/M	M	L	L	L/M	L	M	M/H	L/M	L/M	16
Antibiotics/Hormones	L/M	L/M	L/M	L	M	L	H	L	L	H/M	H	H	M/H	12
Metals	H/M	H	H	H/M	H	H	H	H	H	H	H/M	H/M	H/M	4
Organometallics	H	H/L	L	H	L	L	L	L	L	L	L	L	L	18
Inorganics-salts	M/H	M	H	H	M/H	M/H	L/M	M/H	H	H	L/M	M	L/M	6
Radioactive materials	M	M	M	L/M	H	L	L	L	M	H	H	L	L	15
• Natural														
Organic loading, D.O., pH	H	H	H	H	H	M	M	H	H	M/L	M	M	M	4
Particulates	H	H	H	H	L	M	M	H	H	L	H/M	H	L	7
Red tide	L/M	L	M	M	M	H/M	L	L	H	H/M	H	H	M	7
Nutrients, N,P, etc.	H	L	M/H	H	L	M	L	H	H	H	L/M	L	L	9
Exotic species (e.g., vascular, algae)	M/H	L	L	M/L	M/L	M	M	H/M	H	L	H/M	M	L	14
• Human Health/Organism Pathogens														
Enteric viruses	M	L	H	H	L/M	L	L	L	L	L	H	H	H	12
Dinoflagellates	H	L	H	H	L/M	L	L	L	L	L	H	H	H	11
RANKING	4	9	2	3	7	10	12	11	8	6	1	5	9	

re-vegetation, repopulation of benthic populations such as marine polychaetes and shellfish, and invasion of other species from similar zoogeographical areas. The hydrology is critical because river-dominated estuaries possess certain characteristic salinity regimes and, possibly, current patterns. The density of the human population surrounding the estuary has a great influence on the waste entering the water and the alteration of wetland and other habitats. Human perception of the impact or potential impact of a contaminant does not alter the technical aspects of the impact, but human perception does influence the amount of resources directed toward solving an estuarine contamination problem. The subsistence category refers to resident fishery populations such as oysters, clams, shrimps, and seatrouts. Other categories or factors listed in Table 4 are self-explanatory.

A matrix was constructed that arrayed the contaminants and characteristics and the participants produced an un-weighted ranking of the matrix (Table 4). The ranking of contaminants was accomplished in this manner because the severity of the impact of a contaminant on an estuary and its flora and fauna depends to a great extent on the characteristics of the estuary. For example, the impact of a persistent chemical could be much greater in an estuary that is poorly flushed than one that is rapidly flushed because of greater duration of exposure. Also, chemical speciation is often affected by pH, salinity, and other attributes of the receiving waters.

The rankings shown (Table 4) are not based on scientific facts alone and also include the important aspect of human perception. An example of how the scientific and human perception categories affect the ratings is illustrated with the chemical compound dioxin. Although the public perception of the impact of dioxin on the environment was high, the scientific ranking of the impact on the estuary was low. Thus dioxin ranked eighth, or about in the middle of the scale. In contrast, Table 4 shows how a potential chronic indicator and threat like radioactivity can receive a low overall rating of 15.

It is instructive to note that the top five contaminants are PCB's, pesticides, hydrocarbons, metals, and organic loading, and the five most influential estuarine characteristics are human perception, hydrology, watershed population, susceptibility, and species of interest. The estuarine characteristics apparently influenced concern about specific contaminants. According to this preliminary ranking, if PCB's or pesticides are detected in an estuary, and the magnitude indicates a problem, it is likely that an environmental problem exists. With respect to impact on the estuary, human health viruses and pathogens were rated relatively low even though human perception of this impact might be high.

Demonstration Projects

The consensus of our group was that demonstration projects were needed to test the efficacy of proposed classification and problem identification techniques. A tiered approach might be used whereby an estuary is selected with some relatively clean areas and localized contaminated areas to test the process developed by the workshop. A second tier of subsequent studies in other estuaries may be required to look at various categories of estuaries. One set of protocols may be of particular use in one estuary and not in another. As stated previously, "there is no magic bullet" when it comes to a master assessment protocol.

The group developed a set of criteria for selecting estuaries for demonstration projects (Table 5). First and foremost, the selection would be greatly influenced by the resources available to conduct the study. The availability of only a few resources would, for example, restrict the size of the estuary to be studied and the complexity and numbers of tests to be conducted. Second, a diverse eco-population is desired, including submerged and emergent vegetation. In some instances, an estuary with declining vegetation would be most suitable. An estuary with a range of exposures and good reference sites would be ideal for cause and effect determination. The estuary needs to have a relatively large watershed because the protocols should deal with multiple inputs

Table 5. Criteria for Study Site Selection

1. Diverse eco-population
2. Range of exposure (magnitude and diversity of types)
3. Large watershed (municipal, etc.)
4. Reference sites
5. Historic information
6. Known contaminant, known sources
7. Localized versus widespread contaminants
8. Hydrology "known" - salinity, gradient, residence time
9. Nearby research facility
10. Resource utilization
11. Simple versus complex
12. Choices - resource driven ($)
13. Geochemical - clay, silt, mud flats
14. SAV, wetlands

and non-point as well as point sources. Historic information and known contaminants and their sources would be helpful. A nearby research facility would be useful in that travel cost could be reduced and transient time for samples minimized. Other criteria were included, and it is understood that not all of the criteria can be met; however, this list can serve as a guideline for the ideal situation.

Issues of Concern

- A tiered approach to ranking is required.
- Contaminants should be ranked with estuarine characteristics in mind.
- Demonstration projects are needed to demonstrate efficacy of guidelines developed at the workshop.

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CHAPTER IV
ESTABLISHING CAUSAL RELATIONSHIPS

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This group's (Group III) main objective was to develop an approach for establishing a causal relationship between environmental perturbation and environmental contamination. Groups I and II dealt with observational and correlative information; group III was asked to be more definitive in establishing exposure and effect--the causal relationship. Group III developed the relationship by discussing the two chief elements of a causal relationship - exposure and effect; listing assessment and measurement endpoints of effects; defining "dose" - effects; evaluating a series of hypothetical case histories of environmental contamination; and arriving at a tiered strategy for establishing the relationship between cause and effect. In these discussions, assessment endpoints are considered to be items of interest to resource managers (e.g., a population of blue crabs), and measurement endpoints are measured or monitored to provide information on an assessment endpoint (e.g., the reproductive capacity of the blue crab population)(Warren-Hicks 1989).

Exposure and Effect

The importance of establishing exposure or exposure potential became clear in discussions of the exposure and effect elements of causal relationships. Chemical analysis of residues in sediment and biota and, in some instances, water was critical in establishing exposure and exposure pathways. Bio-markers, or some physiological response of organisms to a specific contaminant, also were useful in establishing exposure. The need for high-quality chemical and physiological analyses was noted.

Quantity and quality of living resources and habitat integrity were established as assessment endpoints (habitat integrity was defined as the extent and abundance of habitat types, including hydrological and geochemical characteristics relative to a historical reference). Measurements to evaluate the assessment endpoints were categorized according to levels of biological organization (Table 6). An assessment can be made from the top (ecosystem level) down or from the bottom (cellular and organisms) up, i.e., measurements of primary and secondary ecosystem production or measurements of growth and reproduction of organisms. In the latter instance, impacts at the organism levels would be projected to population and higher levels of organization through models and observations. The organism level measurements were selected by the group as the most useful in developing causal relationships because of the relative ease in working with organisms in both the field and laboratory compared with evaluating changes in population, communities, and ecosystems.

The group's discussions of cause and effect elicited a definition of dose with respect to the dose-response of biological systems. Dose is an acceptable generic term that is derived from mammalian studies often referring to the administered dosage of a chemical. In terms of eco-toxicological studies, however, dose does not necessarily express the amount of exposure an organism receives from the environment. More appropriate terms for environmental toxicology include exposure-response, concentration-response, or tissue residue-response. The necessity of exposing biological systems to varying concentrations to obtain a dose-response relationship in establishing causality also was discussed. It is possible to establish cause without a graded response. For example, in a field situation where oysters that contain a specific contaminant (and this is the only contaminant) and suffer a loss in growth while oysters in a nearby control (clean) site contain none of the contaminant and exhibit normal growth, a case can be made for cause if a pathway for exposure of the contaminant to the oyster is identified. In most instances, resources will be exposed

Table 6. Measurements to Assess Endpoints

Ecosystem	
	Primary and secondary production
	Bio-geochemical cycles
Community	
	Abundance and diversity
	Distributions in space and time
	Trophic relationships
Population	
	Standing crop and size class
	Distribution
Organism	
	Survival
	Health
	Growth
	Reproduction
	Tissue residues
	Behavior
	Physiology
Cellular	
	Carcinogenicity
	Bio-markers
	Histology

to multiple contaminants and establishing a dose response would require exposures of the biological resources of concern to graded concentrations of the contaminants in the laboratory and possibly in the field. Dose-response information is useful and desirable to those making assessments for at least three reasons: (1) It adds to the weight-of-evidence in that it provides a continuum (dose-response curve) and indicates location within that continuum, (2) when coupled with realistic environmental concentration data, it aids in assigning a level of risk to environmental exposure, and (3) when coupled with contaminant loading data, it provides information for predicting future risks.

Causal Relationships

The group developed concepts of causal relationships in part by evaluating several theoretical case histories involving contamination of estuaries. These cases varied from those involving one resource (non-mobile benthic), one contaminant, and one source to those involving pelagic organisms with more than one contaminant and various sources. An example of a case history that involved developing a monitoring program to enable determination of a causal relationship between a chemical plant effluent and an estuary is shown in Table 7. In this study, the opportunity existed to establish a program to determine a possible causal relationship between the discharge of a chemical plant not yet constructed near the estuary. Thus, a pre-and post-construction monitoring program and other studies were suggested. The preconstruction program mainly characterized the estuary, established populations and sites at risk based on projected effluents from the plant, and began baseline studies. Once the plant was on-line, a tiered approach would first determine if an adverse impact occurred. If so, extensive chemical analyses would be done to establish exposure and pathways of exposure, then laboratory and field experiments would be used to validate field observations and establish cause or to add to a preponderance of scientific evidence of cause.

Table 7. Example of Case History Study Process for Establishing Causal Relationship

Prior to Construction of a Chemical Plant

1. Characterize resource

   a. Survey of literature

   b. Hydrological survey

   c. Living resources
      --Assess resources at risk
      --Establish studies to determine impact
      --Project potential effects

   d. Characterize potential effects from discharge

2. Baseline survey

   a. Survey at-risk and control areas

   b. Chemical analyses of water, sediment, and biota

   c. Biological (based on finding in 1)

   d. Geological

   e. Begin experimental field studies

Post-construction

3. Resource monitoring program (biological and chemical)

   a. Continue experimental field studies, monitoring at-risk and control sites

   b. Establish impact or no impact

   c. Decision to stop or continue to 4.

4. Extensive chemical analyses

   a. Residues in sediment, water, and biota

   b. Analyses of bio-marker response

   c. Evaluate cause-effect relationship

   d. Decision stop or continue to 5

5. Correlate field and laboratory studies-exposure response

The results of case history evaluation indicated that a tiered system was necessary to evaluate the cause-effect relationship. Furthermore, the results indicated that it will often not be possible to establish a true relationship between a perturbed environment and environmental contamination. More frequently, it will only be possible to develop sets of corroborative, correlated information. Within the assessment structure, impacts on the organism level of biological organization will probably be the best endpoint to address. In most cases, it will be necessary to conduct laboratory tests to determine which of many contaminants is the cause of the observed impact or effect. Causal relationships can be established only infrequently and then probably not above the organism level of biological organization. As the level of biological organization increases, the need for more information, thus the complexity of laboratory and field testing, increases as does the cost for making an assessment.

The results of the group's deliberations on causal relationships are summarized in Table 8. Note that the table deals with a strategy for establishing a correlation between cause and effect, not establishing a definitive cause-effect relationship. This subtle, but significant, difference reflects the discussions on preponderance of data (weight of evidence) versus a true cause effect relationship. The table indicates a tiered approach whereby the first step is to confirm that an impact has occurred. If the effects are not real, there is no need to continue; if they are, it is necessary to establish an exposure potential. At this stage, only a potential for exposure needs to exist. With an impact and potential for exposure, it is necessary to evaluate further their relationship. This is accomplished by establishing dose-response, either in the field or through laboratory toxicity studies. The exposure pathway must be verified in the field through a combination of field observations that may include hydrology, location of impacted resources, laboratory analyses of chemical residues in the water, sediment, and biota, and other experiments as required. Last, but not least, is an evaluation of the strength

Table 8. Tiered Strategy to Establish the Relationship Between Cause and Effect

1. Confirm that impacts are real
2. Establish an exposure potential
3. Evaluate causal relationship(s)
    a. Establish dose-response relationship(s)
    b. Verify exposure pathway in the field
    c. Evaluate the strength of the relationship

of the relationship.

The strength of the relationship can be evaluated in many different ways, and the group reviewed a list of criteria used in the field of epidemiology (Table 9). Epidemiologists are concerned almost exclusively with observational correlated data and developed this series of criteria for judging the strength and weaknesses of that correlated information (Hill 1965). Some of the criteria are directly applicable to ecosystem analyses and some are not. The group recommended that the list be adapted for eco-toxicological evaluations. The group noted that it is also interesting to apply legal considerations developed by the U.S. Department of Interior for establishing cause and effect with respect to the injury of natural resources. Based on the Clean Water Act and CERCLA, injury to a resource must involve release of a contaminant, a link or pathway between the source of the contamination and the injured resource, an identified effect or injury (legally defined), and a scientifically determined causal relationship.

Issues of Concern

- It will be difficult if not impossible to establish true causal relationship in most cases.
- As the level of complexity (multiple contaminants, higher levels of biological organization) of a situation increases, the need for information increases.
- Complex situations cannot be solved by field studies only; they probably will require both laboratory and field work.
- Expertise in assessment endpoints is critical.
- Use proven scientific criteria to evaluate the strength of the causal relationship.

Table 9. Criteria for Establishing Causal Relationship in Human Epidemiology (Hill, 1965)

1. Strength - a high magnitude of effect is associated with exposure.
2. Consistency - association observed under different circumstances.
3. Specificity - the effect is diagnostic of a stressor.
4. Temporality - the stressor preceded the effect in time.
5. Presence of biological gradient
6. A plausible mechanism of action
7. Coherence - does not conflict with knowledge of biology
8. Experimental evidence
9. Analogy - similar stressors cause similar responses

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CHAPTER V

SUMMARY AND RECOMMENDATIONS FOR ESTUARINE ASSESSMENT AND CONTAMINANT PROBLEM IDENTIFICATION

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Risk assessment techniques have been used in the past to evaluate the impact or potential impact of contaminants on coastal environments. A formal process of risk assessment or risk analysis is employed currently by regulatory agencies to assess such impacts on human health. And now, regulatory agencies are beginning to see the need for a more formal risk assessment process to determine impact on ecosystems, particularly estuarine systems.

The results of this workshop reaffirm that procedures presently exist by which ecosystem health can be assessed. The need for development of additional techniques is not as great as the need to organize existing procedures into general guidelines and protocols applicable across a variety of Gulf of Mexico estuarine systems. The appropriate assessment design must include spatial, temporal, and historical considerations and must be configured around specific testable hypotheses rather than random sampling for no directed purpose. The design must be generic to the degree that site specific modifications can be implemented. A tiered approach should be utilized to best meet budget, time, and personnel constraints.

The three groups' deliberations produced results that showed many commonalities and some differences. For example, differences were expressed about emphasis on specific organisms employed in the tiered approaches and the priority given to sampling specific media (water column, sediments, biota). More importantly, the three groups commonly shared concerns about several critical issues such as the need for "best professional judgment" in evaluating changes in systems and communities due to adverse impact; the use of tiered approaches involving sequential observations in evaluating assessment problems; the need to thoroughly review the literature, evaluate existing data, and talk with knowledgeable individuals before attempting field or laboratory research; the need to document status and trends in order to evaluate natural biological and physical variation, especially if cause and effects relationships are to be addressed; and the need for occasional "reality checks" concerning limitations (fiscal and personnel) facing environmental managers who are responsible for planning, implementing, and evaluating assessment programs.

The three groups were designed to develop information separately on specific aspects of assessment and contaminant problem identification; however, they were interrelated. Application of results of all three groups are required to meet the workshop goals of estuarine assessment: describe procedures for identifying an estuarine problem; identify the magnitude of the problem, and determine causes of the problem focusing on toxic contaminants and pesticides. The manner in which information was developed by the three groups relating to the goals is illustrated in Fig. 3.

The estuarine assessment process depicted (Fig. 3) indicates the manner in which one could, through sequential observations, detect a contaminant problem and assess the extent of impact on an estuary. For example, one could identify that a contamination problem exists in an estuary by progressing through the tiers in the assessment strategy as shown in Step 1. Once convinced that a problem exists, one would proceed to identify the contaminant(s) and determine the magnitude of the problem by again progressing through the necessary number of tiers (screen - diagnostic) and rating the severity of the contamination as shown in Step 2. Once the contaminant(s) have been identified and the magnitude of the problem determined, a causal relationship can be evaluated through the tiered approach in Step 3. One advantage is that such a process progresses through each step only to the point that sufficient information is provided, i.e., it may be necessary to make only a "windshield" or cursory survey in Tier 2 of Step 1 to

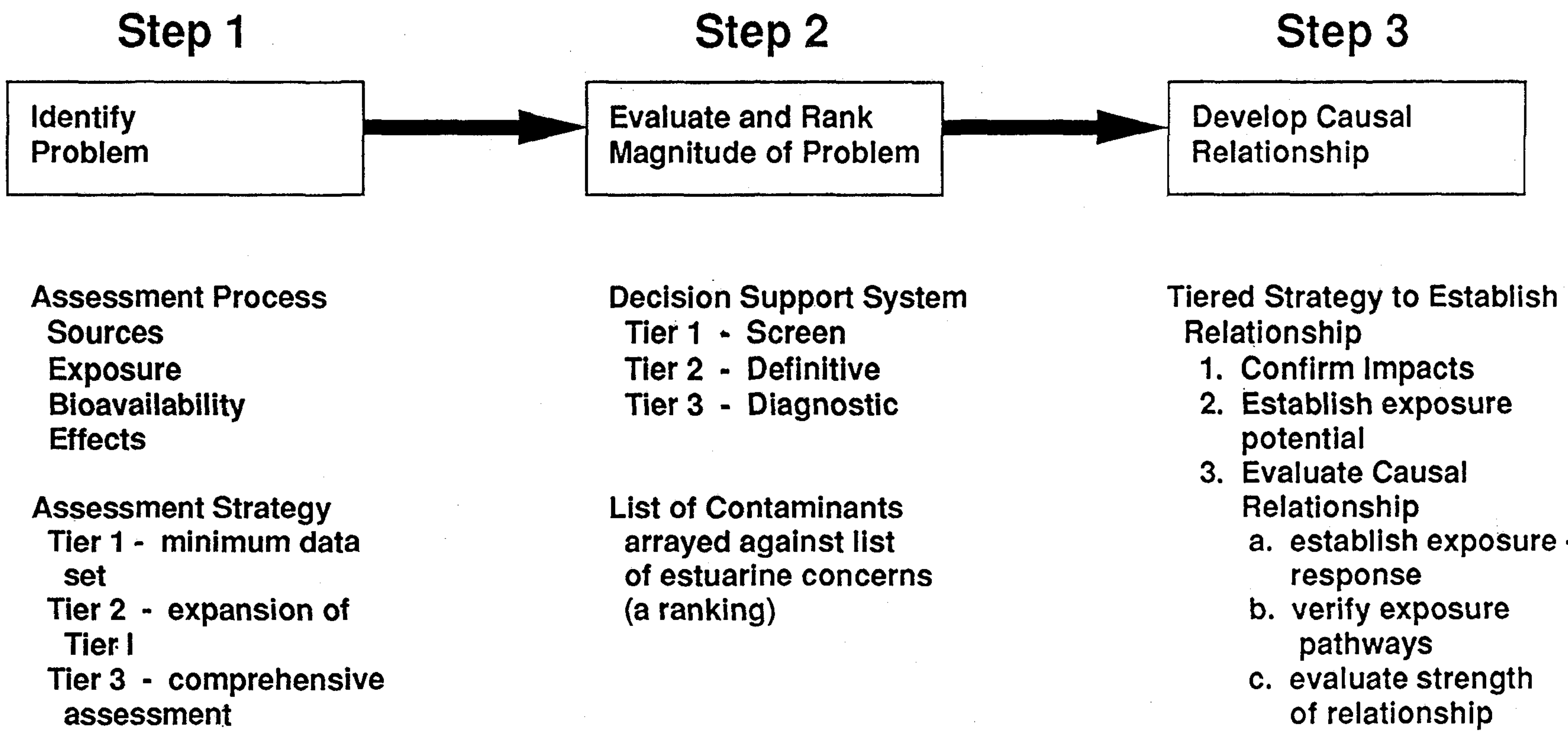

Fig. 3. Process for contaminant identification and assessment in estuaries.

provide sufficient information to complete the process or to proceed to Step 2. This, of course, maximizes efficiency by decreasing the resources required to make management decisions based on assessment results.

The assessment process should address contaminant source, exposure (concentration over time), bioavailability, and effects (Fig. 3). Contaminant source information should be obtained from NPDES and similar permitted activities, from Toxic Release Inventories or Toxicity Reduction Evaluation documents, from land use maps or plans indicating agricultural, residential, recreational (marinas, parks), preserved habitat, or other uses, from reports of inadvertent spills and releases, or from data relative to atmospheric depositions. Contaminant exposure data should involve water column, sediment, and atmospheric measurements. Physical/chemical water column measurements should include suspended solids, temperature, dissolved oxygen, salinity, pH, total organic carbon, nutrients, organics, and metals. Biological water column measurements should include micro- and macrofauna and flora, viruses and bacteria. Sediment measurements should include nutrients, human pathogens, organics, inorganics, and radionuclides. Atmospheric measurements should involve the quantification of depositional material. Contaminant bioavailability can best be assessed by determination of contaminant residues in biological tissues. Tissue residues can indicate an impact on a specific resource by simply indicating that pollution has occurred, or flag exceedence of human health guidelines in fish and shellfish and trigger specific actions relative to particular contaminants from a human health perspective. Physiological bio-markers (mixed function oxidases, metallo-proteins, DNA adducts and effects, bile metabolites, cell death and proliferation, and others) can indicate both exposure and bioavailability, and should be utilized in the assessment process. Contaminant effects can be characterized in the field directly by kills; population shifts; changes in size, abundance, and diversity; reproductive condition; incidence of disease; and indirectly by catch per unit effort and species composition of the catch. Effects on invertebrates can be assessed through measurements of guilds, feeding strategy, and physiological niches. Laboratory evaluations can be conducted to determine contaminant effects relative to behavior, acute toxicity, pathological responses, survival, growth, and reproduction.

The best assessment strategy is a three-tiered approach in which progression from the initial to final tier reflects increased complexity of design, increased costs, and potentially decreased uncertainty due to increased data quantity (Fig. 3). Tier 1 should provide the minimal data set required to determine if an environmental problem exists. Characterization of contaminant effects in Tier 1 should be flexible and can range from the "windshield" or cursory survey in which visual and olfactory observation may be sufficient to detect an odor, foam, floating debris, or other obvious signs of contamination to more detailed data collection, including gross pathology and assessment of liver pathology (which also may indicate exposure), sediment toxicity to benthic organisms, and impacts on benthic communities. Utilization of fishery advisories issued by the states, assimilation of historical data from the site, and collection of preliminary hydrological data can be particularly helpful in the initial tier. Tier 1 bioavailability can be characterized by determining residues in shellfish and top predators. Other critical information in Tier 1 includes physical/chemical sediment data and contaminant residue levels relative to sediment quality standards or criteria. A "positive" in any one of these data sets would indicate a contaminant problem in the estuary. If no data sets show adverse effects, further testing is probably not required.

Tier 2 testing is concerned with both human health and ecological issues. Testing in the intermediate tier would expand histopathological evaluation to organs other than liver, would involve gross pathology, and may involve additional species and organisms. Human health concerns should be addressed through contaminant residue analyses in the edible tissues of estuarine organisms. Ecological information should be gained through the use of short-term water and sediment toxicity tests, through more thorough characterization of the hydrology of the site, and through sediment, water, and tissue contaminant analyses. In situ biological testing could be implemented in Tier 2, as could an in depth evaluation of pathogens and community and population structure.

Tier 3 tests would be considerably more comprehensive, would include many other system, community, and population endpoints, and would encompass other site-specific evaluations. Diagnostics in approaches employed by U.S. EPA (1989a, 1989b, 1991) in Toxicity Identification Evaluations (TIE's) and the U.S. EPA/U.S. Army Corps of Engineers (1991) could be utilized, and extensive laboratory and field testing would be conducted to assess growth and reproductive effects in appropriate organisms. Predictive models could be used to extrapolate information from individuals and populations to communities and ecosystems, and habitat integrity would be assessed. Benthic evaluation could be increased to include submerged aquatic and other types of vegetation.

Workshop participants pointed out the following research needs with respect to estuarine assessments:

- Develop more rapid bio-assessment tools where necessary, but place emphasis on application of existing methods.
- Develop marine TIE effluent and sediment methods.
- Further develop indices of contamination for plants.
- Further develop bio-markers (physiological responses) as an indication of exposure and effect.
- Further develop existing bio-indicators of contamination and produce new ones.
- Develop predictive models for extrapolation from observations on individuals to populations and communities.
- Use demonstration site(s) for testing/validation of approach/protocol.

Once protocols to assess estuarine health are developed, it will be necessary to select suitable sites in which these guidelines can be validated. Validation can be logistically and logically achieved through the use of demonstration projects in which specific estuaries are utilized to evaluate the proposed protocols. Criteria for selection of estuarine demonstration sites should dictate that the estuary be characterized by (1) a diverse eco-population, including submerged and emergent vegetation, (2) a range of exposures, (3) a large, preferably diverse watershed, (4) well-characterized reference sites, (5) a well-documented history, (6) known, localized, rather than widespread contaminant(s) and known sources, (7) known hydrology relative to salinity, gradients, and residence time, and (8) close proximity to a research facility.

It is recommended that subsequent steps in estuarine assessment and contaminant problem identification include convening a workshop and continuing discussions to draft assessment protocols and prepare a guidance document based upon demonstration site and case study evaluations of the process derived in this document.

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