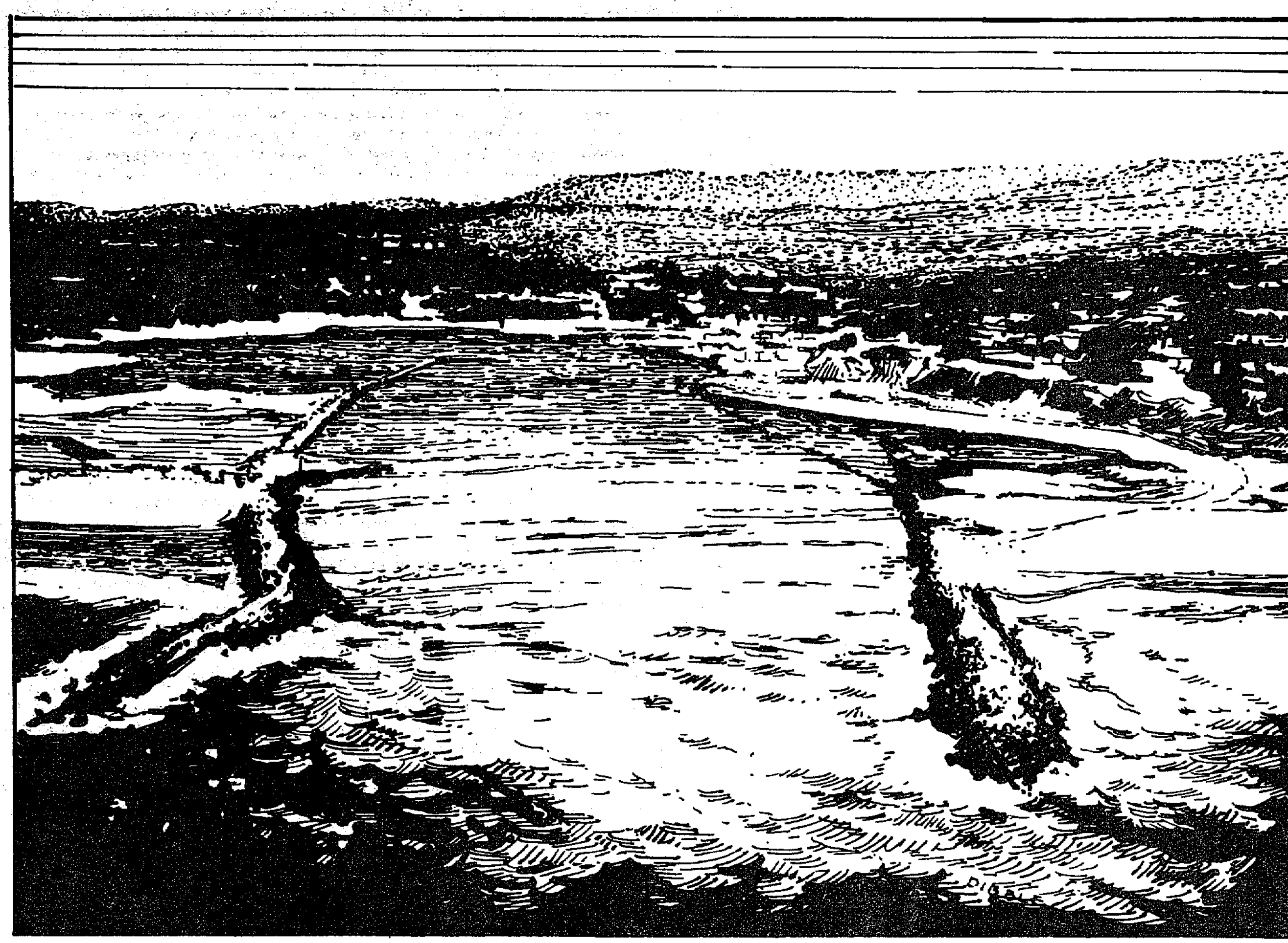
DREDGING IN ESTUARIES

Technical Manual



A Guide for Review of Environmental Impact Statements

Oregon State University

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DREDGING IN ESTUARIES

A Guide for Review of Environmental Impact Statements

TECHNICAL MANUAL

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TABLE OF CONTENTS*

*A detailed table of contents proceeds each chapter.

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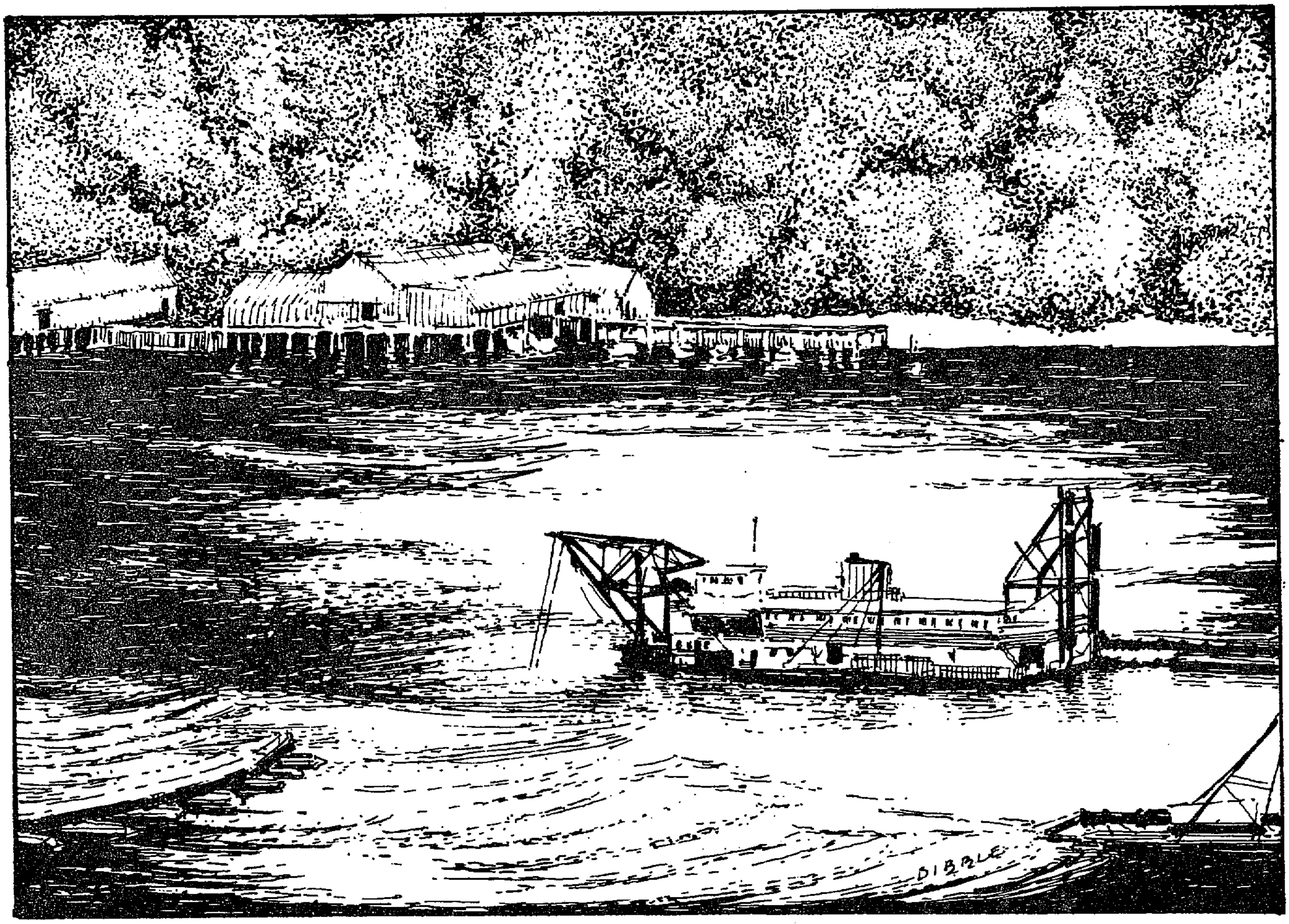


1. Introduction

D. H. K. Farness

TABLE OF CONTENTS

1.1. GENERAL

This "Technical Manual" manual was written as a reference document for a companion volume entitled "Dredging in Estuaries--A Guide for Review of Environmental Impact Statements: Guides Manual." References to sections in both manuals are noted as TM or GM along with an appropriate number indicating a specific section in either the "Technical Manual" or the "Guides Manual."

In the "Guides Manual," specific recommendations are made with respect to the minimum information and analysis necessary for an EIS for dredging which has been prepared in accordance with the National Environmental Policy Act. The purpose of this "Technical Manual" is to document the scientific and technical bases for recommendations in the "Guides Manual" and to provide technical references applicable to the impact assessment process. Specifically described are certain basic estuarine processes, possible environmental impacts of dredging, data collection methods and procedures, and data analysis methodologies including mathematical modeling.

Each chapter in this manual presents the material that in the authors' opinions best summarizes needed information for assessing environmental impacts for dredging in estuaries. The perceived importance of each of these topics varies widely among disciplines and authors. For this reason, the chapters which cover these topics also vary widely in their approach and coverage.

The usefulness of the information in this "Technical Manual" will depend upon the background, discipline, and experience of the particular EIS reviewer. For some, this material may be too complex and verbose; for others, it may be too simplistic and condensed. We have attempted to present the technical material for some "middle point." This material is <u>not</u> intended to serve all the needs of those persons who regularly prepare EIS statments or who are involved in regulating dredging projects. We recognize that such persons must observe institutional rules, procedures, and guidelines; however, we also believe that the latitude permitted as they excercise their own informed judgement within such rules can incorporate much of the material we have offered. The material presented in this manual is intended to assist in the "public review"[1] element of the EIS review process by supplementing the technical information disseminated through Federal, State and Local agencies. It is hoped that this "Technical Manual" will, in some small way, serve to improve the quality of the "public participation in the impact statement process at the earliest possible time".[2]

(1) The Federal Register, Vol. 38(147), Part II, August 1, 1973, Sec. 1500.9(d).

(2) *Ibid*

1.2. THE IMPACT ASSESSMENT AND PROJECT SELECTION PROCESS: AN OVERVIEW

1.2.1. Introduction

This chapter is designed to provide an overview of the impact assessment and project decision process. It is motivated by the belief that a knowledge of the entire process is desireable for both reviewers and writers of environmental impact statements (EIS's) even though their current responsibilities pertain only to particular parts of the process. As a part of the overview, the chapter also identifies necessary information flows which must occur between stages and specialists within the assessment process.

1.2.2. Relevant Impacts

It should be understood that the purpose of an impact statement is to provide information which is necessary to the decision process. The selection of those projects which are undertaken and therefore the decision of whether or not to undertake any particular project is now based on three quite distinct types of impacts. They are (1) the intended economic efficiency impacts, (2) the unintended national economic efficiency impacts which are predominately environmental impacts and (3) the social and economic impacts experienced by the directly impacted region (and possibly other regions which experience large, identifiable impacts).

A comprehensive impact assessment must address each of these impacts, though not necessarily in a single document. Environmental impact statements may be either comprehensive or partial in their content. What is included is a matter of both current institutional arrangements and the conceptual judgments of facilitators of particular EIS's. A good EIS is one which provides relevant and accurate information, whatever its scope with respect to the entire assessment process. At a minimum this necessitates an understanding of some part of the entire process. Ideally, all individuals involved in the preparation and review of EIS's (regardless of their scope) should have an understanding of the entire impact assessment and project decision process.

A broad conceptual view of the process also facilitates an appropriate interaction among specialists working within the process. If the environmental, economic and social impacts are to be properly addressed, not only must scientists be involved, they must exchange information. The output of particular stages of the assessment process are the necessary inputs for other stages of the process.

The three types of impacts listed above, (1) the intended economic efficiency impacts, (2) the unintended national economic efficiency impacts which are predominately environmental impacts and (3) the economic and social impacts experienced by the directly impacted region, will be considered in turn.

1.2.2.1. Intended Economic Efficiency Impacts

The purpose of any investment, public or private, should be to increase human welfare. From the standpoint of an economic efficiency criteria, the worth of a project should be measured by its effect on the gross national product (GNP). A good project adds more to the GNP than it incurs costs to construct and maintain. Its costs are simply the value of the labor, equipment, materials, power and other inputs utilized by the project. The project's contribution to the GNP is more elusive. It is not the gross output of the direct project users. For example, the entire value of an increase in ocean shipping services which result from a dredging project should not be counted as a project benefit. If the project had not been built, the same goods probably would have moved by different routes (or the resources involved would have been used in some alternative production). An increase in the GNP would occur only if cargo could be moved over the route enabled by the project more cheaply than over the next best alternative route. Of course if the project route did not result in cost savings to the shipper the route would not be utilized. To the extent the route is utilized, the principal gain to society is the difference between the costs incurred in using the project route and the next best alternative route. At a minimum, the present value of these savings would have to be equal to the present value of the project costs to justify a project. For most of our history, this criterion alone has been used in project evaluation. If on-site investigations were undertaken they pertained to the engineering problems associated with the actual dredging and maintenance, not the impacts on the environment and on the economic and social life of the impacted region.

1.2.2.2. Unintended Environmental Impacts

In recent years the impact assessment process has been expanded to include unintended effects. These primarily result from the environmental consequences of a project. They can be favorable but more typically they are unfavorable. At the time of the project evaluation they may be either susceptible to being known and measured or not susceptible to being known and/or not readily amenable to measurement and/or if amenable to measurement not amenable to evaluation in social welfare terms. The known and measurable environmental effects can include damage or enhancement to recreational and fishery resources. Various analytical techniques have been developed to convert these favorable and unfavorable consequences into dollar measures which are com parable with the "intended efficiency effects" measurements. Mitigation provides for cost measures of some of the remaining environmental effects (TM 5.12). The other effects which are either unknown or not amenable to measurement or not susceptible to evaluation in social welfare terms constitute one of the major evaluation problems besetting the project selection process. For example, we can not satisfactorily measure the value of environmental diversity and environmental choice. However, it is generally believed that both are adversely affected by dredging projects, particularly in relatively undeveloped estuaries. This view which imputes very high costs to negative diversity and environmental choice effects, discourages developmental projects within relatively undeveloped regions believed to have high natural benefits which are largely intangible and often lost through development (GM 2.2).

1.2.2.3. Economic and Social Impacts on Directly Impacted Regions

Most recently the project assessment process has been expanded to include the economic and social effects experienced by the impacted regions, particularly the directly impacted region. Of all impacts these are the most likely to be misunderstood and therefore measured incorrectly. The relevant regional impacts relate to quality-of-life changes. These are not measured by the production (or employment) changes, although they result from the regional production impacts. If the production impacts were to be counted for all affected regions, they would cancel out except for the net efficiency gain which is appropriately accounted for in the measurement of the intended efficiency effects. In effect, a project redistributes economic activity among industries and regions. In the absence of the project different uses of resources (human, natural and capital) would occur.

This assumes a healthy national economy and full employment or near full employment of resources. On occasion this assumption is incorrect. Under these circumstances a different criteria can be employed at the project selection level, but not at the project impact assessment level. Resources which otherwise would have been idle have a zero opportunity cost. No production is given up by employing them in a particular project. Consequently, the costs of projects can be scaled down accordingly, with the result that some projects which would not be economically feasible in a full employment economy would be feasible under conditions of less than full employment. Again, any decision which justifies a project on this basis should be a high level decision, and the same revised criteria should be applied to all potential projects.

In assessing any particular project the assumption of a full employment economy should be adopted. By this assumption, if the production impacts for each affected region were taken into account they would virtually cancel out. This should not be construed to mean that other production related effects also would cancel out and therefore a project's regional distributional effects can be ignored. All areas do not have the same capacities to absorb a project's impacts without serious social and economic disruption, or conversely, with the same beneficial effects as in cases of seriously depressed areas. To include these impacts in the project assessment process is to recognize that however beneficial a project may be from a national point of view, if it has significant adverse consequences for the directly impacted community (or other impacted communities), society may not be justified in undertaking it out of regard for improvement in the general welfare. Or not unless appropriate compensation is made which would then increase the cost of the project. Conversely, if a project has very beneficial consequences for a particularly depressed area, society may be justified in undertaking an otherwise undesireable project. In the latter case, except for the preferred geographic distribution effects, the resources would be better utilized elsewhere.

These qualtity-of-life, social and economic effects which occur within the directly impacted region (and other areas experiencing large, identifiable impacts) pose difficult measurement problems. Each area is unique. There is no standard calculus by which any particular effect can be identified as a cost or a benefit. The consequences must be inferred from a careful assessment of the aggregate regional production impacts and the social, economic and environmental conditions which prevailed in the region prior to the project. Where possible, indices should be developed for measurement of these diverse impacts. A more detailed discussion of the regional impacts which are appropriate to the project assessment process and the problems associated with their measurement can be found in the economics section of the technical manual (TM 6.5).

1.2.3. Interrelatedness of Effects and Necessary Information Flows

Figure 1.1 outlines the various stages of the impact assessment process, the flows of information which must occur within the process and the particular outputs which are relevant to the project selection decision. The various project consequences are identified at the top of the diagram. They include three stages of production consequences, household consumption consequences and two general categories of regional distribution quality-of-life consequences. The types of impacts appear at the left hand side of the figure. They are environmental and economic and social. The economic and social impacts are further divided into three categories which differ by the geographic area under consideration. The measurement objectives also vary. With respect to society (the United States in the case of U.S. dredging projects) the concern is economic efficiency broadly defined to include unintended effects on production and the environment. With respect to the particular impacted regions, concern

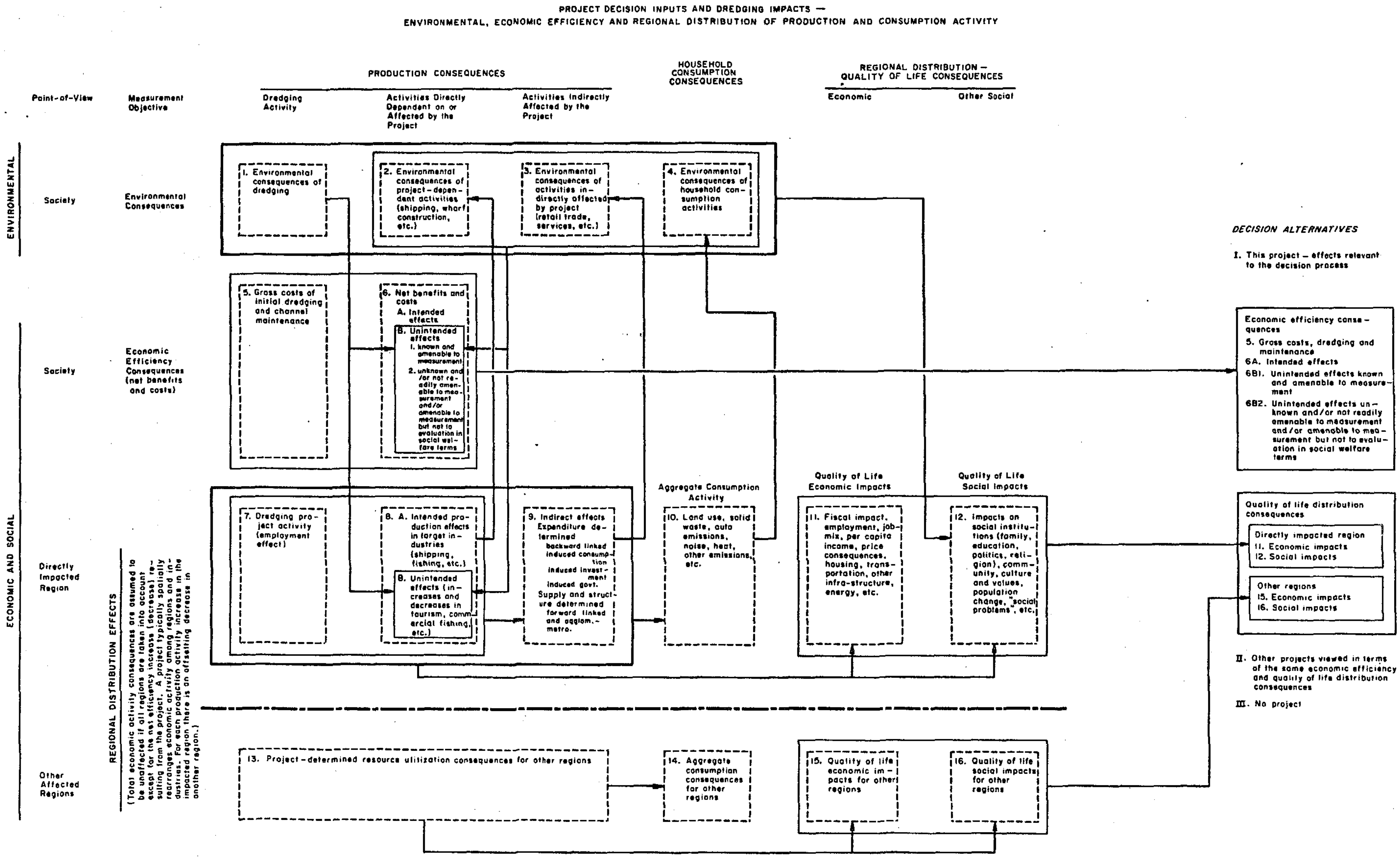


Figure 1.1. Summary of Dredging Impacts and Their Relationships

is for the production and consumption consequences. These in turn enable an assessment of the quality-of-life consequences experienced by the various impacted regions. The environmental impact assessment is from the point of view of society and the measurement objective is the sum of the environmental consequences.

Working across the table, the initial production impact from which all project consequences originate is the actual dredging activity. Myriad environmental consequences result. They are represented in the figure by Box 1. The relevant economic consequence from the point of view of society is the money costs incurred by the dredging and maintenance of the channel (Box 5). From the point of view of the directly impacted region the result is additional employment in dredging activity within the region (Box 7). From the point of view of other regions the result is an offsetting decrease in economic activity (labor employed in dredging in the directly impacted region precludes its employment elsewhere). These impacts are consolidated for all other regions and illustrated in Figure 1.1 in a form more abbreviated than for the directly impacted region. For many projects the offsetting regional effects are not easily identified and/or are not large for any particular region and consequently can be ignored. In cases in which regions other than the directly impacted region experience sizeable project induced impacts which are identifiable, the same detailed analysis outlined for the directly impacted region should be followed.

Proceeding to the second type of production impact, "activities directly dependent on or affected by the project," the relevant economic impact from the point of view of society consists of the net benefits and costs which result from the intended and unintended project effects (Box 6). The intended effects are estimated from information developed independently of other stages of the impact assessment process. Estimation of the unintended effects (Boxes 6B1 & 6B2) however, requires information which is developed in the assessment of environmental impacts resulting directly from the dredging activity, hence an arrow indicating an information flow from Box 1 to Box 6B. Scientists provide environmental impact information, some of which economists can convert into dollar impact measures (Box 6B1) and some of which is passed forward to the decision stage in the unconverted form (Box 6B2). The directly impacted region also experiences intended and unintended production effects (Box 8). Again the intended effects are estimated from information developed independently of other stages of the impact assessment process and the unintended effects from information generated by the environmental impact assessment of the dredging project. Again the arrow from Box 1 to Box 8B indicates a necessary flow of information within the assessment process. Given the estimated projected impact on "directly dependent" production in the directly impacted region and its conversion into land use, solid waste, heat, noise, particulate and other emission consequences, the environmental impact of this activity can be assessed. Economists generate production impact measures which when converted into various pollution and land use consequences enable scientists to address the indirect environmental consequences of a dredging project. The necessary information flow is indicated by the arrow between Boxes 8 and 2.

The third type of production consequence, "activities indirectly affected by the project" are not relevant from a national economic efficiency point of view. They are important from the standpoint of the regional distribution of economic activity. They depend on the magnitude of the "dredging activity" and "directly dependent activities", hence the arrow extending from the box encompassing Boxes 7 & 8 to Box 9 which indicates an information input essential to the calculation of the indirect production impact. Again, once this production impact is known and converted into various land use, emissions and other consequences, the resulting environmental impacts can be addressed. The essential information flow is indicated by an arrow from Box 9 to Box 3.

The household consumption consequences are relevant from the standpoint of the impacted regions. The aggregate consumption activity is a consequence of the aggregate production activity hence an arrow extending from the box encompassing all regional production effects (Boxes 7, 8 & 9) to Box 10, which indicates an essential information flow. Given the magnitude and character of the induced consumption activity, the resulting environmental consequences of household wastes, emissions, etc. can be measured. The arrow from Box 10 to Box 4 indicates an appropriate information movement. In the typical case, in the absence of the project the majority of the affected population would be engaged in consumption activity somewhere else. Since these other locations are difficult to identify it generally is not possible to assign the loss of activity resulting from the project to any other specific regions. Box 14 represents the offsetting consumption effects for all other regions.

As a result of the environmental consequences of consumption and production activity unintended effects of the project may occur in addition to those resulting from the actual dredging. This possibility is indicated by arrows extending from the box encompassing Boxes 2,3, & 4 to Boxes 6B and 8B, indicating relevant information flows. Scientists provide economists with environmental impact information which has been estimated from emission and other production and consumption consequences previously estimated by economists. Economists in turn must make appropriate adjustments in the estimates of the affected production impacts (Boxes 6B & 8B) and other linked activities.

The quality-of-life consequences for the impacted regions are divided into two categories, economic and other social. The economic effects result from the aggregate production consequences of the project. This is indicated by an arrow extending from the box encompassing Boxes 7, 8 & 9 to Box 11. Given these production impacts and appropriate baseline data, various economic consequences which impinge on the well being of the residents of the region can be estimated. These include fiscal, price, per capita income and other impacts. The "other social" quality-of-life consequences are also a function of aggregate production activity (indicated by an arrow from the box encompassing Boxes 7, 8 & 9 to Box 12) and aggregate environmental effects (indicated by an arrow from the box encompassing Boxes 1-4 to Box 12). Economists and scientists provide information on total production and environmental impacts which in conjuction with appropriate baseline information enable sociologists to estimate certain quality-of-life effects. It should be noted, quantification of the quality-of-life consequences is not possible in terms of a single measure which is comparable to the measures of economic efficiency indicated in Box 6 by Impacts A and B1.

1.2.4. The Project Selection Process

The particular outputs of the impact assessment process which are relevant to project decision process are indicated by arrows extending from boxes encompassing Boxes 5 & 6 and 11 & 12 to the decision information boxes at the right of the diagram. The arrow from Boxes 15 and 16 indicate the desireability of including information for impacted areas other than the directly impacted area if such impacts can be identified and are deemed significant.

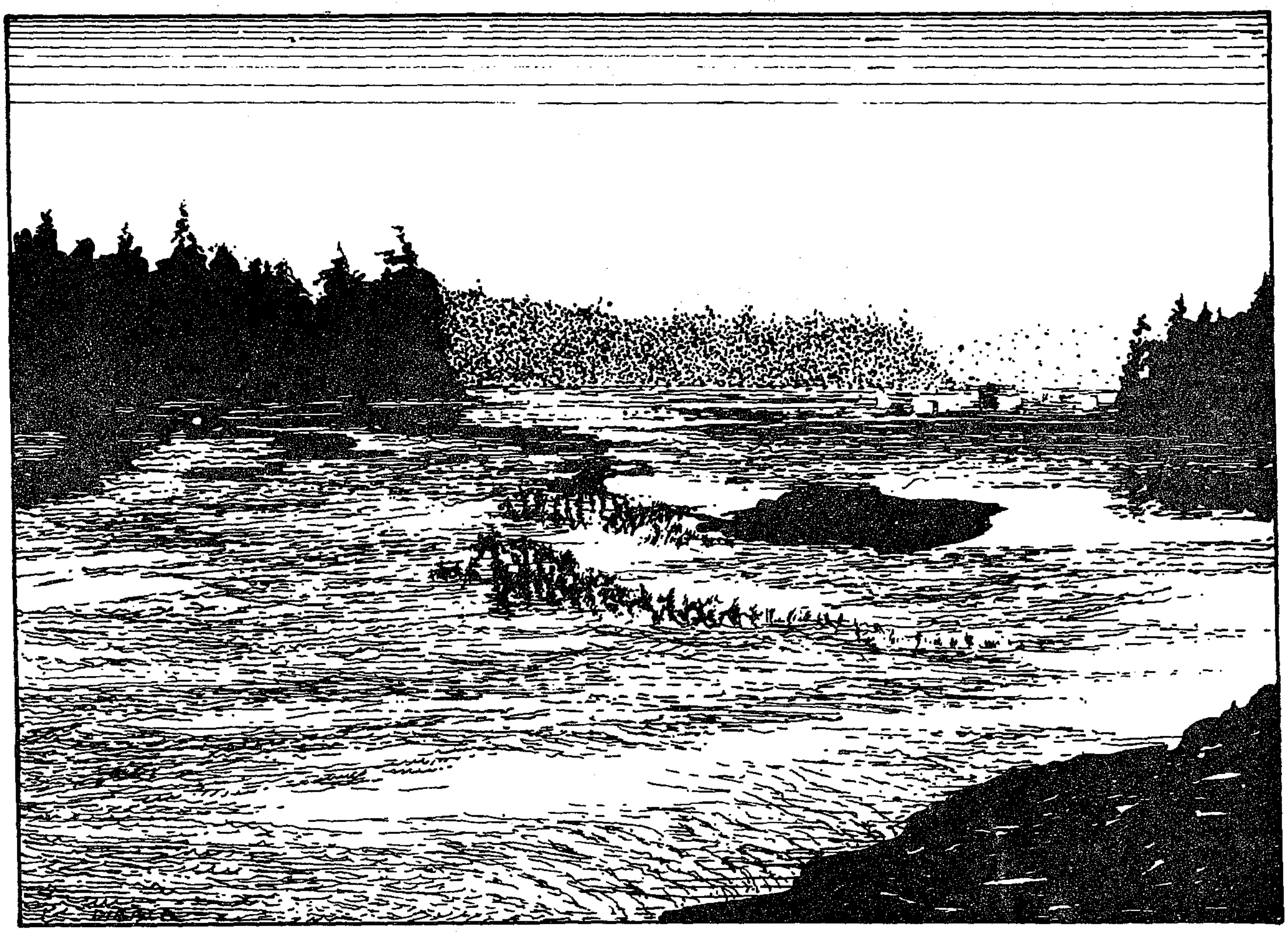
The various impacts relevant to the decision process are denominated in a variety of measures. Only the intended economic effects (Boxes 5 and 6A) and that part of the unintended effects which involve resources of known commercial or recreational value or which are subject to mitigation (Box 6B1) are in dollar measures. The other unintended environmental impacts (Box 6B2) and the quality-of-life consequences for the various impacted regions (Boxes 11, 12, 15 & 16) are expressed by a variety of scientific and social indicators. At the decision level, criteria must be introduced which, in effect, enable the assignment of dollar values to all impacts not already denominated in dollars. This is not the responsibility of the assessment process. Its responsibility is to identify and quantify these environmental and regional distribution quality-of-life consequences as fully and accurately as possible.

Even at the project decision level it is not necessary to establish exact dollar magnitudes for those impacts not measured in dollars in the assessment process. The dollar cost and benefit measures which are provided by the assessment process determine the order of magnitude of these other impacts which would be necessary to justify a project in cases in which the measured costs exceeded the measured benefits or to reject a project in cases in which the measured benefits exceeded the measured costs. The decision to either undertake or reject a particular project involves an implicit judgment regarding the order of magnitude of these impacts which are not denominated in dollar measures.

The same procedures should be followed for all projects, and the decision process should consider all possible alternative projects as well as the possibility of no project.

1.2.5. Summary

Impact assessment teams, reviewers of impact statements and policy decision makers require, in varying degree, this type of a conceputal framework if they are to adequately fulfill their functions. An even higher priority must be assigned to the methodologies employed in assessing the many impacts comprising the final product. These include the various specific impacts which have been obscured in the figure by consolidation of the myriad direct environmental effects within a single box. Recognizing this, the optimal conditions is one in which competent specialists are employed in the estimation and reveiw of the various particular impacts, but who also are familiar with the place of their work within the combined assessment process and project decision process.



2. Hydrodynamics and Circulation

R. T. Hudspeth

TABLE OF CONTENTS

2.1. INTRODUCTION

Environmental Impact Statements (EIS's) for dredging in estuaries which are prepared in accordance with the National Environmental Policy Act (NEPA) are required 1) to describe the environmental setting without the project and 2) to describe the potential environmental impacts of the dredging project. A review of these descriptions in accordance with the NEPA requires 1) *knowledge* of the hydrodynamics and circulation within the estuary prior to the dredging action and 2) an *estimate* of the potential impact of dredging on the hydrodynamics and circulation following the dredging action.

The descriptions which provide *knowledge* of the hydrodynamics and circulation prior to the dredging action are given by simultaneous measurements of fresh water and tidal flow rates, by vertical and areal salinity distributions, and by estuary cross-sectional and plan view geometries. The *estimates* of impacts following the dredging action are somewhat more subjective and almost always highly controversial. This controversy stems primarily from two sources: 1) the experimental and analytical validity of the model employed to obtain the estimates and 2) the representativeness of the data used to describe the environmental impacts following previous dredging projects. The primary aim of this chapter is to identify *why* certain physical parameters associated with the hydrodynamics and circulation of estuaries are important in the evaluation of an EIS for dredging in estuaries and to identify references where more technical information regarding these physical parameters may be obtained. The derivation of equations and their particular numerical or analytical solutions will not be repeated here as these technical aspects are more competently covered in the references cited. These references are not exhaustive of the total available, and should only be considered as a succinct listing from which a broader technical background may be obtained. To reiterate: the emphasis of this chapter is to identify *why* certain physical parameters are important in an EIS review of the environmental impacts of dredging in estuaries; *how* to obtain these parameters and to apply them to a particular impact may best be determined from the technical references cited in each case.

The principal types of models used to estimate hydrodynamic parameters are briefly reviewed in accordance with the classification system developed in two papers by Hinwood and Wallis (1975a,b). This classification system is followed by a discussion of the tide induced dynamics and kinematics in an estuary and follows the material collected by Officer (1976). A discussion of circulation generated by density gradients then follows. These circulation models are also derived by Officer (1976) and include an important estuary classification system based upon salinity measurements which was developed by Hansen and Rattray (1966). Sediment transport through inlets to estuaries is discussed next and emphasizes the stability type of models developed by Dean (1976). The onshore-offshore and alongshore motion of cohesionless sediments by surface gravity waves as reviewed by Komar (1976) concludes this chapter.

2.2. MODELS FOR ESTIMATION

The environmental impact of dredging on the hydrodynamics and circulation of estuaries results from a change in the geometry of the removal and, possibly, the disposal sites. This change in geometry changes the natural hydrodynamics and kinematics of the flow field. Changes in the natural kinematics which are induced by the commercial development on drainage patterns adjacent to the estuary and by increased ship traffic also impact on the natural environment of the estuary.

The primary impact which must be evaluated is the change in the spatial and temporal distribution of the nutrients in the water and in the sediments which are used by the ecological systems within the estuary and of the waste pollutants disposed by the increased commercialization which inevitably follows dredging projects. A three-dimensional conservation of mass equation which describes the patial and temporal distribution of nutrients in a rectangular Cartesian coordinate system for which molecular diffusion is assumed to be very much smaller than turbulent diffusion is given by the following transport equation:

$$\frac{\partial C}{\partial t} + \frac{\partial}{\partial x}(V_x C) + \frac{\partial}{\partial y}(V_y C) + \frac{\partial}{\partial z}(V_z C) =$$

$$\frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(D_z \frac{\partial C}{\partial z}\right) + S \tag{2.1}$$

where C = the mass concentration of the nutrient or pollutant; D_x, D_y, and D_z = turbulent diffusion coefficients which are, in general, functions of space; and S = a nonconservative source or sink contribution. The velocity terms (V_x, V_y, V_z) are also functions of space and time and must be obtained from the solutions to the hydrodynamic equations of momentum and continuity. Thus, the hydrodynamics of the estuary are coupled to the conservation of mass equation by the kinematics of the flow and no general solution exists for this system of partial differential equations with variable coefficients.

The temporal and spatial distributions of concentrations may be estimated by models. Three types of models which have been developed for estuary circulation and mixing estimates have been classified by Hinwood and Wallis (1975a) as (1) physical hydraulic, (2) passive electrical analog, and (3) mathematical. Mathematical models may be further decomposed into (3a) analytical and (3b) numerical. Any combination or, possibly, all of these models may be employed in an EIS to estimate the environmental impact of dredging on the hydrodynamics and circulation in estuaries. A section which briefly describes each of these models follows where, again, detailed technical evaluations have been deferred to the references cited. An extensive collection of papers on modeling techniques may be found in the proceedings on modeling edited by Nihoul (1975) and in the ASCE Symposium on Modeling Techniques (1975). Additional reviews are given by Abood and Bourodimos (1976) and by Fischer (1976).

2.2.1. Physical Models

Environmental impacts estimated by physical hydraulic models must be carefully reviewed and interpreted with experience, judgment, ingenuity, and patience (Vennard and Street (1975), p. 342). Changes in circulation and mixing due to dredging may be estimated and the circulation patterns displayed quite convincingly by photographs from these models.

Analytical validity of physical models must be demonstrated by similitude analysis while experimental validity must be demonstrated by calibration with synoptic field measurements whenever possible. Since these field measurements needed to validate the models will generally only be available following the dredging action, experimental validity will not usually be possible. Estimates of environmental impacts on circulation and mixing obtained from hydraulic models must be accompanied by sufficient data regarding the geometric, dynamic and kinematic similitude criteria, the scale effects experienced, and the calibration data used to validate the model.

A general review of similitude and dimensional analysis may be found in almost any fluid mechanics text [e.g., Vennard and Street (1975), Chapter 8] LeMehaute (1976), offers a special treatment on the criteria for dynamic similitude and on the equivalence of the Richardson number with the densimetric Froude number which are dimensionless ratios generally used to scale dispersive physical models. The overview by Herrmann (1975) and Keulegan [Ippen (1966), Chapter 17] offer depth and insight which may only be obtained by years of experience. The comparison between a physical and mathematical model of tidal flow by Audunson *et al.*, (1975) demonstrates the type of data which are required to validate estimates of environmental impacts obtained from physical models.

2.2.2. Passive Electrical Models

Passive electrical models may be employed to estimate the environmental impacts of dredging in estuaries on tidal and river flows and on dispersive mass transport. There are very few instances of the application of passive electrical models to estuarine flows and Hinwood and Wallis (1975a) attribute this to the prohibitive cost.

Passive electrical models use electrical analogs to solve the governing differential equations with the prescribed boundary and initial conditions. A succinct comparison of these analogs may be found in Olson (1958). Analytical validity must be demonstrated by the dynamic analogies while experimental validity must be demonstrated by calibration data. Examples of applications are scarce.

2.2.3. Analytical Models

Analytical closed form solutions for the spatial and temporal kinematic and mass distributions are possible in one of the thirteen separable coordinate systems [cf. Morse and Feshbach (1953), Chapter 5]. Even in these coordinate systems, general solutions are further restricted because the coefficients in Eq. (2.1) [i.e., V and D] are also functions of space and time. It is frequently possible, and often necessary, to simplify the estuary geometry to a separable coordinate system in order to obtain useful concentration estimates *vis a vis* the trends in the changes in the estuary geometry induced by the dredging action. Even if numerical models are employed to estimate the environmental impacts of dredging in an estuary, they are frequently "debugged" by comparison with known analytical solutions. Therefore, a knowledge of analytical solutions is of paramount importance in reviewing an EIS.

A number of useful analytical models are derived in the tome edited by Ippen (1966) and in a more specialized text by Dyer (1973). An expanded in-depth text which treats tidal hydraulics, mixing, circulation and dispersive analytical models has been prepared by Officer (1976). The analytical validity and experimental (or application) validity of the analytical models are also presented by Officer (1976) and offer the EIS reviewer several explicit examples of a wide variety of applications on a global scale.

When only analytical models have been employed to estimate environmental impacts on the hydrodynamics and mass transport in an estuary, the solutions must be carefully interpreted by the expressed assumptions and limitations of the analytical models used to compute the estimates. It is especially important to correlate the separable coordinate system chosen with the actual geometry of the estuary and the values of the initial and boundary conditions. This further emphasizes the importance of the geometric descriptions required in the environmental setting without the project. Empirical coefficients or parameters (e.g. friction factors and the diffusion coefficients D) must be identified and their relative magnitudes carefully reviewed.

Despite the apparent severe limitations imposed on analytical estimates by the assumptions required to obtain solutions, their importance in estimating environmental impacts should not be minimized. This is especially important in actions which require an EIS by the NEPA; but which are perhaps insufficiently funded to enable extensive numerical or physical model estimations to be computed. Similarly, maintenance dredging actions are frequently conducted in estuaries which have been extensively "channelized" due to previous dredgings and, thus, analytical solutions in separable coordinate systems are rendered more palatable in these instances.

2.2.4. Numerical Digital Computer Models

Probably the most important model used to describe the environmental impact of dredging in estuaries is the numerical digital computer model. So prolific have these models become that Hinwood and Wallis (1975a) developed a classification scheme for numerical models and, in a companion paper (1975b), reviewed an impressive number of digital computer models using their classification scheme. Hinwood and Wallis (1975a) carefully review the principal features of mean motion, river flow, tidal currents, and the dispersion computed by the models. While Abraham and Karelse (1976) and Abbott (1976) disagree with certain elements of the classification scheme of Hinwood and Wallis (1975a), the overall scheme seems appropriate enough to merit serious consideration in an EIS review. Most of the following may be found in the papers by Hinwood and Wallis (1975a,b) with the appropriate corrections to the classification scheme given in their closure (1976).

The mass transport relationships given by Eq. (2.1) may be averaged over three temporal periods of durations and over four spatial degrees. Temporal averaging over a tidal period transforms the turbulent diffusion coefficients, D, into effective dispersion coefficients, $\overline{E}$. Spatial averaging of Eq. (2.1) further simplifies the mass transport relationship and transform the effective dispersion coefficient, $\overline{E}$, to an apparent dispersion coefficient, K. Details on the physics and implications of these temporal and spatial averaging processes are given in the reference cited by Hinwood and Wallis (1975a).

The classification scheme of Hinwood and Wallis (1975a) is especially useful in reviewing an EIS for dredging in an estuary. The relevant economic and physical factors which are incorporated in their scheme enables the reviewer of an EIS to evaluate the environmental impact estimates generated by a numerical model in terms of the temporal and spatial averaging employed. Hinwood and Wallis (1975b) discuss the computational aspects of modeling in terms of the accuracy of the finite difference procedure and the calibration data required to experimentally validate the model.

Estimates of environmental impacts on hydrodynamic circulation and mass transport computed by numerical models should identify the parameters of the numerical model needed to classify the model in accordance with the Hinwood and Wallis (1975a) scheme and should identify the truncation and other stability parameters of the numerical scheme and the calibration data used to verify the model. Experience is required to evaluate the relevance of a particular computer model to a particular dredging action and of the estimates of the environmental impacts predicted by a particular numerical model. A review of the examples discussed by Hinwood and Wallis (1975b) afford a good starting point.

While the emphasis of the classification scheme of Hinwood and Wallis (1975a) is on the assumptions and averaging employed by the models, Fischer (1976) expands on the limitations of computer models. These limitations are divided into (1) computer technology and (2) an ability to represent the physical processes mathematically. These limitations are important in evaluating the relevancy of environmental impact estimates computed by numerical models and should be added to the classification scheme of Hinwood and Wallis (1975a) in an EIS review. The empirical coefficients used in the model must be explicity identified as well as the other limitations noted by Fischer (1976) in representing the physical processes by a numerical model.

Omitted from the models reviewed by Hinwood and Wallis is an especially attractive model which is based upon Fourier series expansions which was developed by Pearson and Winter (1976). It appears to provide considerable computational savings without sacrificing hydrodynamic details for well mixed estuaries which should make it useful for EIS reviews.

2.2.5. Summary of Models

It should be clear by now that a careful and thorough review of the estimates of environmental impacts on circulation and mass transport in an estuary depend critically on the geometric, kinematic and salinity measurements required in the section of an EIS which describes the environmental setting without the project. These data are critical to the selection of an appropriate model and to the subsequent calibration of the model selected. It is mandatory that an EIS contain a carefully prepared description of the environmental setting without the project which specifically includes data which are relevant to the models which are to be employed to estimate environmental impacts.

2.3. TIDAL MOTIONS

Officer (1976) separates the prominent estuarine phenomena of tides, circulation and mixing since this separation enables the governing field equations to be solved separately instead of having to solve a coupled set of simultaneous equations. This technique is useful for isolating these three phenomena and is recommended for reviewing the elements identified in physical impacts for dredging in estuaries.

In estuaries, we are not primarily concerned with the tide generating forces and their harmonic analyses as described, for example, in the classical reference by Dronkers (1964). What is of primary importance is the ocean tide-induced pressure gradient at the entrance to the estuary and the temporal and spatial kinematic distributions along the estuary which result from this ocean tide induced pressure gradient.

An EIS should identify the impacts of dredging on the dynamics and kinematics of tidal induced motions within the estuaries. These impacts will result primarily from the bathymetric changes at the removal and disposal sites. These impacts are especially critical when the removal or disposal site is located at the mouth of an estuary where the ocean tide induced pressure gradient is the primary driving force for the resulting cooscillating tide created within the estuary.

2.3.1. Dynamics

Environmental impacts on the dynamics of tidal motions within an estuary are measured primarily by the forces which govern the motion within the estuary and not primarily by the astronomical tide- generating forces which create the ocean tide at the mouth of the estuary. It is of primary importance, therefore, that an EIS identify the environmental impacts on the dynamic forces of the ocean tide at the estuary mouth, on the lateral and bottom friction forces within the estuary, on the geostrophic Coriolis parameter, and on the cyclostrophic curvature force. Officer (1976) and Ippen (1966) provide introductory insight into the effects of the dynamic forces on the resulting cooscillating tidal motions within the estuary.

The primary impact on tidal dynamics is the change in the bathymetry of the estuary which directly affects the kinematic speed of propagation of the cooscillating long tide wave and the spatially averaged water particle velocities. Changes in the texture of the sediments exposed to the flow field at the removal and disposal sites as well as the removal or addition of flow constrictions directly impact upon the frictional forces. Impacts on the Coriolis force will, in general, probably be of minor importance. Areal changes in bathymetry may directly affect the curvature of the flow channels and impact significantly on the lateral, frictional induced forces and cyclostrophic forces. Mei, *et al.*, (1974) and van de Kreeke and Dean (1975) discuss the effects of friction on tidal dynamics in estuaries while King (1974) gives an analytical method for estimating the impact of dredging on tidal dynamics. Pearson and Winter (1976) introduce a novel harmonic method for treating nonlinear quadratic friction forces.

2.3.2. Kinematics

Kinematic changes result from changes in the dynamics discussed above and impact on the circulation, mixing and sediment transport in the estuary. The environmental impact on the stability of a removal or disposal site near the inlet to an estuary may be estimated by the stability method developed by O'Brien and Dean (1972). Other applications are given by Dean (1976). Kinematic changes may also impact on the marine traffic in an estuary by significantly altering the velocities of tide induced currents and in the phase lag of a cooscillating tide. The impact on the phase lag of tidal currents and amplitudes along estuary channels are especially critical to large ships which may only navigate certain estuaries during periods of high tide and to small boat traffic which may only navigate entrances during periods of slack tidal currents. The environmental impact of kinematic changes induced by dredging are especially important to commercially developed estuaries and must be evaluated in terms of the tidal velocities and the amplitude of the speed of a cooscillating tide propagating in the estuary, and of the phase lag between tidal stages along the estuary and the reference tidal station. Cooscillating tide models are reviewed by Ippen (1966) and by Officer (1976).

2.3.3. Tabular Data

Tidal amplitudes and currents of many estuaries in the Americas are given in tabulated form in publications by the U.S. Dept. of Commerce. EIS descriptions of the environmental setting without the project should correlate tidal amplitude and velocities which have been measured for the EIS with tabular data available either through the Dept. of Commerce publications or through "Boat Sheets" maintained by port or harbor authorities. Estimates of environmental impacts on the tidal phenomena in an estuary should be referenced to these tabular data; especially, if these impacts are chronic with regard to changes in the phase lags or tidal amplitudes and currents.

2.4. CIRCULATION

Circulation effects which are driven by density gradients are reviewed by Officer [(1976), Chapter 4]. These effects result from kinematics which are several orders of magnitude smaller than the maximum tidal velocities which are proportional to the amplitude of the tidal velocity. In the temporal averaging scheme discussed by Hinwood and Wallis (1975a), linear tidal effects are averaged out when the averaging period corresponds to a tidal cycle. Nonlinear tidal circulation effects, however, remain when averaged over a tidal cycle since $\cos^2 \omega t$ averages to a constant (*viz.*, 0.5) when integrated and averaged over the period of oscillation (i.e., $T = 2\pi/\omega$). These nonlinear circulation effects are an order of magnitude greater than the net circulation effects and an order of magnitude smaller than the linear tidal amplitudes of circulation.

Officer (1976) reviews a number of analytical models which describe the weak circulation flows which are driven by small differences between the densities of the fresh water discharge and the ocean water. One of the important consequences to be considered in reviewing an EIS is the impact of these weak circulation flows in the case of the arrested saline wedge. The model discussed by Officer (1976) is important in reviewing a dredging EIS to determine the impact of the dredging action on the shoals associated with the tip of an arrested saline wedge. The removal of the shoal and/or the change in the down estuary channel due to the dredging action may impact on the location of the arrested saline wedge and its potential relocation due to the dredging action. Officer

(1976) discusses both an analytical model of an arrested saline wedge and some important case histories which afford excellent examples for EIS review.

2.4.1. Estuary Classification by Salinity

An especially powerful physical classification of estuaries which has been derived from firm theoretical principles (yet which requires only easily measured quantities which should be available from a description of the environmental setting without the project) has been developed by Hansen and Rattray (1966) and may be succinctly reviewed in Officer [(1976, pp. 3-5)]. Classification of an estuary by this system should indicate which type of hydrodynamic or mass transport model from the Hinwood and Wallis (1976a) classification system would be most applicable for estimating potential impacts on dispersive mass transport and on sediment transport. Any biological or ecological classification system which could be adjoined to the Hansen and Rattray classification system would be an especially powerful method for quickly identifying significant impacts due to dredging action.

2.5. SEDIMENT TRANSPORT

Sediment transport in estuaries is an extremely difficult process to describe analytically. Consequently, estimates of the impacts of dredging actions on sediment transport in estuaries will be equally difficult to describe. Contributing to the difficulty is the broad spectrum of types of sediment transport which may occur simultaneously within an estuary. In the up estuary near the mouths of fresh water sources, the sediment transported may consist of fine grained cohesive material derived from the erosion of adjacent terrain which is transported under unidirectional flow. In the down estuary near the ocean inlet to the estuary, the sediment transported may consist of coarse gained littoral drift derived from the erosion of adjacent beaches by ocean waves which is transported into the estuary during flood tides. In between these two termini of the estuary, any combination of sediment texture and flow field may be possible.

Much of the classical efforts to analyze sediment transport have been directed toward cohesionless sediments transported by unidirectional flows. These analytical and semi-empirical models are reviewed in a report edited by Vanoni (1975). Review of impacts estimated by these models may be applicable near the inlets of estuaries where the sediment transported is primarily littoral drift carried in during flood tides and eroded during ebb flows. In general, however, the material transported usually consists of fine grained silts with nonzero cohesion which is being transported under oscillatory flows in saline water which may significantly affect the depositional behavior of the sediments. The chronic impacts of dredging actions in estuaries which experience sediment transport with cohesive material in saline water under oscillatory flows will generally be very difficult to estimate and are probably one of the strongest candidates for identification as "impact unknown" (GM 1. Introduction).

Advances in stochastic sediment transport models for unidirectional flow may be extended to oscillatory flow. The highly complex model developed by Lee and Jobson (1974) is limited in its application to estuaries by three restrictions. The first is its development for and validation by unidirectional flows. The second is its restriction that each sediment particle may only jump over one sand dune at a time which biases the results toward high frequency step lengths and rest periods. Finally, the model requires a time series record of the motion of the sand waves. This measurement may be very expensive to obtain and to interpret in an estuary under oscillatory flow. A more attractive stochastic sand wave model is the one derived by Hino (1968). The Fourier analysis of the sand waves measured by acoustic profilers provides a measure of the energy content in the sand waves. If a dispersion relationship were available from the analytical model, this wave number spectrum could be easily used to provide the rate of motion and amount of material transported. However, until this relationship between the wave numbers of the sand waves and the speed of the waves is known, the primary application will lie in a correlation of the energy content of the sand waves computed by Fourier analysis with the kinetic energy available to erode the sediment.

In general, it will be very difficult to estimate the impact of an oscillatory saline flow field on the alternate erosion and deposition of cohesive sediments in estuaries. The application in a EIS of cohesionless sediment transport models which have been developed for unidirectional flows should be reviewed carefully.

A second type of sediment transport found in estuaries is primarily of interest near disposal sites within an estuary. These areas may experience surface gravity wave motion which may resuspend the dredged material and transport it to potentially undesirable portions of the estuary. Sediment motion by waves may be primarily of two types: 1) onshore-offshore motion which may be described by the classical tractive force analysis [cf. Ippen (1966), Chapter 9 or Komar (1976)] and 2) resuspension by the dynamic pressures of breaking waves [cf. Shore Protection Manual (1973) or Dean (1973)]. Estimates of the wave parameters required to use these sediment transport models are discussed in the following section. Most of the models reviewed in the references cited above have been developed for cohesionless material. Impacts on cohesive dredged material which are estimated by these analytical models should be carefully reviewed.

2.6. SURFACE GRAVITY WAVES

Descriptions of the impacts of surface gravity waves as a result of dredging in an estuary must consider at least two types of surface gravity waves. First, the waves which obliquely strike the shore adjacent to the estuary inlet place sediment in motion parallel to the shoreline (littoral transport) and in motion perpendicular to the shoreline (onshore-offshore transport). This sediment is carried into the estuary on flood tides and the upestuary extent of its penetration into the estuary depends on the tidal kinematics and dynamics and on the wave field which causes the sediment motion. Second, tide flat areas within the estuary may experience either wind generated or ship generated surface gravity waves which may, again, place the sediment on these tide flats in suspension and disperse them within the estuary.

The mechanics of wave generated sediment transport models are reviewed by Komar (1976). An interesting heuristic model for the along-shore transport has been developed by Dean (1973). The principal wave data required to exercise these models may be estimated by graphical methods using charts presented in the Shore Protection Manual (1973). It is important to note in reviewing wave parameters estimated by these graphs that waves generated in the open ocean are distinct from waves locally generated within the estuary and different graphs are provided for each of these cases. It is important in the review of an EIS to insure that the correct wave parameter graphs have been used whenever wave parameter estimates are presented or employed in sediment transport impact estimations.

The description of ship waves by analytical models has been primarily limited to potential flow theory. The application of these potential flow models to sediment transport problems should be carefully reviewed. Similarly, extension of empirical data for sediment transport by ship waves from the site where the data were measured to any other site should be carefully reviewed.

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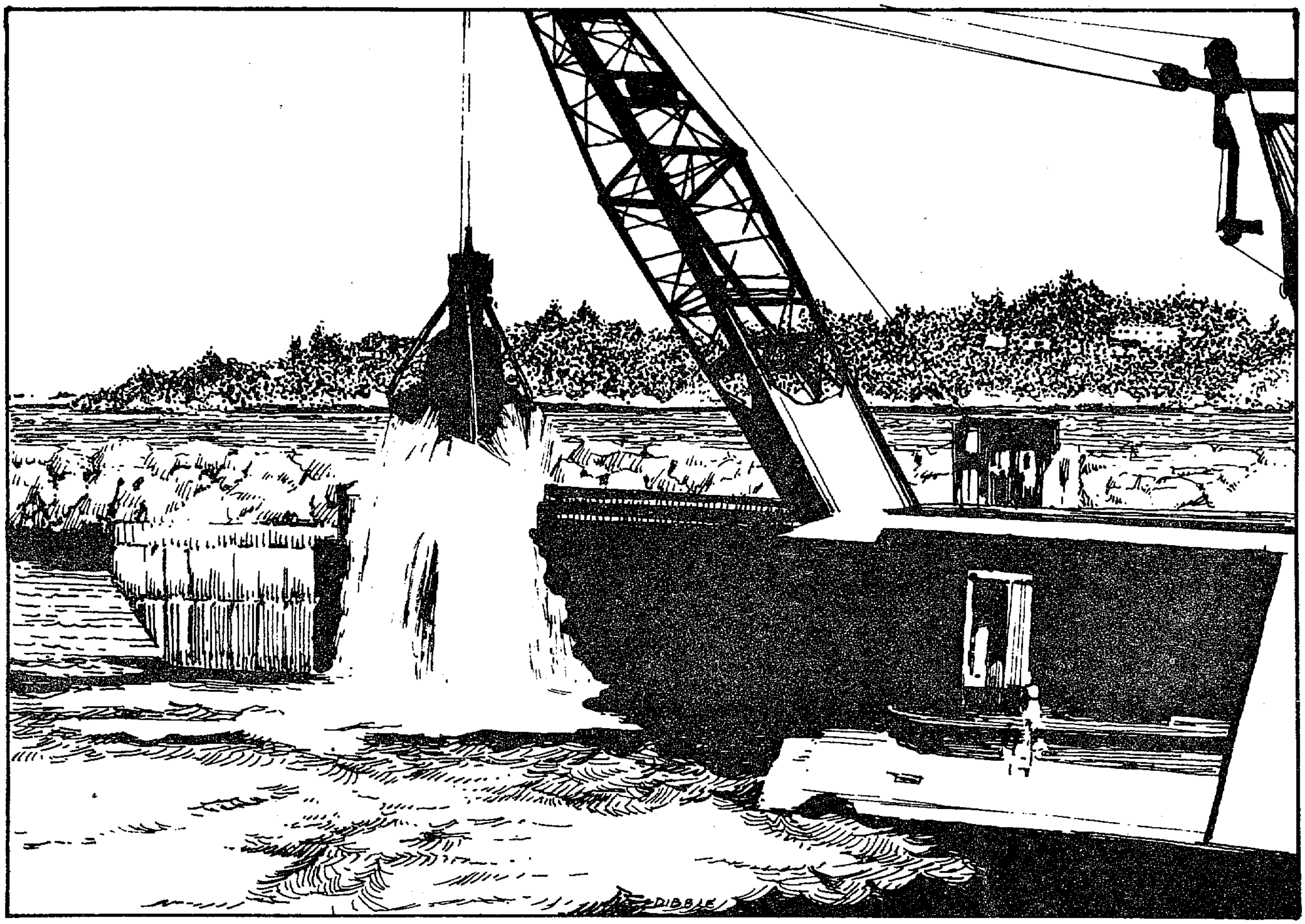


3. Environmental Quality

K. J. Williamson
P. O. Nelson

TABLE OF CONTENTS

3.1. WATER QUALITY

3.1.1. Description of Parameters

An understanding of water quality impacts requires a basic knowledge of water quality parameters and their significance. For reference, some common water quality parameters are defined in this section.

3.1.1.1. Salinity (S)

Salinity is a measure of the total soluble salt content of a water, comprised primarily of Na^{+}, Mg^{2+}, Ca^{2+}, K^{+}, Cl^{-}, and $SO_4^{=}$ and is expressed as parts per thousand (ppt) on a weight basis. Typical sea water has a salinity of approximately 35 ppt and typical fresh water, less than 1 ppt. Estuarine waters will typically be between these two values.

3.1.1.2. Dissolved Oxygen (DO)

Dissolved oxygen is a measure of the soluble concentration of molecular oxygen (O_2) in water expressed as mg/ℓ or mℓ/ℓ. Oxygen is sparingly soulble in water and achieves an equilibrium (or saturated) concentration in contact with the atmosphere. The equilibrium concentration is a function of temperature, salinity, and pressure. Usually pressure variations can be neglected, but the decrease in D.O. concentration with increasing temperature or salinity must be incorporated. Nomographs, tables or numericial expressions summarizing these relationships are available in many references (e.g., Riley and Skirrow, 1975). Extreme values for DO saturation in estuaries may range from about 6 to 13 mg/ℓ depending on temperature and salinity.

3.1.1.3. Total Suspended Solids (TSS)

Total suspended solids is a measure of the total concentration of non-soluble (particulate) impurities in water. This may be comprised of organic or inorganic materials of natural or man-caused sources. Suspended solids are typically expressed as mg/ℓ. Suspended solids range from non-settleable colloidal particles of sub-micron particle size to coarse, settleable solids of greater than one hundred microns. Although the distinction between soluble and colloidal is not clearly defined, in practice the distinction is avoided by operationally defining suspended soilds as the non-filterable fraction after filtration through a filter with 0.45 micron pore diameter. Concentrations in estuaries range from a few mg/ℓ to several g/ℓ during dredging and disposal operations.

3.1.1.4. Turbidity

Turbidity is a measure of the scattering and absorption of light as it passes through water. Turbidity is caused primarily by the presence of colloidal suspended solids in water and can be expressed in Jackson Turbidity Units (JTU), where one JTU is equivalent to the light scattering by one mg/ℓ of silicon dioxide. Other units are also possible (e.g., NTU or FTU).

Turbidity is generally used as a measure of suspended solids concentration; however, correlation is often poor. For this reason, its use is generally not recommended in favor of suspended solids measurements by filtration-gravimetric methods. Turbidity in estuaries range from a few to several hundred JTU's.

3.1.1.5. Temperature (T)

Temperature is an important parameter in estuaries as a determinant of biological and chemical processes and reaction rates and is expressed in degrees Celsius (°C) or degrees Fahrenheit (°F). Temperature affects chemical and biochemical reaction rates by an Arrhenius-type relationship, where the reaction rate approximately doubles for every 10°C increase. Most organisms have adapted to a narrow temperature range, beyond which growth rates are inhibited or the temperature extreme becomes lethal. The solubility of gases in water, including oxygen, nitrogen, and carbon dioxide, decreases with increasing temperature. The physical phenomenon of stratification in estuaries is caused by density differences attributable to the combined effects of temperature and salinity. Temperatures in estuaries are largely dependent on those of inflows and sea water and the mixing regime of the estuary.

3.1.1.6. pH

In aqueous solutions such as natural waters, an important parameter affecting both chemical and biochemical (biological) reactions and processes is the system pH. Specifically, pH is defined as the negative log of the hydrogen ion concentration ($-\log [H^+]$), thus enabling orders of magnitude changes in hydrogen ion concentration to be expressed as whole numbers. Water itself dissociates very slightly into the component hydrogen and hydroxyl ions (i.e., $H_2O \rightleftarrows H^+ + OH^-$), and will have a pH = 7.0, or neutral pH, when the hydrogen and hydroxyl ions are equal in concentration. However, natural waters are a solution of weak acids and bases (among other components) which react with hydrogen and hydroxyl ions and thus usually have a pH other than neutral. Typical fresh waters fall in the pH range 6.5-8.0, while typical sea water is in the pH range 8.0-8.2. The pH in an estuary typically ranges from 7.0 to 8.2 depending on the salinity, or degree of mixing of fresh and sea waters.

3.1.1.7. Oil and Grease

Oil and grease is a collective operational definition of the group of organic substances extractable into an organic solvent. Oil and grease generally includes relatively non-volatile hydrocarbons, such as vegetable and heavier mineral oils, fats, soaps, waxes, greases, and related matter. Results of oil and grease analyses are generally expressed as mg/ℓ total oil and grease.

Due to the insolubility of higher molecular weight hydrocarbons which comprise oil and grease, these organic substances are generally found associated with the sediments and not in the water column of estuaries. Oil and grease substances may also be present as floatable solids since many have a specific gravity less than one.

3.1.1.8. Heavy Metals

This is a general term referring to any of several trace metallic elements with a molecular weight equal to that of chromium or greater. Heavy metals are typically expressed as the concentration of the element of interest in mg/ℓ (ppm) or μg/ℓ (ppb). Elements of interest that are commonly considered to be heavy metals include (but are not necessarily limited to) Hg, Cd, Zn, Cu, Ni, Pb, Ag, Co, Fe, Mn, and Cr. Of these elements, possibly all except Hg and Cd are required as trace nutrients by most organisms. However, if present in excessive concentrations they may become toxic, inhibiting physiological functions and eventually causing death. Typical soluble sea water concentrations of these elements are summarized below (Brewer, 1975):

Element	Concentration, μg/ℓ
Hg	3×10^{-2}
Cd	0.1
Zn	4.9
Cu	0.5
Ni	1.7
Pb	3×10^{-2}
Ag	0.04
Co	0.05
Fe	2
Mn	0.2
Cr	0.3

In fresh waters, heavy metals concentrations exhibit wide variations, but are generally greater than those in sea water. Ranges and typical values of soluble metals for U.S. rivers are summarized below (Kopp and Kroner, 1967; Turekian, 1971):

	Concentration	
Element	Range, μg/ℓ	Typical, μg/ℓ
Hg	<0.1-17	0.07
Cd	<0.1-80	1.0
Zn	1-800	20
Cu	0.9-12	7
Ni		0.3
Pb		3
Ag	0.1-0.55	0.3
Co	0.037-0.44	0.2
Fe		<1
Mn	<1-180	7
Cr	0.1-2.46	1

High concentrations in fresh waters often are indicative of man-caused sources. In estuaries, concentrations of heavy metals are usually intermediate between those of fresh and sea waters, although man-caused sources may increase levels in proportion to input. In addition, heavy metals associated with particulate matter may significantly increase the heavy metal burden in the water column. Overall, the variability of heavy metals concentrations in both time and space necessitates a field sampling program to adequately characterize a particular estuary.

3.1.1.9. Total Organic Carbon (TOC)

TOC is a gross measure of the concentration of organic carbon in a water. On unfiltered samples, TOC represents the summation of suspended particulate organic carbon and soluble organic carbon. On filtered samples, TOC represents "soluble" organic carbon, or carbon in the filtrate comprised of both soluble and colloidal organics. This parameter is usually expressed as concentration of carbon in mg/ℓ. Total organic carbon is often used to deduce organic pollutional loading as a surrogate for BOD. However, correlation is often poor, especially when the quantity of non-biodegradable organic materials becomes a significant fraction of the total organic carbon concentration. Refractory organics are primarily humic substances (humic and fulvic acids) which result from the degradation of plant materials. Soluble TOC may be used to estimate the heavy metal complexing capacity of waters.

Sources of organic carbon include land run-off, biological processes and municipal and industrial wastes. In an estuary, TOC levels are influenced by inflows of fresh waters, sea water concentrations, and point and non-point sources. In nearshore sea water, soluble TOC values range from about 0.5 to 1.0 mg/ℓ and particulate TOC values from 0.1 to 1.0 mg/ℓ or greater, depending on planktonic biomass. Fresh water TOC concentrations are more variable and greater in magnitude. Dissolved TOC values in fresh water streams and rivers ranges from about 1.0 to 10 mg/ℓ, while particulate TOC's may reach 50 mg/ℓ or greater in polluted waters or bogs.

3.1.1.10. Toxic Organics

Toxic organics is a general term for toxic synthetic organic compounds, including biodegradable materials (e.g. phenols, alcohols, certain pesticides) and biologically resistant materials (e.g. chlorinated hydrocarbons and pesticides, PCB's, vinyl chloride derivates). Toxic organics are expressed as the concentration of material of interest in μg/ℓ.

Thousands of organic chemicals are routinely synthesized and manufactured in the petrochemical industry. Of those released to the environment, the halogenated hydrocarbons are of primary interest because of their extreme toxicity, resistance to biological degradation, and tendency to accumulate in organisms and food webs. Two groups of chlorinated hydrocarbons comprise the bulk of these compounds, DDT (and derivatives) and PCB's. Concentrations of these two groups of materials are often determined because of their ubiquitous nature in the aquatic environment. Background concentrations of PCB's have been found to be about 0.02 μg/ℓ, and those for DDT and residues less than 0.001 μg/ℓ, in the Atlantic Ocean (Goldberg, 1975). In fresh waters, chlorinated pesticide residues in major U.S. rivers have been found up to 0.20 μg/ℓ, but are typically less than 0.10 μg/ℓ (ACS, 1969). PCB levels are also greater in most fresh waters than in sea water. Estuaries may be expected to exhibit intermediate levels of toxic organics between those of sea water and fresh water inflows. However, sources of these organic compounds within an estuary may increase their concentration over that from inflows and sea water alone.

3.1.1.11. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

BOD and COD are measures of oxidizable organic matter concentration in water with BOD determined by biochemical oxidation and COD by chemical oxidation procedures. These parameters are expressed as the mg/ℓ of oxygen (BOD test) or the oxygen equivalent of the oxidizing agent (COD test) to fully oxidize the organic matter.

BOD and COD are collective parameters used to assess several factors, including the presence of organic pollutional sources, the oxygen demand of organic materials and the total concentration of organic matter in the water. For the latter factor, BOD and to a lesser extent COD serve only as estimates since oxidation is incomplete. For this reason, total organic carbon (TOC) may give a more accurate estimate of organic matter concentration. Typical BOD values are less than 5 mg/ℓ in sea water and slightly greater in fresh waters in the absence of gross pollutional sources. Estuaries should have intermediate values of BOD unless significant sources of organic matter are present. Accurate COD measurements in sea water and estuarine waters is difficult, if not impossible, due to interferences from Cl^- ion.

3.1.1.12. Nutrients

Nutrients is a general term referring to the presence of selected elements which limit growth of photosynthetic organisms (particularly algae). This term includes compounds of nitrogen (N), phosphorus (P), carbon (C), and occasionally silicon (Si) and is expressed as the concentration of the compound of interest in mg/ℓ.

Natural waters are nutrient solutions from which aquatic biota must extract elements essential for growth. Such ions as Ca^{2+}, Na^+, Cl^-, and HCO_3- are usually present in excess of growth requirements, while others, like PO_4^{3-} (phosphate) and NH_4^+ or NO_3^- (inorganic nitrogen forms), are often present in quantities deficient for growth. The "law of the minimum", as formulated by Liebig, states that growth is limited by the nutrient present in the least amount relative to the plant's or organism's needs. In fresh waters, the limiting nutrient is usually phosphorus or nitrogen and occasionally carbon. In sea water, silicon may also be a limiting element. Nitrogen is usually limiting in estuaries. Typical concentrations of these nutrients are summarized as:

	Concentration (mg/ℓ)	
Nutrient	Fresh Water	Sea Water
N (excluding N_2)	0.1-3	0.2
P	0.01-0.1	0.06
C (organic)	0.1-10	0.3-1.0
Si	0.5-15	2.0

Estuarine waters will typically have concentrations between the fresh water and sea water concentrations.

3.1.2. Important Chemical Cycles

3.1.2.1. Carbon and Oxygen

The carbon cycle in estuaries involves a balance between organic carbon inputs and degradation. The input primarily occurs from algal growth and land sources (non-point, municipal, industrial) which contribute both particulate and soluble carbon. The degradation of these organics is dominated by heterotrophic bacterial metabolism and zooplankton. The typical steady-state concentrations range from 1 to 10 mg C/ℓ depending on the relative input rates.

The carbon cycle is particularly important due to its direct influence on oxygen concentrations. The mineralization of the organic carbon utilizes dissolved oxygen with a typical stoichiometry of 2 to 3 mg O_2/mg TOC oxidized. The oxygen cycle and the steady-state oxygen concentration is strongly dependent on the mixing with seawater and the reaeration rates since only a small quantity of carbon can result in nearly complete consumption of the dissolved oxygen present.

3.1.2.2. Nitrogen

Nitrogen exists in estuarine waters as ammonia, nitrite, nitrate and organic nitrogen; of these four, nitrates will typically exist in the largest concentrations. However, ammonia will be the most critical form in relation to dredging environmental impacts since it can be both toxic to biota and stimulatory to algal growth. Nitrogen and not phosphorus is considered to be the limiting nutrient for algal growth in estuaries (Ryther and Dunstan, 1971). A concentration of 0.1 mg NH_4^+ - N/ℓ is taken as a typical value to stimulate algal growth, although steady-state values during algal blooms can be considerably smaller. The toxic concentration of ammonia have been listed by the EPA as 0.20 to 2 mg N/ℓ to aquatic life (EPA, 1976) and the water quality criteria is set at 0.02 mg N/ℓ. The toxicity is highly dependent on pH since it is the dissolved NH_3 species, (NH_4OH and NH_3) not the NH_4^+ species, which causes the primary toxic response.

Significant inputs of ammonia come from organic-nitrogen degradation, municipal effluents, diffusion across the benthic interface, and non-point source runoff. Typical steady-state concentrations in the water column would be less than 0.1 mg N/1.

3.1.3. Effect of Increased Inputs from Dredging

3.1.3.1. Parameters Which Have Insignificant Inputs from Dredging

The impact of measured changes in certain common water quality parameters from dredging have been shown not to be significant in most estuarine waters. As such, these parameters do not have to be included in impact assessment for the water column. These parameters include: pH; BOD, COD and TOC; total phosphorus; and oil and grease. No significant changes in acid or base concentrations result from the dredging operation so the pH is not significantly altered. BOD, COD and TOC concentrations are not necessary since dissolved oxygen-reductions are primarily chemical in nature, not biochemical. Since nitrogen limits algal growth, phosphorus inputs are considered insignificant. Oil and grease measurement can be avoided because they are not significantly solubilized from sediments, even from those that have high insoluble oil and grease concentrations.

3.1.3.2. Suspended Solids

One of the most obvious impacts of hydraulic dredging in estuaries is that of increased turbidity or suspended solids concentrations at both the removal and disposal sites. The degree of turbidity and suspended solids increase is a function of sediment properties, dredge equipment and operation, mode of disposal, and site-specific characteristics including water column depth and flow velocity, tidal cycle, and wind velocity.

Many investigators have reported increased suspended solids and turbidity levels from dredging. These results are summarized in Table 3.1. A review of this topic is provided in Appendix C of the S.F. Bay EIS (COE, 1976). May (1973) has reported on the turbidity and suspended solids increase from a hydraulic dredging operation with pipeline disposal. Water depth was about 10 feet MLW. At the water surface, suspended solids exceeded ambient levels (50 mg/ℓ) out to 1000 feet from the discharge, although levels were reduced 98% within 200 feet. At mid-depth, ambient levels were exceeded up to 1400 feet from the discharge with significant increases extending about 400 feet. Along the bottom, density flows of 10,000 mg/ℓ up to 400 feet from the discharge and over 1000 mg/ℓ at least 1800 feet from the discharge were observed.

In the San Francisco Bay Maintenance Dredging EIS (COE, 1975), suspended solids increases were monitored for barge or hopper disposal. Suspended solids increases in the water column depended on the physical properties of the sediments, degree of disturbance, and change in water content prior to release. Intact sediment clumps were found to rapidly settle and mound on the bottom, while disturbed sediments exhibited greater dispersion and lower settling rates. Generally, 95% or more of the solids were found within ten feet from the bottom after disposal, the remainder being dispersed in the water column. Concentrations of suspended solids ranged from about two to nine grams/liter in the lower 10 feet of the water column during disposal operations.

In contrast, suspended solids increases from the dredging and loading operation were in the order of hundreds of mg/ℓ, or one to two orders of magnitude less than at disposal sites. Increases at dredging sites were generally confined to the channel and returned to background levels within several hundred meters. For disposal sites, increases in suspended solids influenced areas outside the

Table 3.1. Summary of Suspended Solids Concentrations Associated with Various Dredging Operations

			Ranges of Suspended Solids (mg/ℓ)[1]	
Source	Phase	Dredge Type	Near Field	Far Field
COE, Appendix C (1976)	Removal	Pipeline	43-70	-
		Clamshell	12-282	-
		Hopper	74-871	-
		Hopper	100-800 (mℓ/ℓ settleable solids in hopper overflow)	-
	Disposal	Hopper	12-750+	-
		Hopper	480-8,700 (adjacent to hopper dredge)	
	Removal & Disposal	Clamshell	29-214	-
May (1973)	Disposal	Clamshell (calm day)	30-250	Negligible
		Clamshell (windy day)	45-677	Negligible
	Disposal	Pipeline	50-4000	Negligible
		Pipeline	100-12,000	Negligible
Jeanne and Pine (1975)	Disposal	Pipeline (pond effluent)		
		coarse material	26-50 JTU	Negligible
		sludges	70-180 JTU	Negligible
Westley, et al., (1973)	Disposal	Pipeline	22-82	Negligible
Krizek, et al., (1974)	Disposal	Pipeline (pond effluent)	460 (total solids)	-

[1] except where noted.

site boundaries for distances extending one thousand meters or more. Both removal and disposal operations were found to have very little influence on the upper water column.

A literature review of the biological impact of suspended solids and turbidity is contained in the San Francisco Bay EIS (COE, 1975). In addition, several laboratory studies were conducted to specifically evaluate biological impacts from sediment disturbance (e.g., Appendix G, S.F. Bay EIS, COE, 1975). Generally, results indicate that even sensitive organisms can tolerate short-term turbidity increases such as typically occur in the upper water column during dredging operation. However, potentially lethal concentrations of suspended solids can occur in dredged channels from "fluff" formation at the sediment-water interface which lasts up to several weeks, and in the high density bottom transport zone during disposal, which may last for several days. In the upper water column, suspended solids will usually reach near background levels in an hour or less.

3.1.3.3. Oxygen-Demanding Materials

Dredging operations lead to the release of organic and inorganic materials which create an oxygen demand within the overlying waters. Under certain conditions, significant reductions of dissolved oxygen concentrations can result during dredging operations (Brown and Clark, 1968; Mackin, 1961; Servizi, et al., 1969; Slotta, et al., 1973; Mauer, et al., 1974). Other investigators (May, 1973) (Wakeman, 1974) (Wakeman and Fong, 1976) (Windom, 1973) (Smith, et al., 1976) have reported cases with no significant oxygen depletions from dredging.

The exact causes of oxygen depletion resulting from dredging operations are unknown even though at least two studies have been completed on the oxygen demand of resuspended sediment (Seattle University, 1970, and Touhey, 1972).

The reported insensitivity of the oxygen uptake rates to both bacterial concentrations and salinity strongly suggest that the majority of the demand is chemical in nature, not biochemical. As a result, BOD and COD values are inappropriate for measuring DO impacts from dredging. The suspended oxygen demand is known to be much larger than the benthic demand of the same sediment (Reynolds, et al., 1973). The most probable species involved are various iron sulfides which are rapidly oxidized to $Fe(OH_3)$ and sulfur. The theoretical oxygen demand is 0.75 mg O_2/mg FeS-S. Since the FeS-S content of sediments can be several g/kg, the suspended oxygen demand may be large.

The adverse impacts of low dissolved oxygen concentrations on a variety of pelagic and benthic organisms is well documented. The depletions of oxygen associated with dredging can be of a significant magnitude, but are usually of short duration. No simple methods are presently available to predict what the depletion magnitude will be. The significance of this change will depend on the depletion, the duration and the resident biota. As such, impact assessment requires a considerable amount of professional judgement. Potential dissolved oxygen impacts should be discussed for all dredging projects which involve high-organic sediments, poor water column mixing, or long project durations.

3.1.3.4. Nutrients

Nutrients in the various chemical forms of nitrogen and phosphorus are released from dredge materials; however, ammonia is the only nutrient for which significant increases in ambient concentrations will occur. Cronin, et al., (1970) reported increases near the discharge plume up to 50 times ambient total nitrogen levels. No immediate increase in phytoplankton was observed. Windom (1973) also reported large releases of nutrients in his studies of five estuaries on the southeastern coast of the United States. However, in contrast to Cronin's results, significant algal growths were reported when dredge spoils were placed with the receiving waters in closed bottle experiments. Stimulation of algal growths were also noted at the dredging sites from light-dark bottle experiments. Thus, phytoplankton stimulation may or may not be significant. Factors such as the localized nature of most dredging projects and the large dispersion in most estuaries will reduce the potential of serious environmental problems from nutrient stimulation.

3.1.3.5. Heavy Metals and Trace Elements

In considering the impact and effects of heavy metals in the aquatic environment, two factors must be considered. First, all heavy metals and trace elements are present at a background level independent of man's influence. Second, the impact from increases in concentrations of these elements must be evaluated in terms of effects on some component in the environment, usually the biota. Background concentrations of many heavy and trace elements were summarized in the "Description of Parameters" section. Man-made sources of these elements, their transport and distribution, biological effects, and release during dredging will be summarized as related to the estuarine environment.

Man-made input of heavy metals to the aquatic environment includes point and non-point sources. Point sources are the direct imput of industries and municipalities to receiving streams, and have been well quantified for most sources. For municipalities receiving combined domestic and industrial wastes, the studies of Chen, et al., (1976), Klein, et al., (1974), and Mytelka (1972) provide concentrations of heavy metals in wastewaters and sludges. Klein et al., (1974) also presents effluent heavy metal concentrations from a variety of individual industries. General values for metals and other pollutants in industrial wastes may be estimated with reference to industrial waste text books (e.g., Nemerow, 1971) or monographs for particular industrial wastes or metals (see Literature Review Issue, Water Pollution Control Federation Journal, annual June issue). In addition, effluent guidelines and standards for industrial point source discharges have been established by the EPA pursuant of PL 92-500 (Federal Water Pollution Control Act Amendments of 1972), Sections 306 and 402. All major industrial categories are included.

Non-point sources of heavy metals to the aquatic environment include urban storm water runoff, agricultural drainage, and air pollution fallout or rainout. Quantification of these disperse inputs is difficult and often made by difference from measured versus predicted concentrations. The World Health Organization has convened a series of workshops on "Hazards to Health and Ecological Effects of Metals and Metalloids in the Environment". Sources, turnover, and ecological effects of metals such as cadmium, mercury, and lead have been summarized (WHO, 1973). Similarly, for the marine environment, concentrations of heavy metals and other pollutants and deficiencies in our knowledge have been summarized by the International Decade of Ocean Exploration (IDOE) Baseline Conference in 1972, as reported by Goldberg (1975). Goldberg (1975) has summarized environmental fluxes of mercury and lead, and marine fluxes of other heavy metals including chromium, zinc, copper, silver, vanadium, cadmium, nickel, cobalt, maganese, iron, and molybdenum. Bowen (1966) has summarized much of the available data on heavy or trace elements in the environment, while the monographs of Fulkerson (1975) and Friberg (1971, 1972) contain extensive data on cadmium and mercury in the environment. Lazrus et al, (1970) have reported concentrations of heavy metals (Pb, Mn, Cu, Zn, & Ni) in U.S. rainfall.

Estuaries may serve as a sink of heavy metals and trace elements from riverine inputs and either as a source or sink of these elements for the coastal marine environment. Generally, most soluble heavy metals are adsorbed, complexed, or precipitated on particulate matter and then become associated with the sediments from flocculation and gravitational effects. Close correlation has been found between particle size and heavy metal content, with the higher specific surface area fine particles being more effective scavengers and thus containing higher concentrations. Gibbs (1973) has attributed most of the heavy metal transport in rivers to particulate matter. De Groot, et al., (1973) studied the transport of lead, chromium, copper, arsenic, mercury, cadmium, zinc, and nickel in rivers, estuaries, and the sea and concluded that these metals are primarily fixed to particulate matter in the river, but become mobilized to varying degrees in estuarine and seawater environments. Mercury and cadmium were found to be greater than 90 percent mobilized, with high mobilization also found for copper, zinc, lead, chromium, and arsenic. Nickel was mobilized to an intermediate level, while maganese and some ultra-trace elements were not mobilized. The lower level of mobilization of nickel and maganese may reflect its mineralogic rather than man-made origin. Windom (1976) found that dissolved concentrations in the water column of rivers and estuaries did not reflect heavy metal inputs from industries, but that heavy metals rapidly became associated with particulate matter and sediments. Estuaries were found to act as sinks of iron and maganese and probably other heavy metals. In contrast, Turekian (1971) has summarized the transport of metals in rivers and estuaries and concluded that estuarine sediments are a sink for most metals and a source of iron and manganese for the near shore waters.

Biological organisms, particularly microbiota are known to concentrate heavy metals and trace elements at factors up to several thousand times their ambient concentration in the water column. Brewer (1975) has summarized elements accumulated by phytoplankton to levels at least 1000 times those in sea water. The list includes the heavy metals Cd, Cr, Ca, Co, Fe, Pb, Mn, Ni, Ag, Zn and other elements. Merlini (1971) has summarized enrichment factors of trace elements in shellfish and other marine organisms compared with the marine environment. Scallops, as an extreme example, are reported to concentrate cadmium by 2×10^6 and mussels, by 10^4, times sea water concentrations. Since estuarine water column and sediment concentrations of heavy or trace elements are generally several times those in open sea water, the potential impact is apparent. Pringle, et al. (1968) studied uptake of lead, copper, cadmium, and zinc by mollusks and found that rate of uptake and tissue level attained varied with both time of exposure and ambient concentration. Depletion was found to be slow, thus indicating the potential for long-term acute effects due to accumulation. Recently, Luoma, et al., (1974, 1975a, 1975b) have studied the uptake of artificial sediment-bound heavy metals (Hg, Cd, Co, Ag, Zn) by deposit feeders. Metal uptake (bioavailability) was found to vary significantly among sinks (e.g., organic detrital bound, metal oxide bound, calcium carbonate bound) for the same metal, or to vary significantly within a given sink among metals. Gambrell, et al., (1976) have demonstrated the importance of pH and oxidation-reduction potential on the mobilization and bioavailability of heavy metals in waters and sediments. These studies demonstrate the importance of physical-chemical form as a determinant of metal uptake and availability. Rather than correlating with total sediment analyses, bioavailability of heavy metals probably correlates to a greater degree with selective physical and chemical extractions which are directly related to the biogeochemical properties of the metal (TM 3.2.6.). Since good correlations have not yet been developed, long-term bioassays are presently the only method of assessing this potentially significant impact (TM 5.13).

Windom (1972) monitored the release of iron, copper, zinc, and mercury during dredging operations in a salt marsh estuarine environment. No metals were found to be released with the exception of mercury, which was released at the disposal site, possibly due to volatile mercury compounds. Sediment composition was not found to be related to water quality changes. May (1973) reported on the water quality effects of hydraulic dredging in an estuary. No increase in the soluble concentration of mercury, lead, zinc, cadmium, and chromium was found at the open water estuarine disposal site. Jeane and Pine (1975) found no release of mercury during a port dredging operation. In general, field monitoring studies have not documented any significant release of heavy metals to the water column.

3.1.3.6. Toxic Organics

Toxic organic compounds in natural aquatic environments are comprised primarily of two halogenated hydrocarbon groups, DDT and its analogs (DDD, DDE), and polychlorinated biphenyl's (PCB's). Of increasing significance are the ubiquitous low molecular weight halogenated hydrocarbons, including chloroform ($CHCl_3$), carbon tetrachloride (CCl_4), vinyl chloride derivatives, and fluorocarbons (Freons). Goldberg (1975) and Risebrough (1971) have summarized sources of these materials and their concentrations, transport, and effects in the marine environment.

DDT and its analogs are insecticides used in agricultural and public health applications. Peak concentrations and distribution of DDT compounds in natural environments was probably in the late 1960's and early 1970's, as strict regulations have largely eliminated their use in the U.S. and Western Europe.

PCB's are highly chlorinated synthetic compounds with several important industrial uses because of their unique properties of high stability, non-inflammability, low water solubility, low volatility, high dielectric constant, and plasticizing ability. Applications of PCB's include dielectric fluids in capacitors and transformers, hydraulic fluids, and plasticizer and extender fluids in adhesives, sealants, paints, and printing inks. Although PCB's are still widely used, Monsanto Chemical Corporation (the sole producer) limited sales to closed systems in 1970 to help control its distribution in the environment.

The principle transport path for DDT's, PCB's, and low molecular weight chlorinated hydrocarbons is through the atmosphere. Significant volatilization of these compounds has been found in soil and water systems and has led to essentially complete (though not necessarily uniform) distribution throughout the world, even in areas far removed from direct applications. Subsequent to volatilization, fallout with rain or air particulates, as well as typical municipal and industrial point sources, introduces these compounds to the aquatic environment. Residence times for these compounds in the water column is believed to be relatively short. Associations with living organisms and sorption on particulates leads to these compounds becoming predominantly sediment-bound in estuaries.

Goldberg (1975) has summarized concentrations of DDT compounds and PCB in marine organisms. In general, both plankton and fishes have concentration factors or from 10^3 to 10^7 over ambient levels, with PCB's being more highly concentrated than DDT compounds. Open sea water concentrations of PCB's are in the order of 0.01-0.05 μg/ℓ while DDT compounds are less than 0.001 μg/l.

Goldberg (1975) has summarized toxic limits of DDT compounds and PCB's on marine organisms, while Risebrough (1971) has summarized food chain effects with particular emphasis on marine birds. Toxicity threshold limits for acute (lethal) effects are generally in the few μg/l range for these compounds. This concentration, is attained in natural aquatic systems only in the most heavily polluted areas. However, long-term chronic effects and food chain effects are not quantifiable by short-term toxicity testing and are presently not evaluated, but generally are thought to occur at orders-of-magnitude lower concentrations.

Young (CWRP, 1976) has studied the fate of DDT compounds in the Southern California bight off Los Angeles. DDT entered this coastal environment primarily from a sewage treatment plant outfall which directly received DDT in effluent from an industrial manufacturer. Sediments in the region are highly contaminated, indicating the tendency of these materials to be scavenged from the water column. Despite a 90 percent reduction in the quantity released over the last five years, the persistence of DDT compounds is evidenced by the fact that virtually no change has been detected in the sediment concentrations. Two bottom fauna, crabs and flatfish, concentrated DDT compounds by a factor of 100, with 70 percent of the flatfish (Dover sole) exceeded Federal limits of 5 ppm.

In an investigation of the environmental effects of a dredging project, May (1973) was unable to detect the release of DDT compounds during disposal. However, concentrations in the sediments were near the detection limit, indicating a low contamination level. Other studies of DDT and PCB compounds released during dredging operations have dealt primarily with fresh water environments which do not correlate directly with estuarine effects.

3.1.4. Elutriate Test and Other Laboratory Simulations

The purpose of the Elutriate Test is to quantitatively measure metals and organic compounds solubilized during dredging operations. Results from the test are evaluated after allowing for dispersion in the receiving water (TM 2. Hydrodynamics and Circulation). Concentrations of constituents after dilution should not exceed applicable water quality criteria. Generally, the following materials should be considered for analysis in an elutriate test: organohalogen compounds, mercury and mercury compounds, cadmium and cadmium compounds, lead, silver, maganese, cobalt, nickel, arsenic, copper, zinc, organosilicon compounds, cyanides, fluorides, pesticides and their by-products, oil in any form, radioactive materials, known or suspected carcinogens, nutrients (nitrogen and phosphorus) and major constituents which could cause unacceptable oxygen demand.

3.1.4.1. Summary of Elutriate Test Procedure

The elutriate is the supernatant resulting from the vigorous 30 - minute shaking of one part bottom sediment from the dreding site with four parts water (vol/vol) collected from the dredging site followed by one hour setting time and appropriate centrifugation and a 0.45 micron filtration. Details on the procedures for performance of an elutriate test, including number of samples, sample collection and preservation, apparatus, and test procedure (step-by-step) have been published by the Corps of Engineers Waterways Experiment Station (COE, 1976).

3.1.4.2. Factors Influencing Elutriate Test Results

Lee, et al., (1976) have summarized factors which could influence results of the Elutriate Test. These are sediment-water ratio, shaking time, method of agitation, sample size, settling time, sediment storage time, salinity, type of water, and oxygen status of the test. In sorption-desorption studies similar to the Elutriate Test, Serne and Mercer (1975) identified five parameters as having significant influence on one or more metals. These were oxidation-reduction potential, salinity, agitation time, solids-to-solution ratio, and sediment type. O'Connor (1976) found dissolved oxygen concentration and pH to be important variables and also found that the amount of clay-sized particles in the sediment correlated with the release of metals. Thus, the physicochemical conditions of the Elutriate Test must be closely monitored and controlled to enable meaningful interpretation of results.

The studies by Lee, et al., (1976a, 1976b) on the factors affecting the Elutriate Test showed the current procedure to be adequate except for two conditions which should also be modified. These are that compressed air agitation for 30 minutes should replace the 30 minute, non-aerated, agitation period, and that the sediment-to-water volumetric ratio should be decreased from 1 to 4 (20 percent) to 1 to 20 (5 percent).

3.1.4.3. Elutriate Test Results

Lee, et al., (1976a) performed elutriate tests and evaluated the influence of factors on test results for sediments samples from about twelve harbor areas. Parameters measured were ammonia, nitrite, organic nitrogen, total phosphate, soluble orthophosphate, zinc, copper, nickel, manganese, iron, lead, chromium, mercury, cadmium, arsenic, oil and grease, turbidity, dissolved oxygen, pH, salinity, and temperature. Chlorinated hydrogen pesticides and PCB's were measured in a subset of these samples and only in the standard procedure. In general, the results showed a correlation between only one soluble constituent, the ammonium ion, and its bulk sediment concentration. No correlation was found for phosphorus or the metals measured. Only two compounds or elements, ammonia and manganese, were released in potentially significant concentrations in all of the sediments tested.

O'Connor (1976) reported Elutriate Test results for sediments from the Washington, D.C., Navy shipyard. Cadmium, copper, and zinc releases were studied under varying pH and dissolved oxygen conditions. High concentrations of zinc were found to be released and were attributable to pH decrease during the test. Aeration was found to maintain pH and reduce zinc solubility. The controlling mechanism under aerated, neutral pH, conditions was proposed to be ferric hydroxide, which forms from the oxidation of released ferrous iron and scavenges released heavy metal ions.

The discharge of dredged materials in navigable waters, as regulated by provisions in Section 404 of PL 92-500 (Federal Water Pollution Control Act Amendments of 1972), and discharge into ocean waters, a regulated by Section 103 of PL 92-532 (Marine Protection, Research, and Sanctuaries Act of 1972) and Revisions, (EPA, 1977) may require performance of the Elutriate Test to evaluate water quality effects. Recent environmental impact statements for dredging projects, particularly those for Corps of Engineers projects, will contain the same essential information derived for discharge permits, and thus are a source of Elutriate Test results.

In the Environmental Impact Statement for Maintenance Dredging in San Francisco Bay (COE, 1975), Elutriate Tests using a 1 to 10 dilution factor were performed on a variety of sediments from geographically varied areas in the bay. Parameters measured included mercury, copper, cadmium, lead, zinc, oil and grease, and organohalogens (toxic organics). Increases in soluble metal concentrations were generally less than 50 percent, with decreases found for some samples. Lead was released in greater quantity, with increases up to 200 percent of ambient concentration. In one sample, the cadmium releases averaged 500 percent. Organohalogens averaged about 50 percent release in most samples tested, with one sample having a six-fold increase. PCB's ranged up to 6 ppb in the elutriate, while DDT compounds were two to three orders of magnitude lower in concentration.

Elutriate Tests were also performed on sediment samples for the Maintenance Dredging Project, Sabine - Neches Waterway, Texas, and are contained in the EIS of that name (1975). Parameters measured included total Kjeldahl nitrogen (TKN), arsenic, cadmium, lead, mercury, nickel, and zinc. Increases in the concentrations of these metals were found to be up to ten times their background levels, although generally the increases were from zero to three times. TKN increased up to 30 times its background level and is potentially the most harmful acute effect (ammonia toxicity).

Chen, et al., (1976) conducted 48 hour resuspension tests under varying oxidation-reduction conditions which should correlate somewhat with Elutriate Test results. Parameters measured included iron, manganese, mercury, copper, lead, chromium, zinc, arsenic, cadmium, nickel, silicate, sulfide, nitrate, nitrite, ammonium, organic nitrogen, orthophosphate, and chlorinated hydrocarbons. Changes in concentration over ambient (seawater) levels were negligible for silver, cadmium, and mercury. Chromium, copper, and lead increased from three to ten times, while iron, manganese, and zinc showed even greater increases. Changes in concentration were greater for fresh water than seawater. Nitrogen and phosphorus release was greatest for silty-clay type sediments. TKN reached 10 mg/ℓ under anaerobic conditions while nitrite and nitrate nitrogen attained the same level under aerobic conditions. Phosphate was released from 0.1 to 0.8 mg/ℓ under all conditions. Soluble silica increased to 10-20 mg/ℓ. Chlorinated hydrocarbons were not released in these studies.

Serne and Mercer (1975) conducted sorption-desorption studies under varying conditions to measure the release of selected heavy metals. Metals tested were cadmium, copper, iron, lead, zinc, and mercury. Results showed that oxidation-reduction potential had the greatest effect on fate of the metals. Concentrations of copper, cadmium, lead, and zinc increased under aerobic conditions while that of iron decreased. Iron increased under reducing conditions. Increasing salinity increased cadmium and zinc concentrations in aerobic conditions, iron concentrations in anaerobic conditions. Increasing the length of agitation time increased cadmium, copper, and zinc release under oxidizing conditions. Greater solids concentration (increasing sediment-to-water ratio) increased release of copper and iron in oxidizing or reducing conditions. Overall, under oxidizing conditions, cadmium, copper, lead, and zinc increased concentration in the water column from 30 to 200 percent while iron increased two to four times. Under reducing conditions, iron concentration increased 50 to 3000 times. Prediction equations were developed correlating the variables in the study (oxidation-reduction potential, salinity, agitation time, solids-to-solution ratio and sediment type) with release of metals. Correlation was generally poor, with correlation coefficients for the multiple regression analysis between 0.40 and 0.69 for all metals but mercury. Semi-selective chemical extraction indicated that a large fraction of all metals but cadmium are found in the residual phase which represents metals bound in mineral lattice sites. Organic and sulfidic phases, as determined by hydrogen peroxide digestion, contained most of the cadmium and significant fractions of the remaining metals except iron. Iron would normally be expected to be largely associated with these phases under reducing conditions. Chemical extractions to release metals associated with hydrous oxide phases contained insignificant amounts of metals.

Brannon, et al., (1976) used selective chemical extractions to correlate the geochemical partitioning of manganese, cadmium, arsenic, zinc, and nickel in sediments with the concentration in the standard elutriate. Manganese released was found to correlate with manganese in the interstitial water, exchangeable phase, and easily reducible phase. Zinc correlated with the easily reducible phase and the organic plus sulfide phase. Arsenic and nickel did not correlate with any phases. In general, metals in the sediment phases thought to be most mobile were related to their concentrations in the standard elutriate, while no relationship existed between total metal concentration in the sediment and that found in the standard elutriate.

Fulk, et al., (1975) studied the release of DDT group compounds and PCB's from natural sediment samples in laboratory tests. In 24-hour resuspension tests, soluble or particulate-associated DDT and PCB compounds were not detectable (less than 0.03 ug/l background level) for sediment-to-water ratios (weight/weight) of 1:10 or less. Thus, under the conditions of these tests, short-term release of these materials during dredging is apparently insignificant. This is in general agreement with Chen, et al., (1976) and Lee, et al., (1976b) results.

In summary, elutriate test results have generally shown no significant release of soluble heavy metals and toxic organics when dilution factors are considered. A few isolated samples have shown sufficient release of heavy metals to warrant concern where mixing and dispersion at the disposal site are limited. Manganese and ammonia are most consistently released at levels that could cause acute toxicity and should be monitored in all elutriate tests.

The development of reliable correlations between the geochemical partitioning of heavy metals in the sediments and their concentrations in the standard elutriate would add greatly to the understanding and interpretation of results. More studies on selective extractions and correlation with standard elutriate and possibly bioavailability are needed.

Revisions in the elutriate test procedure should be implemented to aid in the repeatability and reliability of results. In particular, the importance of redox conditions on test results has been demonstrated by several investigators. Aeration of the sample, as suggested by Lee, et al., (1976a), would probably resolve this problem.

It should be emphasized that the Elutriate Test attempts to measure only the short-term, immediate, release of soluble chemical constituents to the water column caused by hydraulic resuspension of sediments. It does not evaluate long-term release of soluble constituents, resuspension of particulate-associated toxic substances and contaminants, and bioavailability of solubilized or particulate-associated substances.

3.2. SEDIMENT QUALITY

3.2.1. Sediment Parameters

The various constituents of the sediments can be divided into two categories: bulk parameters and interstitial water parameters. In relation to dredging, the interstitial water constituents can be potentially released to the water column with high mixing. In contrast, the bulk constituents which represent both the particulate and dissolved phases will only be released to a partial degree depending on the degree of association with the particulate fractions.

3.2.1.1. Bulk Parameters

Total Volatile Solids. Total volatile solids is that portion of the sediment which can be combusted at 550°C. This parameter is typically used to represent the organic content of the sediments and is expressed as g/kg or as as percentage.

Total Sulfides. Total sulfides represents the quantity of sulfides (precipitated and soluble) that is released under a mild acid treatment. The majority of this sulfide is present as amorphous iron sulfides (FeS). Values typically range from 0 to several thousand mg S/Kg.

Reduced Sulfide Capacity. The reduced sulfide capacity represents the quantity of sulfides that can be precipitated by a sediment. As the total sulfides approach the RSC, then free sulfides will occur in the interstitial water. Values of the RSC range from 0 to several thousand mg S/Kg. This parameter does not correlate with total iron or acid soluble iron.

Metals. All the various heavy metals can be measured as a bulk concentration (mg/Kg) by destructive digestion of the sediment in strong acid.

Oil and Grease. Oil and grease is measured as those compounds which can be extracted with an organic solvent. In undeveloped or only lightly developed estuaries, oil and grease levels in the sediments should be less than 50 ppm. In developed estuaries, concentration may reach several thousand ppm in the sediments. Sources of oil and grease substances will include spill from shipping activities, municipal outfalls, and industrial effluents.

3.2.1.2. Interstitial Water Parameters

The interstitial water parameters of interest have been described in the section on water column parameters (TM 3.1.1.) except for free sulfides.

Free Sulfides. Free sulfides is a measure of the total concentration of H_2S, HS^- and $S^=$. This measurement is readily accomplished with specific ion electrodes and is expressed as mg S/ℓ.

3.2.2. Important Chemical Cycles

Inorganics and organics are deposited in estuarine benthic systems. Inorganics including sands, silts and clays, are introduced into estuaries from the ocean, upstream rivers and localized runoff. Organics originate from sources outside the estuary and from primary production within the estuary.

The significant chemical transformations with respect to the carbon, sulfur and nitrogen cycles are primarily mediated by bacterial metabolism with carbon from the deposited organics acting as the primary electron donor. However, the type of bacterial decomposition occurring at any location is determined principally by the availability of electron acceptors. When available, dissolved oxygen is used as the electron acceptor. In its absence and with corresponding low Eh conditions, sulfate becomes the principal electron acceptor. Nitrate reduction, which will occur before sulfate reduction, is usually not significant because nitrate concentrations are nearly always far less than sulfate concentrations within estuarine systems. The effect of various inputs on the carbon, sulfur and nitrogen cycle will be described in the following sections.

The availability of exogenous electron acceptors (DO and sulfates) depends on the transport of overlying waters within the deposits. The transfer occurs primarily by physical turnover of the deposits and molecular diffusion. Dredging and the associated ship traffic in dredged channels can result in increased turnover rates which will affect the availability of electron acceptors and, subsequently, the sediment chemistry. This can contribute to several important environmental impacts.

3.2.2.1. The Carbon Cycle

Sediment carbon primarily results from the deposition of debris from the water column. The subsequent oxidation of this carbon in the sediments is termed diagenesis of carbon (see Berner, 1971). A brief description of those aspects important for dredging impacts is described in this section.

Sediment carbon in estuaries originates primarily from phytoplankton growth during the summer and from terrestrial inputs during the winter (Seki, et al., 1968). In some southern estuaries, marsh plants represent significant sources of organic materials. Increased industrialization of estuaries undoubtably results in increased inputs of organic carbon from municipal and industrial discharges and especially non-point sources (Field and Lager, 1975). These carbon inputs strongly influence both the biological community and physical stability of the sediments within the estuary.

Although dredging is not a source of organics, it can significantly alter the spatial distribution of organics in sediments. Organics will collect with inorganic fines in those areas of poor mixing in the water column (Postma, 1967); dredging creates many locations of poor mixing such as shipping channels, turning basins and boat basins. Thus dredging can result in the concentration of organic carbon into localized areas.

The sedimentary organic carbon is primarily oxidized by microrganisms to intermediate organics or carbon dioxide with subsequent formation of reduced inorganic compounds. The oxygen is transferred from the water column for both aerobic bacterial metabolism and oxidation of reduced inorganic compounds and thus the sediments represent a dissolved oxygen sink. High organic carbon contents result in high oxygen consumption rates (Edwards and Rolley, 1965) with the highest rates of approximately 10 g O_2/m^2-day.

In anaerobic estuarine sediments, the carbon is primarily oxidized by sulfate-reducing bacteria or by fermentative organisms. Both reactions result in the formation of CO_2; fermentative reactions also result in reduced organics such as organic acids and methane. Thus, the mineralization of carbon occurs by several different mechanisms depending on the depth into the sediment. The type of mechanism can greatly alter the chemical characteristics of both the sediment and its interstitial water.

Most of the organic carbon in sediments will be refractory in nature, that is, it will exhibit very slow degradation rates. Foree and McCarty (1969) suggested that a rate of less than 1% degradation per year was typical for algal debris. Terrestial inputs would probably have a much lower rate due to the long times of degradation before it reaches the estuary. Thus a sediment can exist with very high organic carbon contents and have very low rates of microbial degradation. This reason explains why total volatile solids may be a poor indication of the potential rates of decomposition of a particular sediment.

3.2.2.2. The Sulfur Cycle

The dissolved oxygen in the interstitial water will decrease with depth and, if adequate organics are present, will decrease to near zero. Sulfate reduction then will proceed below the aerobic region. The reduction of sulfates by heterotrophic sulfate-reducing bacteria which utilize the sulfate ion as a terminal electron acceptor (Baas-Becking and Wood, 1955), results in the release of hydrogen sulfide which is found in solution as H_2S, HS^- or $S^=$, depending on the pH. In the present discussion, all components of the above relationship will be defined as "free sulfide". At a pH of 6.5-7.0, the free sulfide is approximately evenly divided between H_2S and HS^- with $S^=$ being negligible. Free sulfides are also produced during anaerobic putrification of sulfur containing amino acids, but normally this process is of negligible importance in the marine environment (Cline and Richards, 1969; and Fenchel, 1969).

Free sulfides form insoluble compounds with heavy metals, particularly iron. Free sulfides quickly react with available iron within the deposits to form ferrous sulfide, FeS (Berner, 1969). The input of this iron into the deposits results primarily from the deposition of insoluble inorganics which contain ferric oxides and other insoluble forms of iron (Berner, 1967). Not all of this iron, however, is available to react with the sulfides. Other heavy metals such as zinc, tin, cadmium, lead, copper and mercury all have solubility products significantly below that of ferrous sulfide which indicates that ionic concentrations of these metals within the interstitial waters are not likely to be significant. However, the distribution of heavy metals between the crystalline phase, the adsorbed phase, the organic phase, precipitates and free ionic species is largely unknown for high organic, sulfide-bearing sediments.

Free sulfide concentrations within benthic deposits will remain at low levels (generally below 1 mg/l) when available iron is present. If available iron is sufficiently depleted, free sulfides within the anaerobic regions of deposits will increase until their production at a given location is balanced by the advective and diffusive transport out of that location and by the loss caused by reaction with any remaining available iron. Thus, when the available iron is consumed, free sulfides may diffuse to the aerobic regions of the deposits and into the overlying waters. The available iron can be measured as "reduced sulfide capacity-RSC" (Williamson and Bella, 1975). Physical disruption such as dredging of the deposits may also lead to the release of free sulfides.

Within aerobic regions, free sulfides will be oxidized (Cline and Richards, 1969; Chen and Morris, 1971; and Ostlund and Alexander, 1963). Half lives of free sulfides in aqueous solutions have been reported from 15 minutes to 70 hours. Several studies have described the oxidation of free sulfides to occur via second order kinetics (Cline and Richards, 1969; and Chen and Morris, 1971); however, in natural environments such a description is a simplification of an extremely complex chemical reaction for which temperature, pH, and initial oxygen and sulfide concentrations are all factors affecting the rate of oxidation. The oxidation of free sulfides is catalyzed by the presence of metallic ions, such as Ni, Mn, Fe, Ca, and Mg, and is accelerated by some organic substances such as formaldehyde, phenols and urea. Thus, the oxidation of free sulfides in estuarine and marine water may be much more rapid than in distilled water due to the presence of catalysts. Within oxygenated sea water the half life of sulfide has been reported to vary from ten minutes to several hours (Cline and Richards, 1969; Ostlund and Alexander, 1963). Studies indicate that estuarine waters stored for a period of time after collection will display slower oxidation rates of free sulfides than freshly collected waters (Korpalski, 1973). Since HS^- predominates at the pH of sea water, it has been proposed that the oxidation proceeds by the following reaction (Richards, 1965):

$$2HS^- + 2O_2 \rightarrow S_2O_3^= + H_2O.$$

Following the above chemical oxidation, the thiosulfate ion is more slowly oxidized to sulfate, probably with the intermediate production of other oxidized forms. Sulfur oxidizing bacteria of the genus Thiobacillus appear to be important in this final oxidation step (Ivanov, 1968) (Sorokin, 1970).

If the deposits are physically overturned or flushed with oxygenated water, ferrous sulfide will be oxidized. The oxygenated overturned sediments will normally return rapidly to anaerobic conditions. A portion of the oxidized ferrous sulfide iron will be returned to the sediment as available iron which can further react with free sulfide to form more ferrous sulfide. Thus overturning or flushing of sediments leads to a recycling of available iron.

The oxidation of ferrous sulfide (FeS) results in the formation of elemental sulfur (Leckie, 1975) (Williamson and Todd, 1975) which, under anaerobic conditions, will react with ferrous sulfide to form pyrite, FeS_2 (Berner, 1970). This reaction proceeds very slowly with a time scale of months to years. The formation of pyrite, however, does mean that available iron can be relatively low. Thus the amount of ferrous sulfide may serve only as a rough indicator of the amount of available iron that has been used within a sediment and the limitations of such an indicator must be recognized. In addition, the iron that is incorporated into pyrite will not be recycled to free iron upon turnover since pyrite oxidation is very slow.

3.2.2.3. The Nitrogen Cycle

Although nitrogenous species are not present in significant quantities to be important hydrogen acceptors, nitrogen is important in the chemical transformations within sediments since it acts as a nutrient. In this capacity, the nitrogen cycle can result in significant acute and chronic impacts.

Within the sediment, nitrogen primarily is released from bacterial decomposition of nitrogen-containing organics. Within the anaerobic portions, the nitrogen remains as ammonia (NH_4^+) and is probably sorbed to other organics, silts, clays and other precipitates. Typical concentrations in interstitial waters range from 0.1 to 10 mg/l. Since these values will exceed the concentrations in the overlying water, there will be a continuous diffusion of ammonia out of sediments. Within the aerobic portions the ammonia will be oxidized by nitrifying bacteria to nitrite and nitrate; the mass of ammonia is so small that this does not probably result in a significant oxygen sink. Thus the physical turnover of sediments will result in the release of nitrogen, primarily as NH_4^+.

3.2.3. Effects of Increased Inputs from Dredging

3.2.3.1. Oxygen-Demanding Material

Dredging and secondary effects of industrialization and urbanization can result in increased carbon in both the entire estuary and in localized areas. The increase in carbon inputs from induced activity can be significant; however, this increase is difficult, if not impossible, to quantify. This impact is also highly dependent on the types of industrial and municipal development in the estuary. The increased carbon in localized areas results from changes in sediment transport rates and is also difficult to evaluate since sediment transport in estuaries is difficult to predict. However, organics are known to accumulate in areas where the tidal velocities have been significantly reduced.

Increased inputs of particulate organic carbon into an estuary will ultimately result in higher levels of degradable organic carbon in the sediments. These organics will cause a greater portion of the estuarine sediments in both depth and area to be anaerobic (reduced redox potential) which can cause two important impacts. First, many organisms are dependent on particular environmental redox conditions and organic carbon contents (Sanders, 1956) (Hancock, et al., 1977) and thus an alteration of carbon content and redox may alter the community structure. Second, the availability of many chemical constituents are strongly dependent on redox levels (Lee and Plumb, 1974) (Gambrell, Khalid, and Patrick, 1976). In particular, iron, manganese, phosphates are known to be released when sediments are changed from aerobic to anaerobic conditions. Heavy metals have also been listed as possibly being solubilized under anaerobic conditions (May, 1973) (Windom, 1972); however, the results by both Lee, et al., (1976a) and Chen, et al. (1976) have shown that heavy metals are not released in significant quantities from sediments by changing from anaerobic to aerobic and aerobic to anaerobic conditions.

The increase of organic carbon in a sediment will undoubtedly increase the oxygen-demand of the sediment when it is resuspended. In organic rich sediment, ferrous sulfides will accumulate; this compound will be oxidized to ferric iron and sulfur upon resuspension (Williamson and Todd, 1975) with a subsequent oxygen demand. Estuarine sediments will be periodically resuspended from man-caused activities (dredging, ships, etc.) or natural events (storms, floods, etc.) and the dissolved oxygen adversely affected. The effects would probably be of a short duration.

The increase in organic carbon will also increase the oxygen consumption rate of the sediment. Burdick (1976) has reviewed this impact and its relation to dredging. He reported rates from 0.5 to 6.2 g O_2/m^2-day for a wide range of sediment types and environmental conditions. Reaction rates in estuaries typically can compensate for uptake rates of this magnitude. This impact could be significant for those cases in which a highly organic dredge material in disposed and subsequently distributes over a wide area.

3.2.3.2. Organics for Sulfate-Reduction

Sea water contains high concentrations of sulfates (about 2600 mg/ℓ); estuarine waters, which are a mixture of sea water and fresh water runoff, also contain high concentrations of sulfates, roughly in proportion to their salinities. The sulfates will diffuse from the sea water into the sediment and, since their concentration is large, the flux will usually be large enough to maintain the concentration of $SO_4^=$ in the interstitial water at over several hundred mg/ℓ. As a result, the available organics usually limit the sulfate reduction rate because their concentration is typically below 50 mg C/ℓ. Thus, increased organics should increase the rate of sulfate-reduction.

Free sulfides in the interstitial water will occur if the formation of hydrogen sulfide exceeds the available iron which is measured as the reduced sulfide capacity (RSC, mg S/kg) (Williamson and Bella, 1977). The RSC is defined as that quantity of sulfide that can be precipitated by a sediment. It can range from 0 to several thousand mg/ℓ depending on the sediment type; fine sediments have larger iron contents and, as a result, typically larger RSC values as compared to coarse sediments.

The potential for the occurrence of free sulfides will increase with increased sediment organics since the organics will result in increased hydrogen sulfide formation. This is especially true where organics are trapped in areas which have low RSC values. The stoichiometry for sulfate reduction is approximately 1 mg $SO_4^{=}$ - S/mg C (Williamson and Bella, 1977). Thus, free sulfides will occur in those sediments where the degradable carbon (mg C/kg) exceeds the RSC (mg S/kg); a procedure to estimate when free sulfides will occur is outlined by Williamson and Bella (1977). If the available iron is sufficiently depleted, free sulfides within the anaerobic regions of deposits will increase and then may diffuse to the aerobic regions and into the overlying water. Turnover of the sediments may also cause release of free sulfides. The formation of free sulfide should be avoided due to the extreme toxicity of sulfides to benthic and pelagic animals (Servizi, et al., 1969) (Colby and Smith, 1967).

Dredging and its induced activities can significantly alter the input and distribution of organics in an estuary, and thus significantly contribute to the release of free sulfides. Dredging induces many commercial activities which result in increased domestic and industrial waste discharges. Dikes, docks and boat basins reduce mixing and circulation which results in the settlement of flocculant organic particles into these areas. Shallow, diked areas may grow algal mats which produce significant quantities of organics by photosynthesis. The decomposition of these organics may occur by sulfate-reduction with a subsequent release of free sulfides. Thus several potential impacts of dredging must be considered in relation to formation of free sulfides in sediments.

3.2.3.3. Metals

Among the metals of environmental interest in sediments are iron, manganese, mercury, copper, lead, chromium, zinc, arsenic, cadmium and nickel. All of these metals except iron and possibly manganese are of interest because of their known toxicity to organisms at trace concentrations. In this section, those impacts associated with an increase in the concentration of these metals will be described. Comprehensive reviews of this topic are included in the reports by Serne and Mercer (1975) and Chen, et al. (1976).

Dredging and secondary effects of industrialization and urbanization can increase the sediment metal concentration by the same mechanism by which it increases organic contents. Many metals, especially lead and cadmium, result from man's activities, many of which will increase after dredging of estuaries. Various filling and structures can trap fines in small areas. Since the metals in estuaries are largely associated with the fine particulates (Serne and Mercer, 1975), this alteration of sediment transport can cause localized areas of high metal content.

The chemistry of heavy metals is very complex and beyond the scope of this report. The total metals in the sediments are partitioned among various fractions. Chen, et al. (1976) identified eight fractions as: interstitial water, water soluble, exchangeable, carbonates, manganese and amorphous iron oxides, organics and sulfide, crystalline iron oxides and the lithogenous fraction. Each metal species will be partitioned differently between the eight fractions depending on the chemical availability of the fraction. The importance of the fractions for binding the metals will depend largely on the environmental conditions. For example, iron and manganese oxide phases would not be present in a reduced environment and a sulfide phase would not be present in an aerobic environment. It is difficult to estimate to which fraction of the sediments a metal would migrate from a specific metal input. Little is known about the mechanisms of metals inputs to sediments and subsequent transformations.

The association of metals with the various fractions within sediments is important since each fraction has a different availability to marine organisms. It is generally assumed that the bioavailability is proportional to the ease of leaching (TM 3.2.6.), that is, that the bioavailability ranking is interstitial water > water soluble > exchangeable > carbonates > manganese and amorphous iron oxides > organics and sulfides > iron oxides > lithogenous fraction. From their review of the bioavailability of metals, Jenne and Luoma (1975) concluded that the uncomplexed ion is the most available for biological uptake and that the difficulty in determining its activity in complex systems precludes estimations of the biological impacts of heavy metals. In further work, Luoma and Jenne (1975a) found that the availability of sediment-bound metals to Macoma balthica varied significantly from the order of leaching. The most significant fraction after the interstitial water phase was the biogenic carbonates (clam shells).

Presently, biological impacts from heavy metals cannot be estimated either from known total concentrations or from the concentrations in various fractions. The acute toxicities of metal released from dredge materials are probably not significant; the chronic impacts can only be speculated from current information, but are likely to be of greater significance. Long-term biological accumulation studies correlated with selective leeching or chemical availability should provide a rational basis for chronic impact evaluations.

3.2.3.4. Toxic Hydrocarbons

Chlorinated hydrocarbons have been measured in significant concentrations in estuary sediments and near shore sediments (Serne and Mercer, 1975) (Chen, et al., 1976) (CWRP, 1976). Specifically this class of compounds includes the polychlorinated biphenyls, the chlorinated pesticides (i.e., DDT, aldrin, endrin and lindane), and the chlorinated benzene compounds. These compounds are especially significant due to their known toxicity to organisms and their ability to accumulate in food chains.

Dredging can lead to pesticide concentration by a similar mechanism as for organics and metals concentrating fine materials into localized areas. All the chlorinated hydrocarbons listed above are known to be sorbed at interfaces (Huang and Liao, 1970) which explains their association with fine-grained sediments. A review of the influence of environmental factors (pH, salinity, temperature and other organics) on the sorption of chlorinated hydrocarbons in sediments was presented by Lee, et al. (1976a). However, over the typical ranges of environmental conditions in an estuary, only salinity appears to significantly alter the sorption characteristics.

Numerous measurements of chlorinated hydrocarbons in algae, bacteria and benthic organisms have been presented in the literature. However, the biological significance of these compounds, even when present in apparently large concentrations, is largely unknown. The impacts of having areas within an estuary which have high concentrations of chlorinated hydrocarbons cannot be presently ascertained. As such, measurement of such constituents in dredge material will provide little information to estimate ecological impacts expected in those cases where extremely high concentrations from a known discharge are present.

3.2.4. Effect of Altered Turnover Rates from Dredging

Dredging estuaries can significantly alter the turnover rates of the sediment. This impact can occur from the physical disruption during dredging, anchor dragging from ships, and changes in tidal velocities. The formation of dikes from dredge spoil placement can greatly decrease the turnover rates, while anchor dragging can greatly increase the turnover rates. A change in the turnover rates is significant because it seems to control many of the chemical, physical, and biological characteristics of the estuary.

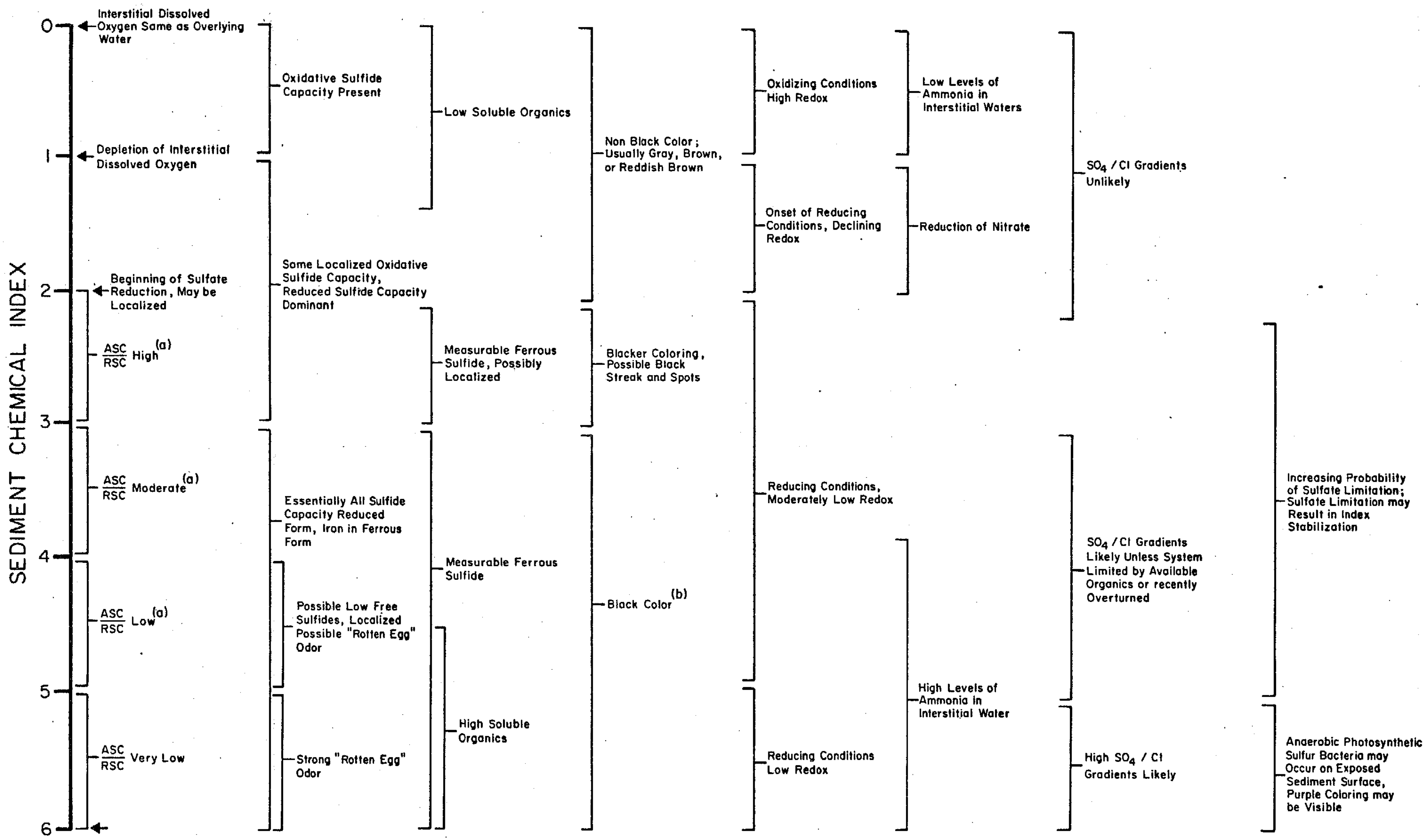
3.2.4.1. Chemical Characteristics

The chemical characteristics of estuarine sediment, if left undisturbed, will undergo a progression with time as shown in Figure 3.1. Williamson and Bella (1977) have suggested this classification scheme which groups consistent sets of chemical characteristics. If adequate organics are present, sulfate reduction will continue and the sediment will progress toward higher sediment chemical index values.

A turnover event will introduce oxygen into the sediment from the overlying water, and will oxidize some of the ferrous sulfides and introduce oxygen in to the intersitial water. This will revert the sediments back to earlier progression state or lower Sediment Chemical Index (SCI) (see Figure 3.1 for the chemical characteristics associated with each SCI value). Thus, the frequency of turnover coupled with a rate of chemical progression will determine a set of chemical characteristics for the sediment. Changes in the turnover rate will cause a change in the SCI values that the sediment will experience.

The impacts from this turnover may be either positive or negative depending on the initial state. For example, a sediment with an SCI of 5 to 6 will have adverse chemical characteristics for most benthic animals; dredging of such an area will revert it to a lower SCI which would be more favorable for a benthic community. In contrast, increasing the turnover rate of a sediment with a SCI of 2 to 3 would probably remove necessary organics for the resident biological community which could result in a significant shift in the biological community.

Measurement of the total sulfides and reduced sulfide capacity provide the necessary information to determine the SCI value in the dredging area. Sediments



(a) ASC = Available Sulfide Capacity, RSC = Reduced Sulfide Capacity

(b) Color may vary to gray if ferrous sulfide is transformed to pyrite

Figure 3.1. Classification System for Sediment Chemical Index (SCI)

with SCI values near 0, 1.0, 2.0, and 5.0 will be especially sensitive to changes in turnover rates because of the significant changes of chemical characteristics at these stages.

3.2.4.2. Formation of Free Sulfides

Free sulfides will occur in the sediment intersitial waters if the available sulfide capacity (reduced sulfide capacity minus the total sulfides) approaches a limiting concentration of about 100 mg S/Kg. If values near this limit are measured and free sulfides are not present, the sediment should probably be managed in a similar manner to that of a free-sulfide bearing sediment.

A sediment with free sulfides can contribute several negative impacts in a dredging operation. Such sediment will contribute toxic hydrogen sulfide to the overlying waters upon both removal and disposal which will be of special concern in relation to the pelagic organism. In addition, the oxidation of the hydrogen sulfide and the precipitated ferrous sulfides (total sulfides) will contribute a substantial oxygen demand.

The negative impact of dredging sediments with free sulfides present can be managed in several ways. First, removal should be done in conjunction at high flow velocities to insure maximum dispersion and oxidation. Second, disposal should be planned to obtain maximum dispersal. This procedure will result in maximum oxidation of the sulfides during disposal, and a reduction in the high organics and an increase in the low available sulfide capacity as the sediments are mixed with existing sediments at the disposal site.

3.2.4.3. Formation of Pyrite (FeS_2)

The reduced sulfide capacity of sediments becomes smaller as pyrite is formed from the reaction of available ferrous iron with sulfur (S°). In some sediments, the extent of pyrite formation becomes so complete that the available sulfide capacity approaches zero. In these sediments, any introduction of available organics will result in the formation of free sulfides and a toxic environment.

Elemental sulfur results from the oxidation of sulfides in high-chloride water as typically present in estuaries. Thus, continual turnover of sediments with total sulfides present will result in a formation of elemental sulfur which will further react to decrease the available sulfide capacity. This can be considered to be a chronic impact of those areas of estuaries in which medium-to-high organic concentrations (5 to 20 g/kg) exist with medium turnover rates (1/week to 1/month). Medium turnover would exist in areas like shipping channels due to the influence of shipping and dredging.

3.2.4.4. Increased Erosion

Sediment transport in estuaries includes many processes including bed load transport, particle siltation, dune migration, suspended loads and littoral drift. The sediment transport of non-cohesive materials in uniform flow can be successful described from both theoretical and empirical relationship (ASCE, 1975); however very little is known about either cohesive sediments in most flow conditions or all sediment types in oscillatory flows. As such, only a general description of the impacts of dredging on sediment transport is possible (TM 4.6.).

The resuspension of sediment from tidal velocity of ship wakes has been identified as an important aspect of sediment transport which can be significantly altered by dredging. This is especially true in areas which have fine-grained, cohesive sediments.

Under conditions of very low turnover rates (<1/10 years), fine-grained sediments will consolidate. This consolidation results in greater binding between particles which results in less erosion from any bed-shear stress. By introducing dredging with a periodic maintenance project, the fine-grained sediments are overturned at a rate which prohibits any significant consolidation. As such, these sediment become much more susceptable to erosion.

Minor, Williamson and Sollitt (1977) conducted some field tests in which velocities were artifically induced over sediment and the resulting suspended load measured. Comparing two stations of similar fine-grained sediment characteristics, the station which was periodically dredged contributed from 10 to 50 times the suspended load for a given velocity as compared to the station which had not been dredged. The consequences of this impact in oscillatory flows would be that the area of unconsolidated sediment would act as a suspended solids or turbidity source for the entire estuarine system. Although turbidity does not seem to present significant acute impacts, the chronic impact of increased turbidity loads may be highly significant (Bella, 1972).

3.2.5. Selective Chemical Extractions

Selective chemical extractions, consisting of successive leaching of sediment samples with specific solutions, may be used to determine metal associations with various fractions of the sediment. This geochemical partitioning may then be correlated with mobilization of the metals during hydraulic resuspension or dredging and also may be correlated with biological availability and uptake. Although many investigators have used chemical extractions for partitioning of metals associated with solid phases, two comprehensive extraction sequences have recently been developed for geochemical partitioning of sediment-bound metals in estuaries. Brannon, et al. (1976), defined five sediment chemical partitions as the interstitial water dissolved metals, the exchangeable or sorbed metals, the co-precipitated or bound metals within iron and manganese oxides and hydroxides, the organic complexed or sulfide precipitated metals, and the residual metals in mineral crystalline lattices. These five partitions are operationally defined by the chemical extractant medium and physical conditions employed in separating the metals associated with each phase.

Chen, et al. (1976), defined eight operational partitions as the interstitial water phase, the water soluble phase, the exchangeable phase (sorbed), the acetic acide extractable phase (carbonate-bound), the easily reducible phase (hydrous manganese oxide bound), the organic and sulfide phases, the moderately reducible phase (iron oxide bound), and the residual phase (lithogenous fraction).

Brannon et al. (1976), found significant correlation betweem the geochemical partitioning of a given heavy metal and its resolubilization from hydraulic resuspension as determined by the Elutriate Test. Generally, those sediment phases thought to be the most mobile and biologically available (interstitial water, exchangeable phase, and easily reducible phase) correlated most closely with metals concentrations in the standard elutriate. No correlation was found between total sediment concentrations of heavy metals and standard elutriate concentrations.

Serne and Mercer (1975) used the selective extraction procedure developed by Brannon, et al. (1976), for sediments from San Francisco Bay. For most of the heavy metals measured, the major fraction was found associated with the residual phase. The organic and sulfide bound phase also represented a significant fraction of most metals. Only a small fraction of any metals were found in the hydrous oxide associated phases. Correlation was not attempted between geochemical partitioning and release of metals during hydraulic resuspension.

Chen, et al. (1976), in both short-term and long-term experiments, found that interstitial water soluble metals was the only phase that correlated with release of metals to the water column. In particular, gross sediment analyses of metals did not correlate with metals release.

Correlation between geochemical partitioning of metals in sediments and biological availability as determined by bioassay experiments was not within the scope of the three chemical partitioning studies cited. In the future, a direct correlation such as this could either supplement or obviate the need for both the Elutriate Test and bioassays for determing the impact of heavy metals released during hydraulic resuspension from dredging.

3.3 BIOASSAYS

Both short-term and long-term bioassays can be used to assess toxic impacts of water column and sediment chemical constituents on the resident biota. Review of this procedure is provided in TM 5.13.

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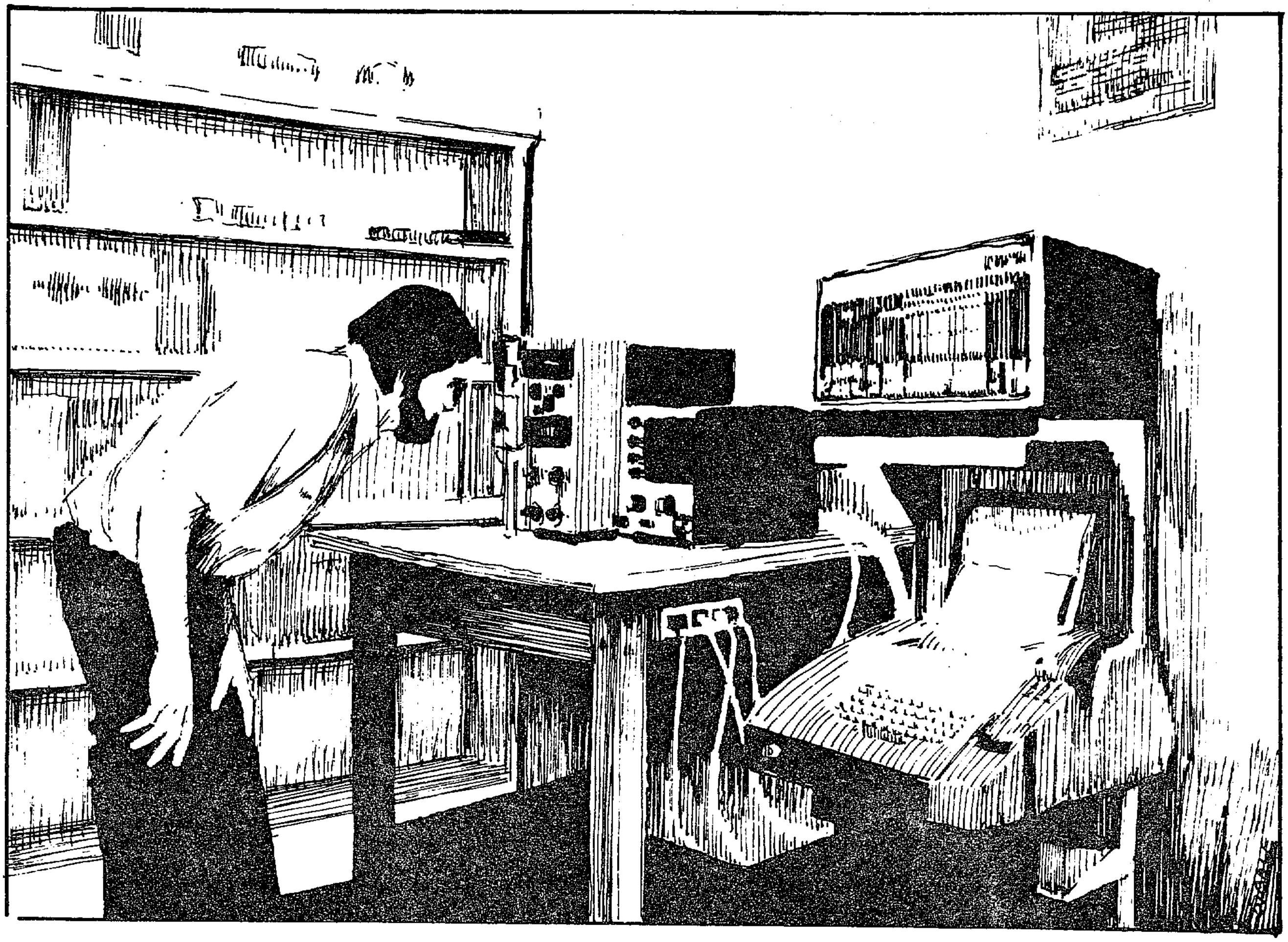

4. Geology

C. K. Sollitt

TABLE OF CONTENTS

4.1. INFORMATION REQUIRED FOR IMPACT ASSESSMENT

4.1.1. Variety in the Estuarine Environment

Estuary boundaries are for the most part sedimentary formations. The sediments which constitute the boundaries are composed of a variety of materials including: mechanically and chemically weathered rock fragments, calcareous and siliceous skeletal structures of marine organisms, decomposable organic matter and inorganic precipitates from the water column. Sediment components may be locally derived or formed remotely and transported via: rivers, tidal currents, waves, winds, biological activity, volcanic disturbances, slope failure and ice rafting. Ocean sediments tend to be uniform spatially and changes occur over long periods of time because material sources, transport modes and topography are relatively persistent. Conversely, estuarine sediments vary in both time and space because of local topographic isolation of various sediment sources and temporal changes in transport modes.

Estuarine sediments are frequently subdivided into two groups: littoral and fluvial. Littoral materials are clean, uniform, relatively coarse sands which have been eroded from adjacent ocean beaches and carried into the estuary on flood tides. Littoral sediments are deposited inside the mouth where the cross section enlarges and velocities are reduced to a level below which transportation ceases. Fluvial materials tend to be fine, well graded sediments eroded from the water shed upriver from the estuary. These materials are carried downstream until the cross section of the river enlarges into the estuary, velocities are reduced and sedimentation occurs. Very fine clay particles carrying anion surface charges repel each other in fresh water, but flocculate when the charges are neutralized in an electrolyte such as sea water. This promotes aggregation of fine particles and increased sedimentation of fines in sheltered estuarine locations where turbulence levels are low enough to permit settling. The response to these two sources of estuarine sediments tends to yield sediment deposits which are coarse near the mouth (ocean end) of the estuary and fine near the head (river end) of the estuary.

Estuaries, however, are not simple drowned river channels responding only to littoral and fluvial sources of sediment. Natural topography may isolate an embayment or slough from exterior sources of sediment so that local erosion of adjacent terrigeneous material dominates sediment sources at some isolated locations. Furthermore, biological activity may modify the sediment composition by consuming organics, cementing fine particulates, mixing heterogeneous components and depositing calcareous skeletal remains. Thus, natural changes in topography producing varied exposures to wind, waves and currents, combined with littoral, fluvial and local sediment sources modified by biological processes produce a variety of sediment conditions within any given estuary.

The spatial variety observed in estuary sedimentary formations extends to the distribution of biota and water masses, indeed to all environmental factors. Some estuaries exhibit greater variety than others, a condition which bears little correlation with gross estuary dimensions. It is generally concluded, however, that this climate of spatial and temporal change is essential to the great biological productivity observed in most estuaries. Because estuaries serve as the habitat or nursery of most important fishery resources, it is important that man's activities within estuaries minimize perturbations imposed on natural changes. Thus, impact assessment must be sensitive to man's effect on removing essential elements of change as well as introducing foreign elements of change.

4.1.2. Hypothetical Impacts

Two hypothetical examples of geological disturbances may be cited which illustrate potentially undesirable impacts to estuaries. It is common practice to stabilize inlets to estuaries by constructing jetties to force littoral transport offshore and induce accretion along naturally meandering spits. The desirable effect is to provide a deep navigation channel at a fixed location which requires minimum maintenance dredging. In the absence of inlet stabilization, the mouth is free to migrate along the length of the spit, occasionally breaking through at new locations, flushing out accumulated sediments and introducing a new boundary configuration. This provides an opportunity for a new habitat to develop locally, and biological cycles which contribute to other life forms within the estuary are preserved. The construction of a jetty, dike or breakwater could eliminate some element of change essential to long term biological processes within the estuary.

A second example illustrates the effect of introducing new geophysical conditions. Dredging navigation channels in confined regions provides local hydraulic relief and generally decreases flow rates in adjacent shallow regions. New geological formations may be exposed in the channel which are subject to either erosion or deposition, depending on the mechanical characteristics of the sediment. The reduction in flow at the shoal areas probably contributes to increased siltation. If the deposition rate is large enough to smother benthic biota or if the accreting sediments are substantially different from the natural materials, then an inpact on the biota is to be expected.

An impact is of concern if it adversely affects estuarine biological processes or if it causes some deterioration in aesthetic quality and/or commercial value of the estuary. Geological factors contribute to an impact if substantially different geological formations are created by dredging, spoiling or the construction of complementary structures and if naturally occurring patterns of erosion and deposition are altered directly or indirectly by the project. Therefore, the assessment process must consider those geological properties which have important biological implications and which contribute to an evaluation of sediment transportation.

4.1.3. Significant Geological Properties - Sediment Physical Characteristics

The important geological properties are limited to relatively few sediment physical characteristics which are known to significantly affect both biological activity and erosion - deposition processes. These characteristics in order of decreasing importance are: grain size distribution, organics content, porosity and, to a lesser extent, strength and mineralogy. Important animal - sediment relationships have been summarized by Rowe (Inderbitzen, 1974) and Webb, et. al. (McCave, 1976). Grain size distribution has been found to provide the strongest correlation with benthic animal activity, e.g., filter feeders prefer coarse sediments and deposit feeders prefer fine sediments, etc. Particle size also provides a measure of erosion resistance and deposition potential for moderate to coarse sediments (Graf, 1971). Organics content is a direct measure of energy input for sediment bio-chemical reactions; biological activity generally increases with organics. Organics tend to be of low density and are subject to erosion and suspension similar to very fine sediments, and therefore may contribute to water column turbidity. Porosity or water content has been found to be an important parameter for tube building burrowers. Water content is also important to estimates of erodability of cohesive sediments. Sediment strength imposes a limiting condition on body weight, shape and motility. Strength also characterizes erosion resistance of cohesive materials. Mineralogy contributes to an evaluation of specific gravity. Specific gravity is required for calculations of erosion and deposition of medium to coarse sediments.

Benthic fauna also impose changes in sediment characteristics. Animal burrowing and crawling through the sediment and swimming adjacent to the surface generally weaken and increase the porosity of near surface materials. Bioturbation tends to improve circulation of pore water within the sediment matrix while increasing susceptibility to hydraulic erosion. Ingestion of sediments by non-selective feeders often produces excreted pellets of conglomerated fines. Mucus secreted by some invertebrates cements particles together and reduces the permeability of both coarse and fine grained sediments. The combined effect of pelletization and mucus secretion is to reduce pore water circulation and erosion susceptibility. In addition, root structures, shell debris and algal mats all provide surface armoring to varying degrees, yielding some increase in resistance to hydraulic erosion. The net effect of benthic infauna activities is to modify the physical characteristics of the surface sediments and establish an equilibrium with dynamic environmental conditions existing in the water column.

4.1.4. Induced Changes in Estuarine Sediments

Some broad descriptions of several estuarine features can be offered in terms of the sediment physical characteristics. Generally, active hydraulic environments tend to promote selective removal of fines and organics, flushing of pore water and reduction in strength. Thus, tidal channels and exposed beaches are composed of coarse, clean uniform sediments. Any biological activity here requires repeated grazing of the sediments or filtering from the water column. Protected embayments and sloughs experiencing minor net through flow are hydraulically inactive and the corresponding sediment structure contains more fines and organics. Porosity tends to be high but permeability low so that interstitial flushing is reduced. The presence of fines and organics and poor circulation often produces turbid conditions in the water column. Biological feeding types are dominantly deposit feeders, frequently non-selective. Tidal flats and intertidal areas may be exposed to wave and current disturbances or sheltered from one or both. Corresponding physical and biological characteristics may vary from those associated with clean, coarse material to organic, fine material. Aquatic plants in these regions may assist in stabilizing surface sediments while faunal activity may have the opposite effect. Marshlands tend to be sheltered from all but extreme high tides or freshet flooding. During periods of inundation, fines and organics are deposited over marshlands where friction reduces current velocities and shoaling prevents wave erosion. Terrestrial biology may be significant in marshlands.

These general animal - sediment - estuarine feature relationships provide a vehicle for impact assessment. If man's activities within some portion of an estuary induce changes in the character of the estuarine feature or its sediments, then some response in sediment transportation and deposition, turbidity and benthic biota is to be anticipated. The response must be calculated in terms of:

1) the characteristics of the sediment exposed by dredging or deposited by spoiling
2) sediment characteristics modified by erosion and deposition due to project induced changes in hydraulic disturbances and sediment sources
3) biota observed to exist under conditions which are hydraulically and geologically similar to those predicted to occur at the impacted site.

Each impact response requires some basic information about local sediment physical characteristics. The information is essential to sediment transport models as well as to animal - sediment relationships. The following sections describe how this information is obtained and used.

4.2. DATA COLLECTION

4.2.1. Historical Records

There are several sources of geological data which provide valuable information for impact assessment. Utilization of available data resources can lead to economies in the conduct of impact studies and improve the assessment process.

Historical bathymetric survey records for navigable waterways are maintained by district offices of the Army Corps of Engineers. Charts dating back 100 years or more for some estuaries indicate natural variation in dynamic landforms and identify areas of active erosion and accretion. Recently, the Corps has begun sampling sediments at active dredge sites. Grain size and chemical analyses are performed on these samples.

Well log records from the U.S. Geological Survey may be interpreted to construct cross sections of underlying sediments adjacent to many estuary locations. Cross sections may often be extended into the estuary to indicate types of sediment likely to be exposed by dredging. This information is useful for planning field studies to obtain additional sediment samples to quantify sediment physical characteristics.

Local port authorities and county offices often have access to additional engineering studies and surveys conducted in the region of interest. Various state agencies and universities within the state frequently conduct environmental studies which can contribute significantly to impact studies.

4.2.2. Field Sampling

Field sampling programs can quickly expand into expensive efforts unless geological, chemical and biological requirements are coordinated. Samples should be obtained which are satisfactory to all participating disciplines with duplicate samples acquired at the same time.

Sediment samples may be obtained by core, grab and trawl. Whereas the latter two methods are common for biological studies, they are not satisfactory for geological and chemical studies. It is important that fines, organics and pore water not escape while the sample is being secured. In addition, measurements of water content and strength require that the sediment matrix remain undisturbed until analyzed in the laboratory. Trawls and grab samples cause significant reworking of the sediment and do not provide adequate protection against loss of fines, organics and pore water. Only core samples satisfy all requirements for minimizing sample disturbance.

Three techniques are currently used to obtain core samples. Gravity cores simply fall through the water column with trailing fins to guide the sampler vertically into the sediment. Additional assistance may be provided by an internal piston which develops a reduction in pressure at the top of the sample (Hollister, et al., 1973). Vibra cores are set down on the sediment surface and use a pneumatic, hydraulic or electric uni-directional vibrator at the top of the core tube to drive the tube into the sediment (O'Brien and Duley, 1971). Drilled cores use well drilling techniques. A bore hole is created to the depth of interest and a thin walled tube is pushed beyond the bottom of the hole to obtain a sample (Jumikis, 1962). Each coring device must have adequate provisions to prevent loss of sample during extraction, e.g., a fingered core retainer at the bottom of the tube and a one-way valve at the top. Core lengths in shallow estuarine waters (less than 50 feet if dredging is required) are limited to one to two meters for gravity cores, two to ten meters for vibra-cores and no practical limits for drilling methods. Costs tend to increase exponentially with length. Cores should be stored vertically and protected against vibration, loss of pore water and temperature extremes.

Recent developments in marine instrumentation make it possible to measure sediment strength and water content, or bulk density, in-situ. The instruments push a 60° cone tipped rod into the sediment at a constant speed and measure the penetration resistance force as a function of depth (Hirst, et al., 1972). Other probes may be fitted to the same drive mechanism to measure water content with a resistance gage (Delft, undated) or bulk density with a nuclear densitometer (Hirst, et al., 1975). These instruments provide direct measurements of important geotechnical properties but are available only as prototypes at present. Remote sampling of geotechnical properties via acoustic methods is also within the scope of current technology (Inderbitzen, 1974).

Sediment transport measurements may be required for verification of transport models. Measurement techniques are significantly different for suspended sediments and bed load. Suspended samplers acquire volumes of water containing the sediment at discrete depths or integrate over the total depth by sampling continuously while being lowered through the water column. Bedload samplers separate the sediment from the water by guiding flow adjacent to the bottom through screen containers of various shapes and sizes. A discussion of a variety of sediment measuring devices is included in Graf (1971). Each sampling device interferes with natural transport conditions to varying degrees. It is important, therefore, that comparisons between different locations and at different times be conducted with the same instrument. Interpretation of the results requires that simultaneous measurements of velocity profiles be acquired at the same location. Velocity measuring techniques are discussed in the hydraulics section of this manual.

Turbidity measurements may be taken in-situ or by obtaining volumetric water samples for subsequent laboratory analysis. Turbidity may vary with depth in poorly mixed flows so that depth profiling is necessary. Turbidity samples should be refrigerated and shielded from light in storage to prevent biochemical changes in suspended material. Turbidity is quantified in terms of the light reflecting capacity of colloidal suspensions in the water. It is essential, therefore, that turbidity instruments operate on the reflection principle and not the photo-extinction principle. Commercial instruments for field and laboratory use are available.

Both transported sediment measurements and turbidity measurements should coincide with maximum ebb and flood currents on consecutive tidal cycles. Of course, samples at various phases of the cycle are preferred for obtaining average values. The contribution of fresh water riverine flow, obtained from U.S.G.S. stream gage stations, should be noted at the time of measurement.

4.2.3. Selection of Sampling Sites

A sampling program should be designed to supplement information available in historical records and past environmental studies. An examination of historical bathymetric charts should reveal areas of active erosion and deposition which may be affected by the project. Sensitive areas of concern are those which will experience a change in hydraulic exposure due to flow channelization, increased shipping activity and structure placement or a change in sediment sources due to spoil placement and altered shoaling patterns. Thus, some preliminary estimates of hydraulic circulation changes should be made, e.g., flow resistance relief brought about by changes in hydraulic radius due to dredging, changes in wave exposure due to jetty placement, etc.

The sediment physical characteristics of these potentially sensitive areas may be evident from U.S.G.S. well logs or past environmental studies. If not, then samples must be obtained to determine the compatibility of the existing sediments with the anticipated new conditions. At the very minimum, the characteristics of materials at the dredge and spoil site should be evaluated. If horizontal homogeneity can not be assured from prior studies, then sample sites should be located at the longitudinal extreme points and at a three point lateral transect across the middle of each sensitive area. Unless vertical homogeneity can be assured from prior studies, then cores at the dredge site should extend to project depth. Surface samples at least 20 centimeters deep will suffice at the spoil sites and other affected areas.

Transported sediment samples should be obtained at those stations required by sediment transport models, preferably near the major areas of concern. If no model is to be employed, then these measurements will serve no use in impact assessment and should be eliminated from the sampling program.

Turbidity measurements are essential for evaluating background levels prior to the project. If no data is available from past studies, then samples should be taken close to the dredge and spoil sites, and near any adjacent sheltered areas that may trap colloidal suspensions resulting from the project.

4.3. LABORATORY ANALYSIS

All of the laboratory techniques required to quantify sediment physical characteristics are well documented. A survey of the relevent procedures and appropriate references are presented.

4.3.1. Texture

Grain size analysis is probably the single most important geological measurement contributing to the impact assessment. It has important implications for hydraulic, chemical and biological processes. Grain size analysis requires a combination of two separate techniques, one for coarse fractions and one for fine fractions. The distribution of coarse material, greater than 76 micron equivalent sphere diameter, is determined by sieve analysis (ASTM, 1973) or Emery settling tube (Emery, 1938). The distribution of fine fractions is determined by hydrometer or pipette analysis utilizing Stoke's Law for laminar settling velocities (ASTM, 1973). The two techniques are combined by comparing results at overlapping, intermediate particle sizes or by analyzing the same known initial sample weight. The combined results yield a distribution by weight of particle sizes represented by an equivalent sphere diameter.

Recent methods have been developed which use optical and electrical counting techniques for sizing fine fractions. These methods, however, generally are unable to resolve the volumetric or mass contribution of all material less than a threshold diameter between 0.1 and 1 micron. This contribution may be important for fine clay sediments.

Combining the Emery settling tube with a wet preparation hydrometer technique has the advantage that the sample need not be dried prior to the analysis, so that cementation of fines does not occur. This allows the sediments to be analyzed in a close to natural state. Whatever technique is chosen, it is important that this same technique be used for all samples so that a meaningful comparison of results can be made.

It is usually recommended that organics be removed by dissolution in dilute hydrogen peroxide or dilute hydrochloric acid. For very organic sediments common to many estuaries, complete dissolution is difficult to attain. It may be equally appropriate to include organics in the grain size analysis if it is desirable to determine the apparent settling character of the entire sediment matrix. If the organics are included for some distributions, then they should be included for all.

4.3.2. Solids Components

The distribution of mineral types within the sediment does not appear to be a critical environmental property. However, the relative proportion of organics to inorganics and the specific gravity are important.

The organics content is most simply determined by measuring the weight loss of non-refractory components due to combustion at 550° C (Standard Methods, 1975). The loss is expressed as the percent of dry weight of the total sample.

Specific gravity of the solids components is required for grain size analysis. It is determined using the Archimedes principle in conjunction with a pycnometer (Lamb, 1951). The specific gravity should be checked on approximately 10% of the samples.

4.3.3. Liquid Components

Water content is measured as the percent weight loss due to evaporation of a saturated undisturbed sample. The percentage is computed relative to the dry weight of the sample. Porosity and void ratio may be solved by combining water content and specific gravity to determine void volume relative to total volume and solids volume, respectively.

The liquid and plastic limits should be determined for fine grain, cohesive sediments. These quantities are required for some cohesive sediment transport models. The liquid limit is determined according to ASTM Standard Specification D423-54T. It is equal to the water content at which the soil will just begin to flow to close a 5/64 inch groove when lightly jarred ten times. The plastic limit is determined according to ASTM Standard Specification D424-54T. It is equal to the water content at which the soil can be rolled into 1/8th inch diameter threads without breaking. The plasticity index is the difference between the liquid and plastic limits and expresses the water content range within which the soild behaves plastically.

4.3.4. Transported Sediments

Suspended sediment samples should be evaporated to determine the weight concentration of suspended sediments. Grain size distribution should be determined using methods described for texture analysis if a large enough sample is available. For dilute suspensions, distributions should be determined by progressive filtering.

Bedload transport samples should be analyzed for grain size distribution using methods described for texture analysis. Specific gravity measurements may also be required for both suspended and bedload transport samples, unless specific gravity can be interpreted from mineral composition.

Turbidity samples should be analyzed in accordance with instructions for the specific laboratory turbidity meter being used.

4.4. DATA INTERPRETATION

Geological data contribute to the analysis of hydraulic sediment transport and the distribution of benthic biota. Sediment transport and biological processes may produce a positive feedback which induce changes in the properties of exposed surface sediments. Modifications by natural processes may tend to restore conditions which existed before the project or may establish new equilibrium conditions. Consequently, it is necessary to interpret geological data in terms of its contribution to, and modification by, hydraulic sediment transport and biolgoical processes.

4.4.1. Geological Formations

The analysis of historical bathymetric and geologic records reveals the occurrence and distribution of dynamic landforms within the estuary. These landforms may be terrestrial estuarine boundaries or lie wholly submerged below the low water surface. Meandering boundaries are indicative of quasi-steady equilibrium conditions which produce changes about some mean state within the estuary. Those landforms which may be affected by the project should be identified and the magnitude and frequency of configuration changes should be evaluated. Periods of active change should be compared with the occurrence of extreme tidal, meteorologic and/or hydrologic events to identify possible causal relationships. If the project interferes with one or more of these events, e.g., dike construction providing shelter from flooding, then some impact is to be anticipated. The magnitude of landform excursions should be evaluated and the proximity effect of project activities estimated. This estimate will require the input of hydraulic considerations for wave and current induced erosion and deposition. Hydraulic considerations should be limited to simple explicit calculations of fractional changes in boundary shear stress caused by changes in local hydraulic radius (due to dredging or spoiling) or by changes in wave exposure (due to removal of natural barriers on construction of artificial barriers). If the predicted changes in boundary shear stress are less than 20% of the undisturbed value, then the magnitude of change is probably less than the resolving power of most sediment transport models and the effect of the project will be small. If on the other hand, the changes in boundary shear stress are greater than 20%, then the geologic formation sediment characteristics (grain size, water content, liquid and plastic limits) should be evaluated so that some estimate of deposition and erosion rates can be calculated from suitable sediment transport models.

4.4.2. Grain Size Distribution

Grain size analysis quantifies the distribution of particle sizes as the per cent finer or coarser by weight over a range of particle diameters.

Important statistical quantities include the median grain size (that diameter below which 50% of the sample is finer by weight), the standard deviation and skewness. As an alternative to the latter two quantities, the sample uniformity is often enumerated; uniformity is equal to the 60% finer diameter divided by the 10% finer diameter. Values of uniformity less than 4 indicate a sorted sample of nearly equal particle size while values in excess of 10 indicate a uniformly graded sample.

The median grain size is a required parameter for most sediment transport models applicable to materials coarser than silt (Graf, 1971). Erosion resistance tends to increase with increasing particle size. Median grain diameter is also a frequently encountered parameter in reported sediment - animal relationships. Gradients in sediment distribution patterns are easily identified by examining the spatial variation in median grain size at selected sites within the estuary. Approximate hydraulic and biological activities can often be inferred from this distribution (McCave, 1976).

The uniformity and/or standard deviation quantify variation about the mean. Small values indicate that all material is of approximately the same size while large values indicate the contribution of significant quantities of material finer than and coarser than the mean. Sediments characterized by large standard deviation are subject to selective removal of fine fractions and deposition of coarse fractions in active hydraulic environments (Graf, 1971).

4.4.3. Water Content

Sediments composed largely of silts, clays and organic detritus are cohesive and the in-situ water content plays a significant role in the determination of erosion resistance. Empirical relationships for critical tractive force have been developed which are functions of the void ratio and plasticity index (Graf, 1971). The void ratio is equal to the volume of voids divided by the volume of solids and may be calculated directly from the water content and solids specific gravity. The plasticity index is equal to the difference between the liquid and plastic limits. Erosion resistance tends to increase with decreasing water content and increasing plasticity index.

4.4.4. Organics Content

Organics measurements serve as indicators for bio-chemical reactions and also correlate well with grain size and water content in many estuarine sediments. Organics content measured using volatile solids methods is a relatively simple procedure compared to grain size analysis and undisturbed water content measurements (Sollitt, 1977). After regression relationships have been established for organics content and various other quantities of interest within a particular estuary, additional organics measurements can be made to extrapolate physical, chemical and biological patterns. Thus, organics content can be used to assist in the efficient interpretation of other important estuarine parameters.

4.5. IMPACT ASSESSMENT - DEPOSITS

Direct geological impacts to estuarine deposits result in changes in the location and/or physical characteristics of estuarine boundaries. Consequences resulting from these direct impacts may ultimately include changes in: biological activity and distribution, industrial activity and distribution, aesthetic and real value of local property, and obligations for future maintenance of non-equilibrium conditions. The significance of direct geological impacts therefore must be interpreted relative to the indirect effect on related activities. An analysis of contributing geologic data combined with appropriate sediment transport models and animal - sediment relationships should allow one to answer important questions regarding the ultimate impact of various dredging, spoiling and related construction activities. An excellent literature review of impacts resulting from dredging and dredge spoiling is provided by Morton (1976).

4.5.1. Landform Modifications

The analysis and interpretation of historical records, recent sediment samples and hydraulic data provide the necessary background information required to assess impacts on estuarine landforms. Although changes in landform shape and migration rates are important impacts to identify, subtle changes in landform character must also be assessed.

4.5.1.1. Removal

The creation of navigation channels by dredging can produce preferred flow channels which alter circulation patterns within the estuary. Because hydraulic transport is a major factor in sediment erosion and deposition at sedimentary landforms, it is important that consideration be given to changes in natural circulation patterns. A survey of appropriate models to be applied to various sediment and hydraulic conditions has been presented by Basco, et al. (1974). The state of the art is such that even the most elegant models are limited in their capacity to accurately predict sediment transport rates and changes in boundary configurations. In spite of these limitations, sediment characteristics can be analyzed to determine whether predicted increases in current and wave activity will significantly increase erosion or whether decreases in current and wave activity, at sites removed from the dredged channel, will produce significant deposition of available source sediments. The impact of these changes must be assessed in terms of the probability of long term, accumulated effects at important landforms (Hovers, 1974).

Increases in marine traffic in improved navigation channels cause increases in hydraulic activity. The effects of prop wake and convective accelerations around hull forms may be limited to the channel itself, however, bow and stern waves may propagate to adjacent shorelines to increase wave induced erosion (Downs, 1976). Increased wave activity generally increases shoreline slope and grades sediment towards coarser particles (Komar, 1976). A change in tidal or sub-tidal habitat may result.

4.5.1.2. Disposal

Subaqueous dredge material disposal in unconfined areas causes a change in the natural profile to a non-equilibrium condition which, over the long term, is eroded back towards original conditions (Basco, 1974). Erosive loss from disposal sites up to 84% of the original deposited volume are reported by Morton (1976). The lost material is frequently eroded by wave action and transported by tidal currents to regions sheltered from hydraulic activity. Thus, spoil sites may serve as a source of sediments to be deposited at the boundaries of sheltered landforms. Accelerated shoreline erosion has also been attributed to the interference of offshore sediment mounds with longshore sand transport (Jordaan, 1970).

Disposal in confined, terrestrial spoil areas effectively removes the coarse material from the estuary system, however, some fines are returned from barrier overflows. It is likely that the deposited materials will destroy any natural habitat existing at the site and continued use of such sites for maintenance dredging prevents habitat restoration by natural processes.

4.5.1.3. Complementary Structures

Jetties, breakwaters, revetments and piers are built to stabilize shorelines adjacent to navigation channels, to protect anchorage areas from wave excitation and to facilitate loading of commercial vessels. Also, surge barriers may be constructed to protect valuable commercial property from inundation by hurricane surge. The net effect is to remove natural perturbations from the estuarine system. Such action causes accelerated siltation in protected estuarine areas. Historical trends in old, "improved" estuaries are reported by Hovers (1974) and Kendrick and Derbyshire (1976).

The construction of jetties and groynes causes increased deposition on the exposed side of the structure, but causes increased erosion due to interference with longshore transport on the sheltered side of the structure. Models capable of predicting long term boundary changes adjacent to these structures are discussed by Komar (1976). Thus, jetties, used to stabilize inlet migration at the entrance to estuaries, impact on shoreline shape as well as on long term changes in flushing characteristics.

4.5.2. Changes in Sediment Physical Characteristics

Dredging and related activities impact on surface sediments by interfering with sediment sources and altering natural disturbance patterns. Symptoms indicative of these impacts include changes in sediment texture, solids composition, water content and strength. An analysis of core samples combined with hydraulic model results will generally provide the information required to assess sediment sensitivity to changes induced by dredging and related activities.

4.5.2.1. Removal

The activities of the dredge itself result in the loss of some fine fractions to the water column. The impact resulting from this loss is of little long term significance (Slotta, et al., 1973). More important are the changes induced in exposed boundary materials and circulation patterns.

Surface sediments in a natural setting will adjust to an equilibrium condition with the requirements of benthic biota and disturbances transmitted from the water column (McCave, 1976). Tube building burrowers and nonselective deposit feeders will stabilize the sediment surface by cementing fines and organics together with mucus and digested excreta. Sediments of large uniformity armor the interface with coarse grain material by selective removal of fine fractions during erosive hydraulic events. Removal of this protective layer by dredging may expose material which is less resistant to erosion (Sollitt and Crane, 1974). If the time required for equilibrium to be reestablished is greater than the interval between maintenance dredging, then unnatural conditions may be maintained within the channel, and changes in resident biota may result.

The excavation of navigation channels may cause significant changes in circulation patterns. Additional disturbances created by ship wake and ship waves may significantly alter depositional processes at many locations within the estuary. Visher (1969) has shown that characteristic grain size distributions are associated with various types of depositional processes. It is to be anticipated, therefore, that dredging induced changes in current and wave disturbance patterns will ultimately alter the distribution of sediments. Because of the strong correlation between benthic biota and sediment grain size (McCave, 1976) an impact on benthic biota and dependent pelagic biota should also be anticipated.

Hydraulic relief created by dredge channels near estuary entrances may also alter sediment sources. Reports of sediment sources changing from predominantly fluvial to littoral are not uncommon (Simmons, 1965; Mead, 1972; and Ippen, 1966). Because littoral sources tend to be coarser and less organic than fluvial sources, the character of surface sediments could be altered demonstrably by a change in sediment sources.

Organic components in sediments tend to be of low density and respond hydraulically like silts and clays. Inverse exponential correlations between organics content and median grain size have been found to apply to estuarine sediments (Sollitt, 1977). Consequently, changes in hydraulic disturbances which cause sediments to become more or less coarse, will also cause the organic components to decrease or increase, respectively. Benthic biological activity is known to increase proportional to organics content (Rowe in Inderbitzen, 1974). Therefore, impacts on biota are expected if changes in organics content result from dredging.

Water content increases and strength decreases as a sediment becomes less consolidated. A decrease in consolidation is brought about by sediment disturbances which remold the sediment matrix. Those dredging activities which increase the magnitude and frequency of wave or current induced disturbances contribute to a reduction in consolidation. An unconsolidated sediment is more easily eroded so unstable boundaries are a symptom of increased water content and decreased strength. Deposit feeding biota are sensitive to water content and large biota depend on sediment strength to prevent rapid descent into the sediment (McCave, 1976). The response to water content and strength may be particularly acute in cohesive sediments where reconsolidation of surface sediments requires the assistance of slow biogenic processes. Impact assessment should include a consideration for those consequences resulting from increased disturbances over cohesive sediments.

4.5.2.2. Disposal

Dredge materials have not been successfully confined in subaqueous deposits (Basco, 1974). Erosion of non-equilibrium profiles results in the dispersion of spoil deposits to points miles away from the original disposal site. Selective removal of fines and organics often occurs at the disposal site with recorded reductions in median grain size exceeding division by two (Nittrouer and Sternberg, 1975; Sollitt, and Crane 1974). The resulting spread of dredge materials may produce a layer of fine surface material in areas with naturally coarse material. Material dredged in brackish or fresh water and spoiled in salt water may produce flocculated layers of fluff in nearby channels (Ippen, 1966).

Materials confined in diked areas have been successfully contained. However, dike failures are common (Morton, 1976). Some loss of fines and organics occurs at weir overflows and additional materials may be eroded from the surface during periods of significant runoff. Thus, some fines and organics may be returned to the estuary adjacent to confined disposal areas unless surfaces are stabilized.

The net effect of subaqueous spoiling is that selective removal of fines and organics at the disposal site increases the probability of fines siltation at adjacent, sheltered sites. The water content of the dispersed materials will be high and the strength, low. Materials remaining at the original site tend to be coarser than the dredged material and are relatively consolidated after the overburden has been eroded away (Nittrouer and Sternberg, 1975). Improper placement of deposits may also interfere with natural circulation patterns causing aggrevated siltation in quiescent areas. Decreases in mean water depths by more than a factor of two have been reported (Brever, 1962).

4.5.2.3. Complementary Structures

Constructed facilities designed to maintain dredged navigation channels often increase flow within the channels but decrease flow in areas removed from the channel. The result is siltation of fine grained material at boundaries behind protective structures (Kendrick and Derbyshire, 1976). Some structures such as surge barriers and dikes generally reduce hydraulic circulation and may encourage widespread siltation (Hovers, 1974).

Structures which provide shelter from ambient wave and current conditions will generally increase the slope of submerged bed forms (Komar, 1976) and decrease the median grain size of surface sediments (Visher, 1969). An increase in organics and water content is also likely to accompany the reduction in grain size (Sollitt, 1977). A change in resident biota will probably result from the change in sediment conditions (McCave, 1976).

4.6. IMPACT ASESSMENT - SUSPENSIONS

Changes in the geology of sedimentary deposits within the estuary may be accompanied by a few undesirable responses in the water column. These responses are due to the introduction of non-equilibrium conditions by modified circulation patterns and increased ship activity within the estuary. Generally, increased hydraulic activity will result in increased sediment transport either as bed load or suspended load. Even if no net increase in erosion or deposition takes place, increased particulates in the water column may impact on filter feeding biota by clogging ingestion and/or respiration filters (Morton, 1976).

Turbidity appears to be a short term impact of actual dredging and spoiling activities. However, if additional hydraulic disturbances such as ship waves are introduced into a sheltered region such as a slough or shallow embayment, then fine surface sediments may be kept in suspension and contribute to localized turbidity. If natural circulation by tidal and riverine currents is restricted in this sheltered area, then the turbid waters will not be flushed away and chronic, long term turbidity may result. Turbidity interferes with light transmission so that photo-synthetic processes may be impaired as long as turbid conditions persist. Short term increases in turbidity are often compensated for biologically by increases in available nutrients (Morton, 1976). Long term increases in turbidity, however, may not be tolerated by plants and animals which require light for their primary life functions.

Density currents may result from spoiling on long submerged slopes. Although some entrainment of ambient water and expansion of the density current occurs at the head, the effects are confined to a relatively small flow region and deposit area. These areas are altered significantly by the momentum of the density current so care should be taken to avoid disposal in sloping regions where natural bottom conditions are to be preserved.

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5. Biology

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TABLE OF CONTENTS

5.1. INTRODUCTION

This chapter describes and explains some of the techniques used in the analysis of impacts on biological systems due to dredging projects in estuaries. Twelve topics are covered. The section on each topic was written with consideration for a reviewer who is not completely familiar with the sciences of biology and ecology.

Section TM 5.2. habitat analysis, describes some of the problems and methods of examining natural and man-made environments relative to dredging impacts. The section on sampling and data analysis (TM 5.3) briefly covers sampling theory, problems of sampling in estuaries, some pitfalls of data analysis and interpretation, and appropriate sampling equipment and statistics. There is a short discussion (TM 5.4.) on how to perform and appraise taxonomic work. The effects of disturbance on food webs by dredging activities, measurement and meaning of production and productivity, and problems in considering recovery of perturbed biological communities are covered in Sections TM 5.5, 5.6, and 5.7, respectively. The specific influence of dredging activities on some specific classes of plants and animals is covered in Sections TM 5.8 to 5.10 on recreational species, endangered, and commercial species.

A section on ecosystem modeling (TM 5.11) is included because, although they have not often been employed in environmental impact assessment it is likely that impact analysis using ecosystem models will become more common in the future.

A relatively new subject, the use of "in-kind" mitigation to create or restore estuarine environments is briefly discussed in Section TM 5.12. The final section of the biological chapter (TM 5.13) very briefly covers the use of bioassays in determining the effect on various organisms of toxic materials released during dredging operations. Acute effects of suspended solids increases and dissolved oxygen deficits on estuarine biota are described in TM 5.14.

Because of the complexity of biological systems and their interactions with the physical environment, the designation of critical areas of study and technical standards is constantly being changed. The information presented here is not presumed to be a compendium of all the proper ways to perform biological analyses--not now, and certainly not in the future. The information is presented in the hope that it will help the reader and reviewer to judge the quality of a dredging project EIS in relation to the goals set forth in NEPA.

5.2. HABITAT ANALYSIS

5.2.1. Natural Habitats

A habitat is defined as the "home" of animals or plants,. Sometimes it may be characterized by mostly physical features, such as a rocky intertidal area, or open water. Often in the estuary, a plant species (which has its own habitat) defines the habitat for myriad other organisms, as is the case in a mangrove swamp or an eelgrass bed. An estuary may be mapped into habitat zones, and an EIS will generally have a series of maps indicating the different habitats that may be found there. Functionally, each zone is not totally discrete and isolated. Birds may use the wetlands for nesting, intertidal areas for feeding, and open waters for resting. Understanding the function of each habitat and the impact that a particular dredging project will have on that zone (and its function) is necessary in evaluating the impact of the project. In Table 5.1 we have defined and listed the functions of ten habitats that might be affected by a dredging project. The water column, estuary bottom, grass beds, tideflats, vegetated tideland, and wetlands are within the estuarine boundary, but kelp beds, coral reefs, barrier islands, and natural and artificial reefs are usually on the estuary margin. They are included because impacts in these marginal zones may influence the estuary. Possible impacts from dredging are listed in Table 5.2. A general discussion of most of these habitat types is found in Clark (1974).

In assessing an impact on a habitat it is important to remember that biological events in the estuary are regulated by seasonal events. The processes of spawning, nesting, migration, rearing, settling, algal blooms all occur seasonally, and specific impacts may be reduced by critical timing of the project.

Table 5. 1. Estuarine Habitats (adapted from Clark, 1974)

HABITAT	DESCRIPTION	FUNCTION
Water column	Open aquatic environment	Habitat for phytoplankton, zooplankton, fish and larval forms of many organisms. Functions include larval distribution, site for primary productivity, nutrient distribution and cycling, shelter for species which normally live offshore, and is an acclimatization zone for transient species such as anadromous fishes.
Subtidal benthic	Floor of the estuary below lowest tide	Habitat for many species of burrowers, grazers, filter feeders, browsers. These include worms. crabs, shellfish, etc. Functions include nutrient storage in sediments, removal of toxic materials from the water column, feeding areas for crabs and fish, and substrate and shelter for many of the above organisms.
Submerged grass beds	These are regions where the sea grasses grow below the mean tide line. The species of grass which defines the habitat may vary (it is predominantly Spartina on the Atlantic and Pacific coasts) but most estuaries with quiet, undisturbed waters will have some kind of grass bed.	Functions include shelter and food for grazing animals, provisions of organic detritus and nutrients, oxygen production, nursery areas for larvae, a stabilizing effect for bottom sediments, providing a key element of the energy flow pattern of the estuary, and a feeding and resting place for waterfowl and mammals. This is an extremely productive habitat and is particularly important in estuaries which have diminished marsh areas.
Tideflats	These exist below the tidelands and are exposed only on very low tides. They are open areas of mud and sand, without vegetation.	Shellfish, worms and other burrowing creatures live here. Tideflats are often a basic nutrient source, are a source of food for fish and birds, and have recreational and commercial potential for human use of shellfish.
Vegetated tidelines	This is essentially an intertidal area with vegetation. It includes mangrove swamps and salt marshes.	Habitat for many small species; is a nursery area for larval forms of many organisms. This is a very highly productive area from which flows much nutrients and organic detritus. Nutrient storage, water purification, trapping of sediments, acting as a barrier for storm waves, natural drainageways, energy storage for entire ecosystem, and aesthetic attraction are all functions of this habitat.
Wetlands	That area above the high tide but below the level reached by the highest annual storm surges.	This is an area of rushes mangroves, or grasses. Plants which live here are tolerant of wet soils and salt. The functions are much the same as the vegetated tidelands. The natural habitat serves to clean runoff waters and regulate flow. It serves as a buffer zone between the terrestrial environment and the estuary.
Coral reef	Reefs formed by the living coral organisms. Coral reefs must be maintained in the living state to continue existing. They are found in the U.S.A. in Florida, the Virgin Islands and the Hawaiian Islands.	Habitat for an vast array of organisms, especially fish. The reefs serve as a barrier to storm surges; are shelter, substrate, and food for reef-dwelling creatures.
Kelp beds	Kelp is a large attached algae found in waters off the rocky Pacific coastline.	The habitat in the kelp bed is formed among the fronds and holdfasts of the plants. They provide an area for feeding and other activities of marine mammals, they are a shelter for young fish and other animals, and help to damp wave energy. They also add to the primary production of the area.

Table 5. 1. Estuarine Habitats (continued)

HABITAT	DESCRIPTION	FUNCTION
Barrier islands	Long islands or peninsulas formed by the action of the sea. Found on Eastern Seaboard and Gulf Coast.	Serves as a barrier to storm waves on the ocean side. On the estuarine side they are mostly marsh or mangrove swamps. Dunes protect the seaward side. The function therefore includes those of vegetated tidelands. They may be important nesting areas for waterfowl and are important wildlife habitats.
Natural and artificial reefs	Rocky outcroppings or artificial submerged structures found in bays, estuaries, or offshore	They functon as current and wave barriers, are important recreational fishing areas, feeding areas, shelter, substrates for invertebrates, and absorbers of wave energy.

Table 5. 2. Impacts of Dredging on Estuarine Habitats

HABITATS	IMPACT OF NEW PROJECT	IMPACT OF MAINTENANCE PROJECT
Water column	Direct effects of turbidity and solubilization of toxic substances (if dredged material is polluted); channelization may change salinity and currents in the estuary which will have an effect on pelagic organisms.	Direct effects are the same as for a new project; not likely that there will be a change in salinity or currents due to maintenance dredging.
Estuary bottom	Changes in salinity can cause freshwater kills of shellfish; direct removal of organisms; changes in circulation pattern will influence bottom characteristics which may cause problems with larval settling and burial of adults. (Possible resuspension and settlement of toxic dredged material)	Possible resuspension and settlement of toxic dredged material.
Submerged grass beds	Reduced light penetration due to turbidity; grasses have difficulty rooting because of fine sediments; boat traffic will stir up sediment and damage plants; disposal activities may bury the grass bed.	Organic pollution can over-fertilize the grass beds; diked sisposal will destroy the habitat.
Tideflat	Drainage pattern may be altered disposal on tideflats will destroy them.	Diking and burial will destroy the habitat.
Vegetated tideland	same as tideflats	Diking and burial will destroy the habitat; possible secondary impacts from polluted runoff waters from disposal areas.
Wetlands	same as vegetated tideland	Same as vegetated tideland.
Coral reef	Silt fallout can cause kills of coral; turbidity can cause direct kills; coral larvae will not settle on soft sediment deposited by dredging operation; if salinity is lowered, reefs will suffer.	Same as impacts of new project.
Kelpbed	Disposal will diminish habitat by burial covering holdfasts with sediment, and covering the rocky substrate which the kelp requires.	Same as impacts of new project.
Barrier islands	Channelization through and around islands may change circulation pattern and influence island stability; direct disposal will alter vegetation.	Same as new project.
Natural and artifical reefs	Direct removal if a barrier to navigation; circulation changes may affect reef-dwellers; or affect other habitats previously protected by the reef.	Same as for new project.

5.2.2. Human Habitats

Few estuaries are untouched by the presence of humanity. Man has made the estuary a habitat for his own species. The conjunction of the human estuarine habitat with the natural estuarine habitat need not be destructive. Some human uses, such as sewage treatment, oyster culture, and fish culture, are very compatible with the natural energies and rhythms of the estuary. Other uses such as shipping lanes and shoreline structures do not fit as well and require careful planning and large amounts of maintenance energy to counter act the natural functions.

The impact of dredging a dredging project will be felt relative to the present development of the estuary. It is possible to see the historical development by using old charts and maps and current visual surveys. Establishment of the pattern can help establish the extent of change of the original estuary. Human use patterns may be evaluated in eight categories: industrial use, commercial use, transportation, residential use, outdoor recreation, farming, logging in the watershed, and agriculture in the watershed (Wilsey and Ham, 1974). These activities will alter the estuary, but changes in the estuary can also affect the activities.

5.2.3. Presentation of Habitat Data

Maps, possibly overlays, should be used to show the human activities, the projected activities which will develop with the completion of the project, and the existing natural habitats and areas of mitigation (TM 5.7) in order to facilitate evaluation of the total impact. It is important to remember that the estuarine habitats are not static and will respond to many changes outside their immediate realm. The EIS should predict these responses and make them understandable to the public and the planners.

5.3. SAMPLING AND DATA ANALYSIS

5.3.1. Sampling Theory

Sampling theory is that body of theory which describes the properties of estimators used to describe parameters of interest in the real world. In other words, sampling theory is the language of translating real problems into a model of the world. There will be errors in this translation. This is a concomitant fact of the translation process. The science of statistics attempts to theoretically estimate the amount of error.

> "So far as precision is concerned, we cannot foretell exactly how large an error will be present in an estimate in any specific situation, for this would require a knowledge of the true value for the populations. Instead, the precision of a sampling procedure is judged by examining the frequency distribution generated for the estimate if the procedure is applied again and again to the same population. This is... the standard technique by which precisions is judged in statistical theory." (Cochran, 1963, p. 9).

Theorems formulated in sampling theory say that if sampling is performed in a given manner, and an estimator is constructued in a particular way, then the properties of that estimator are known. Sampling theorems have been stated for a large number of sampling techniques and these include simple random sampling, stratified random sampling, cluster sampling, circular systematic sampling, common systematic sampling, two-stage sampling, double sampling, replicated sampling (with and without replacement), variable probability sampling, regression estimates, sampling with units of equal and unequal size, and so on. The reader is referred to William G. Cochran's book Sampling Techniques (Wiley, 1963) for detailed expositions on the theory and application of different techniques. Although Cochran's book is concerned primarily with conducting field surveys using interviewers and questionnaires the principles and theorems are the same as in any other kind of sampling.

5.3.2. Sampling in Estuaries

Cassie (1967) has stated that:

> "the most significant physical feature of an estuary is the determinate gradient of properties between river and sea. In some cases there may also be abrupt discontinuities in this gradient produced by the interaction of tides and topographical features. Many statistical techniques assume sampling from a population that is distributed randomly, but in an estuary the gradients and discontinuities are non-random features that "cannot be thrown indiscriminately into a random (statistical) model."

Thus, it is important that sampling be performed with several replicates at each station in the estuary, and that determinate effects due to environmental factors be accounted for. This is not easy. Cassie (1967, 1972a, 1972b) warns that sample stations located a short distance apart in estuaries may show very different situations, and consequently replicate sampling in estuarine work (particularly benthic work) often shows as great a variability between replicate samples supposedly taken from one station as exists among all stations in an estuary. Therefore an EIS reviewer should look at more than the summary information. Sampling should have been performed with several replicates, and determinate factors included. Transects are often used to deal with the problem of spatial heterogenaity in estuaries.

Because estuaries are so highly variable in habitat conditions the place of location is critical. Unless sample stations are precisely located it may be impossible to use the information as a baseline for future studies, or to check for the data for reliability. This is particularly important in studies on maintenance dredging because the community of organisms found in a regularly dredged channel is apt to be adapted to frequent dredging and no significant change in community may be observed. Sample stations located a short distance from the channel may show a completely different situation. Natural events often mask man-made impacts so time series data are very important for baseline studies.

The time of collection is also a critical factor. Some organisms such as copepods and plankton have blooms (or swarms) which are highly seasonal and can bias measures of abundance. The chosen periodicity of sampling usually depends on the time and resources available to the study group. Ideally, monthly samples should be used when conditions are stable, weekly samples for planktonic populations or chemical constituents that change frequently, and daily or hourly samples to investigate rapid changes and short lived phenomena (Mackenthum, 1969). The time of day when samples have been taken must be noted as the tidal cycle can have a great effect.

The study should cover at least one year to take into account seasonal changes. A shorter sampling program of 3 to 6 months may miss an important seasonal event such as zooplankton swarms, phytoplankton blooms, or fish spawning and runs which should be considered in the EIS.

All habitats in the estuary should be considered since each one will respond differently to the dredging project. A sampling program should also include non-biological data. Salinity, depth, current velocity, substrate composition and chemistry must all be known in order to predict how they will be altered by primary or secondary impacts of the recorded project.

5.3.3. Data Analysis

Data used for preparation of EIS's often comes from ongoing or previous studies in the project area. Occasionally, for very large projects, scientific studies are carried out to establish a "baseline" or "benchmark" against which to judge future effects of the project.

Guidelines for environmental impact statements require that presentation of data be in summary form and very simple. More complex analyses are reserved for technical appendices to the main report. The result is that EIS's usually contain mostly qualitative biological data which are normally presented in the form of species lists, habitat type lists, area maps, and distribution maps. The NEPA requires a statement about the diversity of the biological community and the long term productivity in the study area, but does not precisely define what diversity is.

These qualitative statements are important because they allow individuals who aren't specialized (including the public) to make judgments on the environmental impact of a dredging project. A critical reviewer should check if the quantitative data on which the qualitative statements are based accurately supports those statements.

In reviewing an EIS, another item of interest is the data variability. In benthic sampling, for instance, within-station variance is often as great as the between-station variance. This is due to the patchiness of the environment. Comparisons of variation within a group of replicate samples to the variation across stations should be made to verify that observed trends across environmental gradients are indeed significant. If the data are of poor quality, elaborate statistics may end up concealing that fact.

Control stations are important in "before and after" studies. Baseline data may be misleading without these controls because natural events can mask the effect of a human impact, or be mistaken for a human impact.

5.3.4. Diversity Measures

Diversity is usually presented in an EIS as a measure of biological health. Biological diversity is a property of a community of organisms that accounts for both the number of species in the community, and the distribution of individuals within the various species. Thus, it includes both variety and abundance. Variety is often used as an synonym for diversity, and that is incorrect. It is properly referred to as species richness.

Samples from a population only serve as a basis for estimating measures about the population. Likewise, all measures of diversity are only estimates of some true population parameter. A list of the species with their abundances is common in EIS's and from that data an intuitive feeling for diversity can be obtained. In the biological literature it is more common to find one or more diversity indices employed, the most common of which is Shannon's measure (Shannon and Waver, 1963), also known as H'. The estimator for H' is H", defined as

$$H'' = -\sum_{i=1}^{S} p_i \log p_i \quad \text{or} \quad H'' = \sum_{i=1}^{S} p_i \ln p_i$$

where

$p_i = n_i/N$

N = total sample population = $\sum_{i=1}^{S} n_i$

n_i = number of individuals in species i

S = total number of species in sample population.

There are many other indices of diversity. Each one has a different behavior and bias with populations possessing different richness, evenness, and density. These different species composition parameters include those of Brillouin, McIntosh, Pielou, Simpson, Lloyd Lloyd, Ghelardi, and Levins (see Pielou, 1969). There are several good references to the problems of diversity measures and their differences (Brookhaven Symposium, 1969; Goodman, 1975). It is important to note here that many of the diversity indices are subject to sample size bias. They are also subject to what Warren (1971) calls "groupings of convenience." Unless the sampling strategy is carefully designed it is possible to unwittingly have highly biased data--especially when sampling from such a diverse environment as an estuary.

High diversities are often quoted as indicators of high stability and final phases of ecological succession. This point is still in question. Margalef (1967, 1968) pointed out that low diversity is assoicated with a high density of populations. He goes on to say that "it is an indicator of poor organization under the influence of flow and of changing conditions" (Margalef, 1967; p. 520). But it doesn't seem to hold true that the most highly organized communities are the most diverse.

> "Even as Margalef was refining his hypothesis, four lines of investigation and evidence were combining to undermine part of it. First, the results of many separate studies of terrestrial and aquatic ecosystems showed that diversity does not always increase with succession, particularly in the final phases. Second, investigations of plant associations by Whittaker and his colleagues tended to show that the interdependence and interactions of the species found in mature communities had been exaggerated--at least if one looked at a single trophic level. Third, the mathematical analysis of May (1973) failed to confirm the intuitively attractive notion stated by Commoner that the greater the number of interactions, or links, the greater the stability of the system" (Ehrenfeld, 1976; p. 651).

May's models seemed to support the cybernetic approach of Gardner and Ashby (197) which showed that increasing connectance in randomly generated systems was associated with increasing probability of instability

Thayer, et al. (1975; p. 90), working on seagrass systems, declared that

> "the species diversity of the community, together with temporal and spatial variation of biomass, render the seagrass community itself difficult to describe. When this dynamic community is considered as an integral part of the larger, complex estuarine ecosystem to which it belongs, it is not easy to design and carry out sampling programs adequate to define the effects of man's activities."

The point is that diversity, however it is measured, is not going to tell very much about the system unless there exists a good understanding of the estuarine organisms, their biology, and their interactions with each other and the habitat. While it is known that diversity may be temporarily reduced in many cases by new dredging and spoil disposal, it isn't clear that diversity alone is the significant measure of the impact.

5.3.5. Sampling Equipment

The following tables summarize sample methods used in different habitats. They are abstracted from a report for the U.S. Army Corps of Engineers (1974).

TABLE 5. 3.

METHODS FOR SAMPLING AND EVALUATING PHYTOPLANKTON

Name of the method	Apparatus required	Critical appraisal	*Literature
Capture with a net	Plankton net	Exclusively useful for qualitative work on the meso- and micro- plankton; nonnoplankton and ultra-plankton are not captured.	Hensen, 1887 Volk, 1901
Quantitative Methods			
Chambers	Flat chambers of precise volumes (0-5, 1, 2ml)	Only advisable for nannoplankton and ultraplankton with higher plankton densities	Kolkwitz 1907, 1911
Sedimentation methods	No special apparatus needed	Degree of the plankton density can be adjusted to the conditions at the time; rather cumbersome to operate	Volk, 1901 Glenk, 1954
Tubular chamber method	Inverted microscope; special tubular chambers	Advantages of the chambers and sedimentation methods are combined; the best limnological method.	Utermohl, 1925, 1958
Centrifuge method	Electric centrifuge (a hand centrifuge is not suitable)	Possible to investigate the whole plankton in a living state.	Lohmann, 1908
Membrane filtration	Membrane filtration apparatus	The whole plankton is captured but delicate organisms are deformed; convenient to operate by hand.	Kolkwitz, 1924 Schmitz, 1958
Chlorophyll estimation	Membrane filtration apparatus and photometer	Saves considerable time; only the total plankton is captured; no individual values; suitable only for problems of production biology.	Harvey, 1934 Handke, 1941 Gessner, 1942, 1943, 1949
Estimation of the photosynthesis	Geiger-Muller counter	Suitable only for determining the primary production. Regarded as troublesome by some investigators.	Steemann Nielsen, 1952 Strickland, 1960 Findenegg, 1964 Rodhe, 1958

*These references can be found in Schwoerbel, 1970.

Periphyton are usually sampled using artificial substrates which are subject to colonization. True quantitative sampling of periphyton from natural substrates is difficult.

Table 5.4. Macrophyta Sampling Equipment

Suggested Application	Type of Apparatus
Important root systems	Scoop; diver operated
Mud, small root system	Ekman dredge
Hard bottom, poor sampling	Peterson dredge,
Hard bottom, better sampling	Peterson dredge, modified
Soft bottom, upright plants, small root system	Cylindrical sampler
Soft bottom; tall plants, small root systems	Quadrat frame sampler
Luxuriant vegetabion; roots only from soft bottom	Pronged grab

Table 5.5. Methods for Sampling Zooplankton

TYPE OF APPARATUS	SUGGESTED APPLICATION
Clarke-Bumpus sampler	large, deep waters
Water sampler	shallow waters
Point or linear samples	utilized when relation between condition of animal populations and food supply is critical
Pumped samples	used when water is accessible. Observations at inlet should be made, as well as day and night sampling.

Filtration is always involved in zooplankton samplers.

Table 5.6. Methods for Benthic Sampling

HABITAT	BOTTOM	APPROPRIATE SAMPLER
Soft	shallow	Core sampler Ekman dredge Jaw type dredges must be fully closed
hard	shallow	Ekman dredge on a pole Kaczmarek sampler O'Conner sampler Simple grab samplers no good retrieval of large rocks trays with stones
soft	deep	Core samplers jaw type dredges (Ekman, Kajak, etc.)
very soft deep	deep	Drzycimski, Elgmork, or Jenkin Samplers
hard	deep	Core samplers with additional weight, Jaw types with additional weight, SCUBA hand-manipulated samplers, artificial substrates.

The substrate is field sampled and organisms removed later by sieving, flotation, hand picking, etc.

A wide range of equipment is used for making both qualitative and quantitative samples of fish. Quantitative sampling is much more difficult, and although it uses the same equipment, many environmental factors must be considered.

Table 5.7. Methods for Sampling Fish

HABITAT	SAMPLER
Shallow water	Hand seines Electrofishing equipment Toxicants
Deep water	Gill nets Trammel nets Trap nets SCUBA Explosives Trawl nets Purse seines Camera Hook & Line

Table 5.8. List of Units in Which Results of Biological Sampling are Expressed

Organism Type	Units in Which Results are Eexpressed	Appraisal
Phytoplankton	number (#/ℓ)	best, but time-consuming
	weight (mg/l)	faster, best expressed as dry weight of organic matter
	volume (microns^3/liter)	good but requires much time and effort
	pigment (chlorphyll *a*/liter)	gives a rapid index of photosynthetic capacity, but numbers and species are unknown without additional samples
	carbon (mg/l)	productivity and energetic studies
	energy (calories/liter)	productivity and energetic studies
	Carbon (mg C/m^2-hr)	expression of productivity rate; usually used with C uptake studies or other productivity techniques.
Periphyton	number (#/m^2)	this is the recommended unit, but on an area basis.
Macrophytes	weight (g/m^2)	wet, dry, and ash-free organic matter weights are generally used after suitable pretreatment to remove excess moisture.
Zooplankton	number (#/ℓ)	probably the best, but time-consuming
	weight (mg/l)	faster, same units as for phytoplankton
	volume (microns^3/liter)	same as for phytoplankton
Benthic organisms	same as for zooplankton but specified per unit of area	

Table 5.8. (continued)

Organism Type	Units in Which Results are Expressed	Appraisal
Fish	number or weight (# or kg/net set)	a fast index, but not as meaningful as others
	number or weight (# or Kg/seine haul)	fast, but only applicable where it can be used
	number or weight (# or Kg/hectare)	gives meaningful numbers, but estimate of sampled area is difficult to obtain

5.4. APPROPRIATE TAXONOMIC WORK

5.4.1. The Need for Good Taxonomy

Most of the data that are derived from biological collections are eventually analyzed by statistical or empirical methods. In every case, the person who does the analysis assumes that the data are valid. Implicit in this assumption is the validity of the taxonomy. Thus, good taxonomy becomes the keystone to the biological conclusion in any impact statement.

With this background, then, there are several questions which must be addressed: What determines good taxonomy? What is the minimum that can be acceptable? How does one judge the quality of the taxonomic work? How does one do taxonomy? What is the role of the specialist? What is the role of the trained technician? What literature is available? How can it most effectively be used? How does one handle unidentifiable species when the expertise is not available or funds do not permit complete identifications? What is the responsibility of the taxonomist in defending his input to an EIS? Can he defend rewritten or edited portions of his report? What is the proper use of a species list? What are the limitations?

The point of all this is that taxonomy is exceedingly important in ecological work and that species lists in environmental impact statements should be accepted for what they are. If they are detailed lists of identified species they may be used with some confidence in making ecological decision, however if they are lists of taxa at several levels, their use in making ecological decisions is quite limited.

5.4.2. What Determines Good Taxonomy?

It is very difficult to judge the quality of taxonomic work. The following checklist will help.

1. Are the persons responsible for the taxonomy competent? This assumes that the responsible persons are identified, and suggests that they must have demonstrated their competence by reputation. If the worker is well known, and his reputation regarding taxonomy is good, we can probably accept the taxonomic work at face value, especially if questions 2 and 7 seem to adequately answered. If the person responsible for the taxonomy is unknown, a review of the peer-reviewed scientific literature may serve to help determine his reputation.

2. How does the species list compare with species lists by other workers from the same or similar habitats? There may be no comparable studies, at least from similar habitats from nearby areas, or if there are similar studies, they may have been done under different specifications. The fact that these are major differences in species lists does not necessarily mean that the taxonomy is bad, but there ought to be some logical way of rationalizing the discrepancies. For example, the habitats really aren't similar, sampling methods may have differed, pollutants or human activities may have altered the habitats, or the biota are truly different.

3. What resources have been used for identifications? The species list should include primarily species from good regional keys but should also include other species. These keys contain only the common species, and very often omit large groups or cover them inadequately. For instance, manuals often contain no keys to many of the smaller worm groups which are common in estuarine muds and sands. Thus, such a source should be supplemented with others. The use of a single source might suggest that the taxonomy was left to technicians, and was not adequately supervised.

4. Have experts been consulted to identify or verify identifications? Almost all competent taxonomists will recognize their inability to identify all groups, and will feel the need to use some experts. Reviewers of EIS's should not hesitate to contact these experts to determine their degree of involvement in the work.

5. Have museum collections been used to confirm some identifications? Almost no intensive taxonomic study can be completed without some reference to a museum collection. This usuallly is a collection from a major museum, but some of the larger universities have fairly good, though often spotty, working collections.

6. Have monographs or other extensive taxonomic works been cited for identification of some of the lesser known species? Every EIS should include a bibliography of the major taxonomic sources including not only the regional keys but also the scientific literature that has been used. The only time this need not be done is when most of the identification has been done or verified by acknowledged experts, consultants, and they, of course, should be identified. Any reviewer of an EIS statement should spot check a few of the identification sources to verify their applicability to the particular situation.

7. What taxa have been used in the species list? Are all the identifications to species or are many of them only to a higher taxon (genus, family, class, or phylum). It is almost impossible to identify every species in a collection. Limitations in time and expertise suggest that this is impractical and probably not necessary. But none of the species which have been placed in a higher taxonomic category should make up a significant portion of the collection either in terms of biomass or numbers. While it is almost inevitable that some higher taxa be used, it is extremely important that they not be used in making ecological conclusions. They should be used only to say "We have

identified the following organisms to species level, but we are unable to identify certain taxa with that degree of refinement". If all members of a higher taxa can be determined with certainty to be the same species, they can be labeled as (taxon) Species A, etc. While not as good as a complete identification, such taxa can be used as an "identified species" if conclusions based on their use is clearly acknowledged.

5. Finally, can the taxonomy stand the test of a peer review? Portions of the taxonomic work should be sent to a specialist if there is any doubt about the quality of the taxonomic work.

5.4.3. Use of A Species List

The species list submitted as a part of an EIS should be quantitative and as complete as possible. It should be an accurate inventory of the organisms that inhabitat a particular part of an estuary or sometimes the entire estuary. They are most often used to indicate what the potential biological worth of an estuary really is, but such use may be questionable because estimates are based on a limited number of samples and estuaries are highly complex.

Another use is to show change; the species list serves as a baseline for comparison with later species lists, or in a few cases, previous lists.

Species lists are also of value in comparing one estuary to another. This is useful if the taxonomic work and sampling are of equal quality and comparable, but different sampling methods or different degrees of refinement of taxonomic work can greatly affect the validity of such comparisons. Species lists can also be used to indicate rare, endangered or declining species.

Limitations of species lists are probably reflected most often in the thoroughness of preparation and in the manner in which they are used. No species list is complete, and most that appear in an EIS will probably omit major segments of the biota or at best aggregate major components. Species lists in an EIS seldom contain species of microorganisms such as bacteria, protozoans, or often phytoplankton or neuston. Often they are limited to macrofauna, to commercial and recreational species, or to some other select group. When using a species list these limitations should be recognized. A species list is only as valid as its taxonomy, and the sampling scheme from which it has been generated.

5.5. FOOD WEBS AND ENERGY FLOW

5.5.1. Background

The basis of production of all biomass is primary production by plants. The common image of a biological community is the primary producer eaten by the herbivore, the herbivore eaten by a carnivore, and the carnivore perhaps in turn being eaten by a top carnivore. While this notion was a breakthrough in its day it was quickly realized that nature did not work that way. Lindman (1942) and Ivlev (1945) realized that ecosystems are not ordinarily easily decomposed into trophic levels with each species remaining in its particular level. Thus, we have come to the present day acceptance of the food web as the paradigm for ecosystem structure and function. Warren (1971) presented an excellent discussion of the development of this hypothesis.

In a food web, individual species and individual organisms often cross the trophic boundary (a boundary more clearly discernable to the ecologists than to the organism) to be both a deposit feeder and a herbivore, a herbivore and a carnivore. Some species may occupy one trophic level in the juvenile stage and another as an adult.

5.5.2. Effects of Disturbances on the Food Web

A food web can often be extremely complex and the elucidation of all the pathways of material and energy flows takes many years. Since production may be discussed in either biomass or energy terms food webs are often given as energy flow diagrams. H. T. Odum pioneered this work (Odum, 1957) and others have elaborated upon it (Slobodkin, 1962; Smalley, 1958). Complete energy budgets, including solar inputs and respiratory losses, have been worked out for several estuarine systems. E.P. Odum (1967), H. T. Odum (1957, 1967) Teal (1958, 1962), Darnell (1961) and Day, et al. (1973) are examples of complex energy and food web analyses of estuarine ecosystems.

From the viewpoint of food web and energy analysis the effect of dredging and disposal must be some alteration of the food web. This can take place either by directly removing or decreasing the population of one or more constituents of the web, or by indirectly influencing the viability of one or more constitutents of the web. Cronin's excellent review (1967) of "The Role of Man in Estuarine Processes" lists many of the potential impacts. Alterations to the salinity or temperature regime may effect spawning times and rates or allow formerly excluded predators into the estuary. Introduction of a new species is a common effect upon the food web.

It can safely be stated that any long-term environmental alteration is likely to make some change in the food web and energy flows of an estuarine system. It is not clear that this is the case for short-term effects. These short-term effects include those of dredging such as direct burial, turbidity increases, changes in substrate type, stirring up of toxic sediments, and direct removal of benthic organisms. Except for new projects, direct kills of plants and animals from dredge activities are usually negligible, and several reports bear this out (Windom, 1972; Sherk, et al., 1974, 1976; Ingle, 1952; Davis, 1960; Stickney, 1975; Pearson, 1975). Disposal activities are another matter, however.

Long-term effects such as substrate changes, changes in water flow, temperature effects, pollution increases, and indirect impact of urbanization and land fills (which are usually encouraged by dredging activities) are likely to have more serious effects upon the system.

5.5.3. The Key Element Concept - The Role of Detritus

W. E. Odum (1971) pointed out that key elements of a food web may exist in a shallow estuary (see also Day, 1973). In his example, mangrove trees in Louisiana, which had been declared "useless", were found to be a major food source for the estuarine ecosystem. Because of the abundance of litter from the mangroves a key group of ominvores was making this food source available to the higher trophic levels.

> "There is a group of consumers, made up of a few species but many individuals, and this group is composed of herbivorous and omnivorous crutaceans, mollusks, insect larvae, nematodes, and a few fishes, all of which derive their nourishment from a diet of vascular plant detritus and small quantities of fresh algae... Moreover, fecal material extruded by one organism in this group may be re-ingested a short time later by another species and the entire process of microbial enrichment and subsequent digestion by the detritus consumer be repeated" (W.E. Odum, 1971, p. 147).

In the Spartina alterniflora (marsh grass) marshes of Georgia, E. P. Odum and A. De la Cruz (1967) found "organic detritus as the chief link between primary and secondary productivity, since only a small portion of the net production of the marsh grass is grazed while it is living." The implication is that the major significance of a food web study is to pinpoint critical pathways or critical organisms. If a dredging project were to influence those important species then its impact could go beyond the direct and short-lived effects expected by the destruction of some small creatures or particular area of shoreline. If critical pathways or species are known then effects of dredging should be looked at in terms of specific impacts on those elements.

For another example, Clark (1974) pointed out the importance of nutrient storage as a function of an estuarine ecosystem. Darnell stated that

> "organic detritus represents a major storage--organic matter produced at one time is released later; transport--downstream away from the point of production; and buffer--availability during seasons of low primary production. Most of the organic detritus is of vegetable origin. Since few of the larger estuarine consumers feed upon vegetation alone, the

real primary consumers of the community are the microbial species (decomposers). ...It must be concluded that the estuarine community is one of the most complex known to mankind, and this is largely because of the presence of organic detritus. Elaboration of all the nutrient pathways will be an undertaking of some magnitude". (Darnell, 1967, p. 381)

5.5.4. Impact of Dredging on Food Webs

In assessing the impact of a dredging or spoiling project the resiliance of the biological system is of great importance. It depends upon the initial disturbance of key elements, the removal of food sources such as detritus inputs, the source of recruitment of replacement stocks, and the length of the project and the time it is performed relative to the season of the year.

It is commonly accepted that high biological diversity implies ecosystem stability. This is now a controversy in the scientific community (Brookhaven Symposium, 1969; Ehrenfeld, 1976) and consequently, a complex food web should not be held up as evidence that the impacted system is necessarily a highly resiliant one. It is more likely that the situation is that which W. E. Odum (1971) found--that there are key pathways within the complex system that must be guarded carefully.

As more complete studies of various estuarine systems are completed, "type" estuaries will be used to estimate the effect of particular projects in areas which have not been directly studied. In evaluating an EIS which uses a food web or energy flow study the following questions should be asked:

1. Is the study an original one, or was it performed in a different region?
2. If it was performed elsewhere, is it appropriate for this region?
3. Does it represent a particular season, or was it done over a period of time so that many seasons are represented? This is significant in that many energy pathways are seasonal ones, e.g. plankton blooms.
4. Were all the appropriate organisms considered?

5. Were all appropriate pathways included? Has the influence of nutrient cycling and detrital effects accounted for?
6. Were external food and nutrient sources included inputs listed?
7. Does the food web study in the impact statement depict a natural system, or was it one subject to previous dredging or other environmental impacts? Does this match the situation under study?

5.6. PRODUCION AND PRODUCTIVITY

5.6.1. Background

The quality of an estuary may be measured by the amount and type of biomass that is there, but perhaps more important is the ability of the estuary to replace that biomass. Production and productivity refer to this ability. Ivlev (1945) stated that

> "The actual evaluation of the production process in a body of water must be based on a knowledge of four features: (1) the process of synthesis of the basic organic matter; (2) the path of transformation of the latter into the final "product"; (3) the loss of energy resulting from failure to utilize all the edible forms present in each trophic link of the type consumer food; and (4) loss of energy of absorbed matter and the degree of utilization of the latter for the process of growth."

Warren (1971, p. 248) elaborated this in stating "it is never enough to seek measurements of production apart from the understanding of how production is determined and influenced by its physical, chemical and biological bases. The production of a population is a general expression of the characteristics of its species and those of its environments". In other words, the role of a population in an ecosystem must be known for production to have any meaning. In most EIS's the detail required for this type of evaluation is not presented. Technical information not appropriate for the EIS itself is often contained in supplements and technical appendices. Since there is an explicit requirement to state in an EIS, "the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity" (Federal Register, 1973, p. 20554) it is important that any statements about the productivity of the natural environment be subject to careful review. The critical point is to determine the probable <u>change</u> in production due to the proposed project.

5.6.2. Primary Production

The biological basis of animal production lies with plant production. Thus, the productivity of an estuary ultimately depends on its ability to elaborate plant material. In an estuary primary production is accomplished mostly by phytoplankton and macrophytes (large rooted plants such as Spartina). In shallow, calm areas the macrophytes are more productive than the phytoplankton communities under comparable conditions (Westlake, 1965). Thayer, et al. (1975, p. 291) stated that "as much as 45% of the plant production in eelgrass beds in North Carolina estuaries may be carried to adjacent systems, thus supplying detrital material to them. These eelgrass systems also maintain larger populations of invertebrates and fishes than the adjacent estuary". Thus, salt marsh production has an effect beyond the immediate area in which it occurs. They described the effect of dredging on seagrass systems as follows:

> "In general, dredging and other disturbances of the bottom sediments or sedimentation rates can destroy several seagrass species. Additions of toxic materials have been shown to affect animal components of seagrass communities, but not the seagrass itself...Dredging not only creates suspended material and accelerates sediment deposition but also causes changes in the redox potential of the sediment. Under these conditions eelgrass density may be reduced considerably. It is not known whether the reduction is caused by direct smothering the grass, by the redox potential of the surface sediment, by rapid addition of oxidized materials, or by toxins released from the suspended sediments" (Thayer, et al., 1975, p. 292).

Thayer also pointed out that growth rate, which is reduced immediately after dredging, is sometimes enhanced the following growing season due to possible increased nutrient supply.

The high fertility of estuaries has three sources: "(1) river water leach plant nutrients from the soil and carry a constant supply through the estuary; (2) pollution, either locally within the estuary or indirectly through the river, may enrich the waters and increase productivity; and (3) the subsurface counter-current, which is a unique characteristic of many estuarine circulations, may enrich the estuary when the sea water is drawn from below the euphotic zone where nutrient concentrations are higher than at the surface. In each estuary these three processes proceed simultaneously" (Ketchum, 1967),

5.6.3. Measuring Primary Production

There are many other methods of measuring primary production, and each method has its advantages and drawbacks. These methods include Carbon-14, pH-CO_2, pigment analysis, and biomass techniques. The most common is the C^{14} technique which measures the uptake of radioactive carbon from a known amount of $N_aHC^{14}0_3$. Westlake (1956) has reviewed the criteria for biomass and productivity. He pointed out that it is important to consider the roots of macrophytes, which often make up to 50% or more of the plant's biomass. He also discussed growth curves and biomass estimates of productivity. Wetzel (1965) pointed out that in situ oxygen light and dark chamber techniques should not be used for estimating production rates in vascular aquatic plants. This is because during the day oxygen accumulates in the internal spaces of the plant and is used during the dark periods. The dissolved oxygen in the water is then not proportional to the photosynthetic rates. The same criticism is true for C_{14} light and dark bottle techniques.

The time span over which measurements are made is also critical. Since gross photosynthesis can be expected to exceed total respiration in the phytoplankton from spring to early fall, measurements which do not extend over a whole season are apt to lead to erroneous conclusions.

A summary of methods of measuring primary production are given in TM 5.3.

The method of diurnal oxygen curves is another method used to estimate primary production.

> "It has long been accepted that the dissolved-oxygen content of natural waters is an important sanitary index of their quality. The distribution of oxygen in a river gives a measure of the balance between the processes of supply and demand" (Owens, 1965; p. 211).

The change in concentration of dissolved oxygen is a combination of gains and losses due to diffusion, gains from photosynthesis, and losses due to respiration. The daily curve can be used to estimate the productivity.

5.6.4. Influence of Dredge Operations an Production and Productivity

Any substantial change in the environment of a species will lead to a change in production (Warren, 1971, p. 265). This is true of estuaries as well as species. The National Estuarine Pollution Study of 1970 (p. 306) stated that productivity of biotic communities is generally reduced by dredging. This is "due to many factors including reduction or overprovision of nutrients, abrupt changes in temperatures and salinities, changes in circulation patterns, and destruction of physical components of the system". Reduction in ambient light levels, reduction in speed of larval development and direct burial , are all possible adverse effects (Leckie and Webster, 1973; Windom, 1972; Sherk, et al., 1974, 1976; Ingle, 1952; Davis and Hidu, 1969; and Davis, 1960). Most of these references indicate that short term impacts upon the biota are negligible, and it is likely that production of the estuary will only be affected when areas of high productivity are permanently removed. Thus, maintenance dredging of a long-dredged area will not have lasting changes, but cutting a channel in an area of salt marsh or tidal flat will remove productive beds and disposal of spoils behind dikes can also cause a loss of production. Dunstan, et al. (1974) pointed out that the salt marsh ecosystem depends on periodic flooding by tides. Raising the substrate beyond tidal influence (by diking) removes that area from Spartina growth thereby reducing the amount of marsh production entering the estuary. This is why the Corps of Engineers have directed much of their research toward rehabilitating spoils banks.

5.6.5. The Meaning of Production and Productivity

There are also secondary impacts which can involve land fill of highly productive sites, increase of sewage loads due to concomitant population increases, over-nutrification, shoreline reduction, and so forth.

Secondary production is the elaboration of animal biomass. Warren (1971) gave an excellent review of this topic. He and Ivlev (1945) noted that there are three important concepts to consider: (1) biomass, (2) production, and (3) productivity (Warren, 1971: Ivlev, 1945). Biomass is the amount of living material in a given area, production or production rate refers to the replacement or elaboration of biomass during a stated time period, whether or not all of it survives to the end (Ricker and Foerseter, 1948 quoted in Warren, 1971). If non-surviving material is not included, the term used would be yield. Standing crop is a term which refers to the above ground vegetative matter (i.e. exclusive of roots). If applied to animal populations it is equivalent to biomass. Net production is biomass elaboration while gross production includes the materials metabolized. The approach of fisheries biologists like Warren (1971) and Ivlev (1945, 1961) has been to focus upon a particular product-of-interest.

In general, production equals biomass times growth rates for small increments of time where growth is linear. High biomass does not always imply high production. The amount of food that can be obtained by an individual organism may decline if there are many animals competing, and thus growth rate may decline, i.e., there is a density-dependent relationship between biomass and production.

Productivity is the basic capacity to produce a product, regardless of the prevailing rate of production, which is very much dependent upon the biomass of the product. Production is always given as a rate, usually as mg/m^2/year or cal/m^2/day. TM 5.3. reviews the various methods of establishing production rates in aquatic systems.

Production values in an EIS are usually not from studies made for that express purpose. Often they refer to other areas, sometimes on different coasts and in different ecosystems. It is generally agreed that the estuary is a very productive place, and that the long term effect of dredging is negative when the impacts are upon tidal flats or salt marshes. Since net production varies seasonally, any studies that may accurately represent production measures in an estuary must include one or more complete cycles.

Making a decision based upon the productive capacity is difficult. The high biomass elaborated by the estuary may appear to have the ability to withstand loss of production, but the focal position it occupies may highly influence the production of organisms such as anadramous fishes and others that are transient in the area.

5.7. RECOVERY OF BIOLOGICAL COMMUNITIES AFTER DREDGING AND SPOILING

5.7.1. Background

Information on the rate of recovery of biological communities can provide a means of determining or estimating the magnitude and duration of impacts on individual populations of communities which have been physically removed, buried by spoils, or altered by secondary effects such as changes in hydrology or sedimentation. These data can often be the key to distinguishing direct, short term impacts from longer term impacts.

There are often technical problems encountered in the measurement of changes in complex biological communities. Before re-establishment or recovery can be measured, the impact or change in the community must be determined. Actual measurement of recovery of highly motile species, which include most of the 200 plankton and many demersal invertebrates and fishes, is most difficult at the present time (Sullivan and Hancock, 1977; King, 1977). More information exists on recovery (i.e. re-establishment, readjustment) processes for the more sessile benthic communities. Therefore, the following discussion relates mainly to benthic systems. It should be stressed, however, that in order for the data from recovery experiments to be meaningful, the experiments and field studies must be properly designed and executed.

5.7.2. Use of Re-establishment Information

Knowledge of whether or not a community has the ability to re-establish itself after stress, and the rate at which it does so, is important when assessment is required for any new dredging project in an estuary. This is especially true for communities containing long-lived species or species requiring a stable environment. The frequency of a maintenance dredging project very often precludes the development of stable bottom communities and measurements of community recovery in these areas suggest that the communities have accomodated biologically to the frequent burial or disturbance (McCauley, et al., 1976). This finding suggests two things; first, that measurement of rates of recovery or re-establishment for most current maintenance projects will not provide very meaningful information and second, any time a new dredging or disposal project is proposed which will require future maintenance dredging, a large change in benthic communities may occur and recovery or re-establishment information will be useful.

Re-establishment of biological systems implies that the community or population has the capacity to return to a pre-existing state. This capacity, called resiliance, depends on many factors, among them the duration of the perturbation, nature of surrounding communities, innate capacities of the remaining biota to re-establish themselves, successional changes, etc. (Holling, 1973). Time series studies of biological communities before, during and after disturbance give indications of the resiliance of a community and involve several of the measures discussed in TM Section 5.3. These would include measures of community structure such as species composition, abundance, diversity, and biomass.

Both removal and disposal project sites may show recovery or restablishment of the original biotic communities if the stress is removed. The mechanism, as well as the time involved in the recovery process, may be quite different depending on the species and type of bottom community under consideration.

Generally, the following information is necessary.

1. Quantitative data on abundance, distribution and some indication of community structure.
2. Knowledge of temporal and seasonal fluctuations in populations or communities.
3. Amount of community or population removed.

4. Duration of disturbance and time schedule of future disturbances.

5. Time series data on community recovery to establish rates-of-recovery.

In addition, knowledge of burrowing, larval transport, and resettlement or migration of recruits for the species concerned may be pertinent. Studies of actual rates of burial or recolonization, studies of larval dispersal strategies, migrations to an area, ability to tolerate stress, or information on animal sediment relationships may be necessary to assess or predict the recovery of an area.

Parr, et al., (1973) have demonstrated that the rate of readjustment after dredging and spoiling may be a function of the past history of a dredging site. After frequent maintenance dredging of an area the fauna that occurs will be one which can tolerate the frequency and magnitude of the disturbance. They further suggest that information about the natural history and population dynamics of the project area and species of interest can be useful. For example, in the heavily industrialized section of Coos Bay, Oregon they found that within 24 hours after dredging some readjustment had occurred and almost total readjustment after 28 days and only one station had not readjusted after the 56 day period following the dredging (Parr, 1973).

This study demonstrates that conclusions drawn from recolonization or readjustment studies are very sensitive to the past history of an area and the sampling frequency plays an important role in interpretation of results.

An effect of spoil deposition involves the actual burial of benthic organisms. Studies of burial have been made (Wilson, 1950; Dunnington, 1968; Maurer, 1967; Stanley, 1970; Saila, et al., 1972; Parr, 1973; Oliver and Slattery, 1976). In most instances, weak burrowers, epifaunal species, and suspension feeders are more susceptible to rapid deposition or burial than are strong burrowers, infaunal species, and deposit feeders. Saila, et al., (1972) demonstrated that some benthic organisms establish "blow holes" to the surface and smaller animals of any type of any type had the greatest chance of being destroyed. Stanley (1970) indicated that some marine species are much more tolerant to conditions of burial than originally considered. Oliver and Slattery (1976) found high mortality to invertebrates with the exception of worms covered by soft sediment. The short term impacts and the rates of recolonization appear highly variable and related to species and type of sediment.

5.8. RECREATIONAL SPECIES

5.8.1. Background

Estuaries are prime recreational areas - favored spots for fishing, crabbing, and clam-digging. There are many other recreational aspects to be considered in an EIS that are not strictly related to biological species. These include boating, swimming, hiking, motor vehicle riding, motorcycling, sunbathing, nature walking, beachcombing, hunting, etc.

Estuaries and their marginal salt marshes are extraordinarily fertile areas, many times more so than the corresponding terrestrial areas, or the open coast or deep sea. They are a feeding ground for fish and wildlife. For many aquatic organisms they also serve as a refuge from the predators of the open ocean.

Some fish such as bluefish, weakfish, flounders, croaker and spot reproduce in the open sea and use estuaries for nursery grounds. Other fish such as salmon and steelhead pass through estuaries on their way to breeding grounds upstream in fresh water. Alewives and shad also pass through estuaries on their way to spawn. Smelt, too, are anadromous (returning to fresh water for spawning), but as adults they spend their time near shore and in estuaries. Walford (1971) gives a good account by region of the sport fish found in and around the nation's estuaries.

5.8.2. Impacts of Dredging

If a recreational species such as a fish or clam is affected by dredging or filling it will either be through a direct effect such as killing or removing the organism, or through an indirect effect such as altering the food web by removing food sources for the recreational species.

Dredging and filling will influence recreational species in one or more ways. Alteration of the physical habitat can remove land from production that will influence the productivity of the estuary for the recreational species, or it can directly destroy the habitat, for example, burying a clam bed. Increasing the stream flow by channelization may cause changes in both the salinity regime and bottom sediments which may have the effect of relocating areas for particular clam species. Resuspension of organic matter at the time of dredging may result in an immediate and temporary lowering of dissolved oxygen levels.

Disposal impacts are different from dredging impacts. Disposal impacts will directly affect detritus generation (detritus is defined as organic debris and bacteria). Removal of detritus generators such as mangroves can have a significant effect on the food chain (Odum, 1971). The most long-lasting impact will be through the food chain to recreational species. This is because species prized by humans are usually at or near the top of the food chain.

The U.S. Army Corps of Engineers, (1974) in a document entitled "Environmental Assessment Manual for the Columbia River" includes a section on recreation in general. This manual notes the importance of the project in either enhancing or reducing "recreation-days." Thus, recreation use should be given in angler-days or hunter-days. The effect of the proposed dredging and filling must be given in terms of the recreation use with and without the project, including all the secondary effects of the presence of absence of the project.

> "Detailed assessment of the effect that an action may have on recreation use requires estimates of the recreation use that would be made of the geographic area influenced by the action under two conditions:
>
> 1) That the proposed action <u>will</u> be implemented, that the action will continued for a finite length of time, and that the expected recreation use of the area be based on recreation facilities and resources access to the area, competition from other nearby recreation areas, and the propensity of the region's residents to engage in the outdoor recreation that will exist after adoption of the action.

2) That the action will not be implemented, that recreation use of the same area during the same time period as used in 1 (above) be related to the area's recreational facilities and resources, access to the area, competition from other nearby recreation areas, and the propensity of the region's residents to engage in outdoor recreation that will exist if the action does not occur.

Estimates of recreation use of an area with and without the proposed action must be consistent. They must both cover the same time period and the same geographical area. Each must recognize the influence that access and competing recreation areas have on the recreation use of the action area. To the extent that the action may directly and indirectly support additional employment in the local area, regional population estimates may differ. These estimates of regional population should then be used to estimate recreation use. In both cases, estimates of future recreation use should not exceed the capacity of the area for such use.

Detailed assessment requires an indepth evaluation of the resources that will support recreation use. This often requires field investigations to develop the information required. Supplemental information should be gathered through review of literature and contact with recreation specialists" (Corps of Engineers, 1974, p. 252).

Since federal and state agencies are responsible for managing water and land resources for recreation use they usually are the source of the best data.

5.9. ENDANGERED SPECIES

5.9.1. Background

The term endangered species is defined in the Endangered Species Act of 1973 as "any species which is in danger of extinction throughout all or a significant portion of its range". The Act goes on to exclude insect pests from this definition. The use of the term "threatened wildlife" is used to include species who are not yet on an official Endangered Species List, but who are good candidates for it (U.S. Fish and Wildlife Service, 1973). Classes of threatened species are those that are threatened worldwide, those that are threatened only within the boundaries of the United States, and those that are rare or endangered within the boundaries of individual states. The philosophy behind the protection of rare and endangered species is that the extinction of a species permanently removes genetic information from the global gene pool. Mankkind cannot always determine the value of this information. In many cases there are also aesthetic reasons for preserving species.

5.9.2. Federal Acts

The Federal Endangered Species Conservation Act of 1966 and the amended version in 1969 do not prohibit the taking or possession of native fish or wildlife. Other federal regulations, such as the Bald Eagle Act, the Migratory Bird Treaty Act, and the Marine Mammal Protection Act, afford protection to certain groups of animals. The law acknowledged a national responsibility, directed the Secretary of Interior to designate rare and endangered species, and authorized him to conduct research on these animals and to acquire habitat peculiar to them. The amended version in 1969 broadened the coverage to include all vertebrates, molluscs, and crustaceans. It authorized the acquisition of acquatic as well as terrestrial habitats and increased the authority for conservation of foreign wildlife.

The Endangered Species Act of 1973 allocates federal money to help states acquire habitat and conserve ecosystems necessary for endangered species. It also prohibits the import and export of endangered species and forbids the taking of them upon the high seas.

5.9.3. Endangered Species Lists

The official list of endangered species is prepared by the Secretary of the Interior and only those plants and animals named on this list are elgible for the benefits named in the act, with the exception of threatened species which must be explicity named by the Secretary. This list, and additions and deletions to it, are published in the Federal Register. The Smithsonian Institution maintains the current list of endangered plant species.

The U.S. Fish and Wildlife Service publishes a bulletin on "Threatened' Wildlife of the United States." This does not comprise the official list, but is intended as a "reference for compiling the official list of endangered native fish and wildlife, as a means to stimulate interest to impart knowledge and to solicit information about threatened wildlife." (U.S.F.W.S.,1973,p.iii).

Many states also have lists of rare, endangered or declining species which must be included.

5.9.4. Comment and Relation to Dredging EIS's

Low numbers are not the only criterion used in determining an endangered species. Populations which have begun to decline, even if they are currently at reasonably high levels, and populations which are determined to be at critically low levels may be sufficient reason to declare a species threatened or endangered. A threatened habitat is also a cause to declare a species as endangered.

Environmental impact statements usually will provide a list of endangered species in the area and make a statement about the likelihood of the dredging or disposal project infliciting damage on the organisms or on their habitat. A brief description of the species is often included along with comments on its range, residence time, etc. These lists are generally compiled with the cooperation of state scientists, local conservation groups, and other regional and local experts.

Frequently, it is birds that are threatened by dredging and filling projects, but not always. Upland disposal sites may involve vascular plants and terrestrial creatures. Some benthic invertebrates have been known to disappear from lagoons which are now boat basins. It is likely that the list of endangered plants and invertebrates will be lengthened now that many of the more obvious rare and endangered birds, mammals and fish have been identified.

The habitat is another point to consider, for often a special habitat exists which is capable of supporting an endangered species, even though the range of the species has been reduced to the point that the local habitat is not occupied. The Act specifically recognizes the importance of habitat preservation as well as direct protection of the organisms.

5.10. COMMERCIAL SPECIES

Commercial species are those organisms harvested by man for profit. Many of the comments for commercial species are similar to those for recreational species. The fertility of the estuary and salt marsh make them an important element of the life cycles of many commercial species. Destruction or alteration of habitat and food organisms can negatively influence commercial species. On the other hand, the dredging is often necessary for the operation of the commercial facilities and commercial vessels which utilize the resource. Very often there are social and economic problems related to Native American fisheries. See TM 5.9. for a more detailed account of the biological problems.

Estuaries are important for commercial fisheries beyond their boundaries. Regional and international fisheries often harvest fish which were spawned or reared in an estury far from the fishing ground. This increases the difficulties of estimating the impacts of a particular dredging project and is a consideration which is often overlooked.

5.11. ECOSYSTEM MODELING

5.11.1. Background

A model, in essence, is a physical, mathematical, or verbal construction--"a caricature of reality"-- which attempts to mimic a portion of the real world. The validity of a model depends partly upon the purpose for which it was designed. Spofford recognized this when he made a distinction between management models and environmental models. Environmental models are models in the scenario or simulation mode. They are descriptive models and are used "by themselves as tools for predicting alternative states of the natural world," given various exogenous environmental impacts (Spofford, 1975, p. 23).

Management models are built for the purpose of ranking management alternatives by some set of criteria, usually social or economic, and generally include an environmental model as part of the structure. Spofford described these models as being in the normative or prescriptive mode. Most models that have been built of estuarine ecosystems are not management models. "For aquatic ecosystem models to be useful in a management context, they must be able to accept as inputs man-induced changes and disturbances, such as modified hydrological regimes or the introduction of residuals (waste) discharges and they must provide, as output, information that is relevant and meaninfgul for making policy decisions on the level of use of a given water resource" (Spofford, 1975, p. 21). The resources management system then dictates the input and output information for the ecosystem model.

There is another distinction between models--there are those built for practical purposes of predicting effects of changes on natural populations and those built for the heuristic purposes of discovery of general ideas, instruction, and learning. The former, should include as much detail as possible, the latter should include as little detail as possible (Smith, 1974). Both kinds are useful for structuring research design.

Although there are many approaches to models they all possess varying degrees of the qualities of rigor, precision, generality, and realism (Holling, 1966 and Eberhardt, et. al. 1976). Tradeoffs exist between these four qualities--it isn't currently possible to have a model with all of them, e.g., precision is often sacrificed in favor of realism, and generality is often sacrificed in favor of precision.

An EIS is not usually concerned with generality because applicability to the particular estuary is of paramount importance. Rigor is not as much a concern as precision and realism. We need to determine if the model in question will accurately predict future condition so of the biological community if the proposed action is taken, no action is taken, or various alternatives to the proposed action are taken.

5.11.2. Dredging and Biological Models

Simulation modeling is an increasingly important activity, yet models are not now capable of producing reliable predictions on a broad front (Yorque, 1975,). Those models with a narrow focus, such as certain primary production and bio-constituent models of chemical processes, can have high predictive value, but the large-scale ecosystem model does not. Hall (1976) provided a good, if difficult to read, overview of the ecosystem modeling as it related specifically to dredging. It should serve as a primary reference for any EIS reviewer faced with evaluating a simulation model. Hall considered both physical and mathematical models. The physical models included bioassays used to predict the degree of biological response which results from a stimulus, microcosms which are "micro-ecosystem simulations" defined as a functional ecological unit in isolation from the rest of the world, and scaled ecosystem models which are physical models which focus on processes and not on physical dimensions. The latter are restricted to immobile or small organisms whose function does not depend on spatial boundaries (Hall, 1976).

Hall's work considered other forms of mathematical models. Mathematical models which are pertinent to estuaries and dredging may be divided into four categories:

1) DO models which are very simple models that focus on the spatial and temporal distribution of dissolved oxygen,
2) chemical models which focus on reactions among chemical species in natural waters,
3) phytoplankton models which focus on effects of nutrients, and
4) ecosystem models which include many species, food chains, abiotic factors, and interactions between them all (Hall, 1976).

According to Hall there is a lag in estuarine ecosystem modeling because of the emphasis placed on lake and stream modeling by the International Biological Program. Also the lack of adequate two- and three- dimensional hydrodynamic models of marsh and stratified estuarine systems has hindered advancements.

5.11.3. The Focus of Modeling

In his publication a review of current work is presented (Hall, 1975). Until recently most published models of animal communities consisted of a set of simple differential equations representing a linear food chain (Paulik, 1971).

Most models were (and still are) aimed at management of a specific resource, ordinarily one of economic significance. Modeling is beginning to move away from the product-of-interest viewpoint in considering the ecosystem as a behavioral entity in time and space. Fiering and Holling (1974) wrote that trying to set environmental standards based only on criteria for stability (where the stability boundaries are set by a political process) may be expensive and counter-productive. "Natural systems should be allowed to swing freely over relatively wide extremes located with respect to the boundaries of the natural domains of attraction. This focuses the attention on persistence rather than on stability" (comment by Spofford, 1975). We are much too concerned with trying to make our environmental systems accident-proof. Concern over the long-term survival of natural systems would have us plan for rare, unexpected catastrophic events (Holling, 1973). One of the advantages of ecosystem modeling is the exploration of the response space of the model ecosystem under simulated "catastrophes."

It is still necessary, of course, to focus on species. One of the reasons is that the data available is usually in the form of separate studies performed on single estuarine species or assemblages. Paulik (1971) suggests the following processes as being of special importance to estuarine-dependent species:

(1) synergistic physiological responses as a function of simultaneous exposure to multiple stresses at different levels of critical parameters such as temperature, dissolved oxygen, turbidity and salinity

(2) spawning requirements, and tolerance ranges and optimums for chemical physical variables

(3) larval behavioral responses to flow conditions and to such factors as dissolved oxygen and total dissolved solids

(4) migratory behavior and effect of environmental gradients on movements

(5) growth response as a function of quantity and quality of nutrient supply under different environmental conditions

(6) normal mortality rates and morality response to environmental pollution.

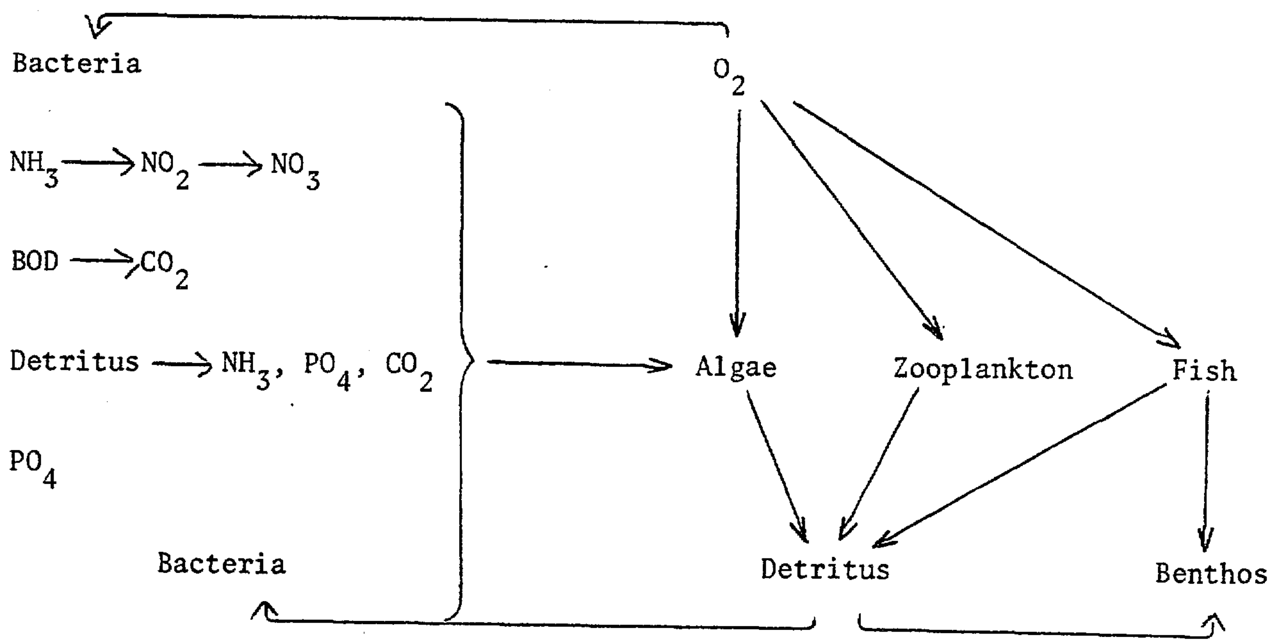
Modeling can compliment biological surveys and long term baseline studies in unpolluted estuaries. The interaction between modeling and biological observation should accelerate the modeling development" (Paulik, 1971, pp. 448-449).

The following table from Chen (1975, p. 85) illustrates the important ecological processes for modeling. They are divided into physical processes and biological processes.

1. Physical processes which are important:

   a. advection between segments
   b. diffusion between segments
   c. sedimentation between segments
   d. external input to the segment
   e. output to external from the segment
   f. reaeration
   g. solar insolation

2. biochemical transformation, uptake and release associated with the following:



The problem of hydrodynamic modeling is usually approached by dividing the estuary into a number of vertical and horizontal compartments, with transfers taking place between them. Often an estuary is considered a network of nodes with the processes considered to occur at a single point (Chen and Orlob, 1972). An elaboration of Chen's table is given by Dugdale for estuarine models:

> "sets of equations are required for: (1) growth rate of phytoplankton as a function of incoming radiant energy and a limiting nutrient; (2) ambient radiant energy intensities at physiological wave lengths; (3) limiting nutrient concentration as a function of uptake, regeneration and supply by mixing of surface waters with deep water; (4) loss rates for the phytoplankton, from grazing zooplankton and fish, from natural

mortality, sinking and mixing; and (5) activities of zooplankton and higher trophic levels (these terms may allow for increase in biomass or be held fixed when short periods of time are to be simulated)." (Dugdale, 1975, p. 188).

In an estuarine ecosystem model the foregoing processes are usually organized into low resolution compartments, usually employing combinations of the following categories: (Gade, 1975, p. 256)

biotic	abiotic
phytoplankton	nutrients
zooplankton	temperature
fish (nekton)	salinity
microbes	turbidity
benthos	detritus

In constructing the models and in attempting to include the above processes and compartments, the values used in the mathematical equations are often determined from varying sources:

1) independent laboratory measurements,

2) field data,

3) regression and extrapolation of original data,

4) professional "guess-timates", and

5) combinations of the above. (after Gade, 1975; p. 256)

Gade points out that "there exist very few truly verified estuarine models. This paucity is due largely to the costs involved in obtaining quality prototype data." (Gade, 1975, p. 256).

The use of systems models in assessment of ecological impacts in practiced in its most advanced state by the group of people working at the Institute of Resource Ecology at the University of British Columbia and at the International Institute for applied Systems Analysis at Schloss Laxenburg, Austria (Holling, 1974; Yorque, 1975, 1976; Spofford, 1975). Yorque (1976) in the introduction to "Ecological and Resiliance Indicators for Management" reports on an ongoing international project to "provide a series of handbooks for the environmental impact assessment process, modeling and assessment techniques and case studies demonstrating these techniques". This project should be finished in 1977 and it is suggested that the reader contact the Institute of Resource Ecology, University of British Columbia, Vancouver, B.C., Canada for information.

5.11.4. Apprpriateness of Models

Holling (1974) gives some criteria by which to judge if a simulation model is appropriate in an assessment of environmental impacts. Some other references useful for evaluating models are Holling (1966, 1973, 1975), Fiering and Holling (1974), Yorque (1975, 1976), Paulik (1971), Watt (1968), Hall (1976), Nihoul (1975), and Russell (1975). It may be necessary to use modeling if:

(1) it is necessary to handle large quantities of data

(2) there are many complex links between the elements of the system

(3) it is essential to determine the changes of the environment with time as a result of the proposed actions

(4) some or all of the relationships between the elements of the assessment can only be defined in terms of statistical probabilities (Holling, 1974, pp. 4-9).

It is important to be wary because no experimental test is ordinarily possible when a model is used for an EIS. The model should be "designed, from the start, with policy questions as the first consideration" (Holling, 1974, p. 11).

Therefore, it is unlikely that a full-scale ecosystem model will be associated with an EIS on dredging in the near future, but if it is the reviewer should consider the following points:

(1) Are all the major subsystems included in the model? (Holling, 1974)

(2) Are the geographical limits of the problem properly defined? (Holling, 1974)

(3) Are the "time horizons" of the model adequate to study the impact? (Holling, 1974)

(4) Are flow diagrams and variable identifications adequate?

(5) Who constructed the model? If it was built by one or two people it is less likely to represent a synthesis of disciplines than if several people from different fields contributed to the effort.

(6) Was adequate testing performed? The model should be run under extreme conditions as well as normal ones to explore its stability boundaries.

(7) What assumptions were used in building the model? Are they reasonable ones and are they hidden or explicit?

(8) Results should be presented in more than one form (Holling, 1974).

5.12 MITIGATION

5.12.1. Background

Occasionally, the tradeoff between public good and environmental good can be made more acceptable through the practice of "in-kind" mitigation. Mitigation has come to mean more than the transfer of ownership of estuarine lands, (including wetlands and submersible lands) to public ownership, the dedication of estuarine lands for certain natural uses, and the provision of funds for research or land acquisition. Mitigation is also more than either preservation or compensation for a resource--it is the process of actually creating new habitat or restoring areas previously impacted. Mitigation increases the cost of a project, alleviates adverse impacts from the project, and carries with it some risk of whether or not the stated outcome will be achieved.

5.12.2. Identification and Assessment of Sites

In identifying and assessing sites to mitigate the effects of dredging or filling, the following factors should be considered (from Oregon, 1977):

1. In selecting sites of similar biological potential, areas should be chosen with similar ecological characteristics. The intention of the requirement is to provide an area that, with time, will develop a qualitatively and quantitatively similar fauna and flora. The emphasis is on similar potential, not substitute productivity. The area provided does not have to be fully developed biologically; the opportunity, at least, should exist for it to develop once the area is returned to the estuarine system. However, the surface area of the estuary should not be diminished.

2. The most appropriate sites would be those in the general proximity of the proposed dredge or fill action. These would probably contain the most similar ecological characteristics. If similar areas are not available nearby, then areas in other parts of the estuary may be selected according to the similarity of the following characteristics (in order of importance, most important first):

   a. salinity regime
   b. tidal exposure and elevation
   c. substrate type
   d. current velocity and patterns
   e. orientation to solar radiation
   f. slope

3. If similar areas, or those with a similar potential, cannot be found or provided , then mitigation efforts should seek to restore areas or resources which are in the greatest scarcity compared to their past abundance and distribution. That is, those resources which have been most severely impacted by man's activities, measured by a ratio of present to past abundance, should be restored through mitigation.

4. Appropriate locations for mitigation activities include:

   a. Dredged material islands, which could be lowered (by removal of spoil) to the intertidal level, thus adding the surface area back to the estuarine system;

   b. Diked marsh areas which have been abandoned or are in disrepair; and

   c. Estuarine areas removed from effective circulation by causeways or other fills, where circulation can be restored or improved through replacement of the causeway with pilings or culverts.

5.13 BIOASSAYS FOR DETERMINING TOXICITY

5.13.1. Biological Responses to Toxicity

Dredging activities may release toxic materials into the water column. During removal when the sediment is disturbed, toxic substances either are solubilized or are transported with suspended solids to the water column. Unless precautions are taken, the supernatant runoff water from disposal sites may contain toxic substances leached from polluted spoils.

The response of marine organisms to this type of pollution is variable. Some organisms are able to resist many toxic materials, while others find that their ability to concentrate these trace elements for metabolism becomes a liability when excess concentrations are present. Some compounds which are unknown in the natural environment are similarly accumulated (e.g. PCB's) (Soule and Oguri, 1976). Specific sites of accmulation in animals include muscle, liver and gonadal tissues, and shell.

Soule classified the responses to a toxic substance as:

(1) "immediate death from lethal toxicity...

(2) the sustenance of life of the existing individual, but without growth or reproduction...

(3) the sustenance of life with growth, or

(4) the sustenance with growth and reproduction...."

> She also stated" the inhibitition of growth and development, while regarded as sublethal, actually becomes lethal over a larger period of time if the organisms cannot reproduce. In some cases, weakening of the organism causes the behavior patterns essential to feeding, protection, shelter, or reproduction to be abandoned. The impact of toxic substances...may not result in death during the (standard)...96-hour mortality tests...if behavioral patterns for habitat, feeding and reproduction are impaired" (Soule and Oguri, 1976).

In other words, there may be long-term deleterious effects which are not apparent in the short-term.

5.13.2. Bioassays

A bioassay, when used to determine tolerance levels for toxic substances, involves assaying sediments and elutriates resulting from resuspension of heavy metals, pesticides, and other pollutants. Animals or plants of various kinds are placed either in the elutriate or on the sediment samples and various measurements are made. Standard exposure times are (1) the 96-hour mortality test, and (2) the seven-day mortality test. Sacrifical analysis for heavy metals and other pollutants is then made (Brewer, 1976). Bioassays may be conducted on a static basis, such as an algal bottle test, or on a continuous flow basis as discussed by Brung (1973).

5.13.2.1. Short-Term Effects

The classical method for measuring the toxicity of a chemical to a marine organism is by the LC_{50} test. In this test the concentration which kills 50 percent of the test organisms in 48 or 96 hours is determined. This method has been heavily criticized because a) the organisms used have not been approprite b) the time durations of exposure are too short, c) the organisms may survive the test but have been affected in subtle ways such as growth, behavior, or spawning, d) the organism may react differently to the same concentrations in nature (avoidance, lack of boundary conditions) and e) that chemicals and environmental conditions are tested singley where as mixtures occur in nature Gray and Ventilla (1973) have suggested using growth rates of sediment living marine protozoans as a toxic indicator of heavy metals in sediments instead of the classical bioassay method.

Phytoplankton and zooplankton are the organisms most likely to be affected by short-term releases of toxic materials. The Corps of Engineers "404" guidelines (USACOE, 1976), Appendix C, states that short-term effects of chemicals released into the water column may best be evaluated with algal bioassays. The guidelines recommend the assay species and spell out techniques for sampling the sediment, preparing the standard elutriate, growing the cells, and evaluating their responses. The importance of control samples and replicate treatments is stressed. The algal cultures will respond with stimulation, no response, or inhibition. If the response is the same for the test algae using the elutriate as for the control algae, then this is taken to mean there would be "no adverse effect on phytoplankton at the disposal site" (USACOE, 1976). It must be stressed that algal bioassays are good for short-term effects and connot predict the long-term effects due to accumulation and "biomagnification" at higher trophic levels. Algal bioassays are also discussed in Weber (1973), USEPA (1971), and Patrick (1973). Slotta, et al., (1974b) describe in-situ bioassay attempts at a dredging site and discusses some of the problems encountered.

5.13.2.2. Long-Term Effects

The benthic and endemic pelagic organisms will be the ones subject to long-term effects. Techniques for bioassay using benthic organisms are not as well-developed as the algal assays. "Most (techniques) have been designed to test only the soluble phase of a single substance or perhaps a mixture of two or three substances" (USACOE, 1976).

In performing benthic bioassays, an attempt is generally made to simulate the bottom after disposal. The sediment at the dredging site is used as the test material and controls should include disposal site sediment and sediment from an undisturbed nearby reference area, or some other uncontaminated material. Disposal site water should be used in both test and control aquariums. Controls and test organisms should be handled in an identical manner, (i.e., illumination, feeding and, oxygenation must all be the same). When possible test organisms should be species from the study site or similiar habitats. Oxygen, in particular, is a problem in bioassays using benthic organisms because uncontrolled aeration can cause possible loss of volatile substances (USACOE, 1976).

Observation should be from several days to several weeks. Enough controls should be used to allow the measurement of effects on behavior. The response should be measured as "the effective concentration for 50 percent of the test organisms (EC50), defined as the concentration of the test material at which 50 percent of the test organisms exhibit the response being measured after a specified period of exposure" (USACOE, 1976). The exposure period must be fixed for this test, e.g. 96-hour exposure.

Recent work, reported in Soule (1976) describes the use of anchovy (Brewer, p. 15) killifish and croaker (Chamberlin, p. 33), crabs and zooplankton (McConaugha, p. 49), and polychaetes (worms) (Emerson, p. 69) as assay organisms. Also in Soules' work (1976) are two bibliographies, one by Chen and Eichenberger, and another by Reish and King, which cover studies of trace elements, hydrocarbons, and heavy metal concentrations in marine organisms (Soule, 1976).

5.14 EFFECTS OF SUSPENDED SOLIDS AND REDUCED OXYGEN ON THE BIOTA

5.14.1. Biological Effects of Suspended Solids

5.14.1.1. Background

The effects of suspended solids and high levels of turbidity on estuarine organisms are of concern in both removal and disposal projects. Several studies have summarized the ecological effects of suspended and deposited sediments (Sherk and Cronin, 1970; Sherk 1971; Sherk, et al., 1972; Perkins, 1974; and USACOE, 1975). In considering suspended sediment Mauer, et al., (1974) stated "There are so many provisions (season, original composition of sediment, hydrography, magnitude of dredging, frequency of dredging, type of dredging, number of dredges operating) that generalizations are difficult to make".

Sherk (1971) and Perkins (1974) suggest that increased suspended loads can affect estuarine biota through mechanical or abrasive action such as clogging of gills, and irritation of tissues. Deposition of suspended matter may interfere with demersal eggs of fish and zooplankton in upper estuarine areas (Mansuetti, 1961; Sullivan and Hancock, 1977). Decreases in egg and larval development of many shellfish and significant reductions in pumping rates of oysters occur at suspended particle concentrations in excess of 100 mg/l. Reduction of light penetration, availability of a surface for growth of bacteria and fungi, absorption and adsorption as well as release of various chemicals including nutrients and changes in temperature and oxygen fluctuations are effects also associated with increased sediment concentrations.

In areas which normally experience low turbidity values, the effect of increasing turbidity from dredging and disposal could have biological consequences within a few hours, while estuaries with naturally high turbidity values (20-400 mg/l), it is difficult to document causal relationships between dredge operations and response of the biota (Mauer, et al., 1974; Slotta, et al., 1974).

5.14.1.2. Acute Impacts

The impact of acute high concentrations of suspended sediments are related to the evolutionary history of the organism as well as its ability to acclimate (Hedgpeth, 1957; McCauley, et al., 1977). Laboratory studies of central California estuarine organisms found that species which normally inhabit muddy bottoms were not sensitive to high levels of suspended bentonite, while the species of fish, sandy bottom epifauna and fouling organisms which normally do not encounter long exposure to high levels or suspended solids were sensitive to high concentrations of suspended solids.

5.14.1.3. Chronic Impacts

The ecological effects of chronic turbidity are much more difficult to predict and more serious because of their potential for long term reduction in estuarine productivity, and our inability to accurately measure chronic effects (TM 5.5., TM 3.1.3.2.).

Prediction of impacts for any one sediment load (most estuaries contain many types of sediments and particulates) must at least account for the duration of exposure, the species affected, their life history stage, sediment concentration, sediment type, and the indigenous habitat of the species (Sherk, 1972).

5.14.2. Biological Effects of Reduced oxygen

5.14.2.1. Background

The effects of oxygen depletion in estuarine waters are of concern in both the removal and disposal phases of a dredging project. Oxygen depletion results from increased organic loading such as the stirring of organic sediments which have a biochemical oxygen demand (BOD). Resuspended material exerts an oxygen demand on the order of eight times that of the same material in bottom deposits

(Issac, 1965). Secondary effects of dredging projects such as canneries, urbanization, or projects which change circulation or flushing (marinas, dikes, docks) can result in increased organic discharges and subsequent oxygen depletion. Areas of known advective resuspension of substances toxic to phytoplankton or benthic algae can reduce the oxygen production.

Prediction of changes in dissolved oxygen is possible only if estimates of advective mixing, BOD (using techniques modified for seawater), temperature, salinity, and depth are quantitatively assessed. Rarely are all the required data present. Subsequent assessment of DO deficits on the biology then can be made through bioassays or existing data.

Estuarine environments generally require minimum dissolved oxygen concentrations of 0.75 to 2.5 mg/ℓ for test species to resist death for 24 hr and most marine species die when dissolved oxygen falls below 1.25 mg/ℓ (Perkins, 1974).

The Federal Water Pollution Control Administration (1968) listed reduced swimming speeds and changes in blood and serum constitutents occurring at dissolved oxygen levels of 2.5-3.0 mg/ℓ. Dissolved oxygen levels between 5.3 and 8 mg/ℓ are satisfactory for survival and growth, but in excess of 17 mg/ℓ, adverse effects are produced. Diurnal or other fluctuations in DO from 8 mg/ℓ produce significantly more physiological stress in fishes than fluctuations from 3 to 6 mg/ℓ.

Cairns and Scheier (1958) and Lloyd (1961) found that a fall in the oxygen concentration may increase the activity of any toxicants present in the water. In freshwater, the acute toxicity of zinc is increased by 50% when the dissolved oxygen falls from 6-7 mg/ℓ to 2 mg/ℓ.

5.14.2.2. Oxygen Depletion Due to Removal

Perkins (1974) suggests that although the sludge and mud in the bed of the Thames has a low oxygen demand, the dredging performed to remove the sludge deepened the estuary and therefore inhibited re-oxygenation. Short term oxygen sags have measured in the vicinity of hopper dredging (Slotta, et al., 1974); however, unless these low oxygen zones are wide spread or remain in the estuary for extended periods, or they occur during migration of diadromus fish which pass through estuaries on their way to or from the spawning and feeding grounds, they are not likely to be of concern or are impacts on the biota likely to be predictable.

Reduced oxygen is generally caused by stirring of sediments which contain a high chemical oxygen demand and must be considered for projects which occur in areas with low flushing rates. Since flushing and circulation may be seasonal, potential oxygen problems are also likely to fluctuate seasonally.

5.14.2.3. Oxygen Depletion Due to Disposal

Reduced oxygen from disposal usually occurs from the dispersal of dredged material which has a high BOD usually through aqueous disposal or runoff from containment sites. More chronic changes in oxygen structure usually occur through alteration of circulation patterns by the creation of dikes, spoil islands or other structures. These changes obstruct flushing or tidal prisms and can magnify DO impacts.

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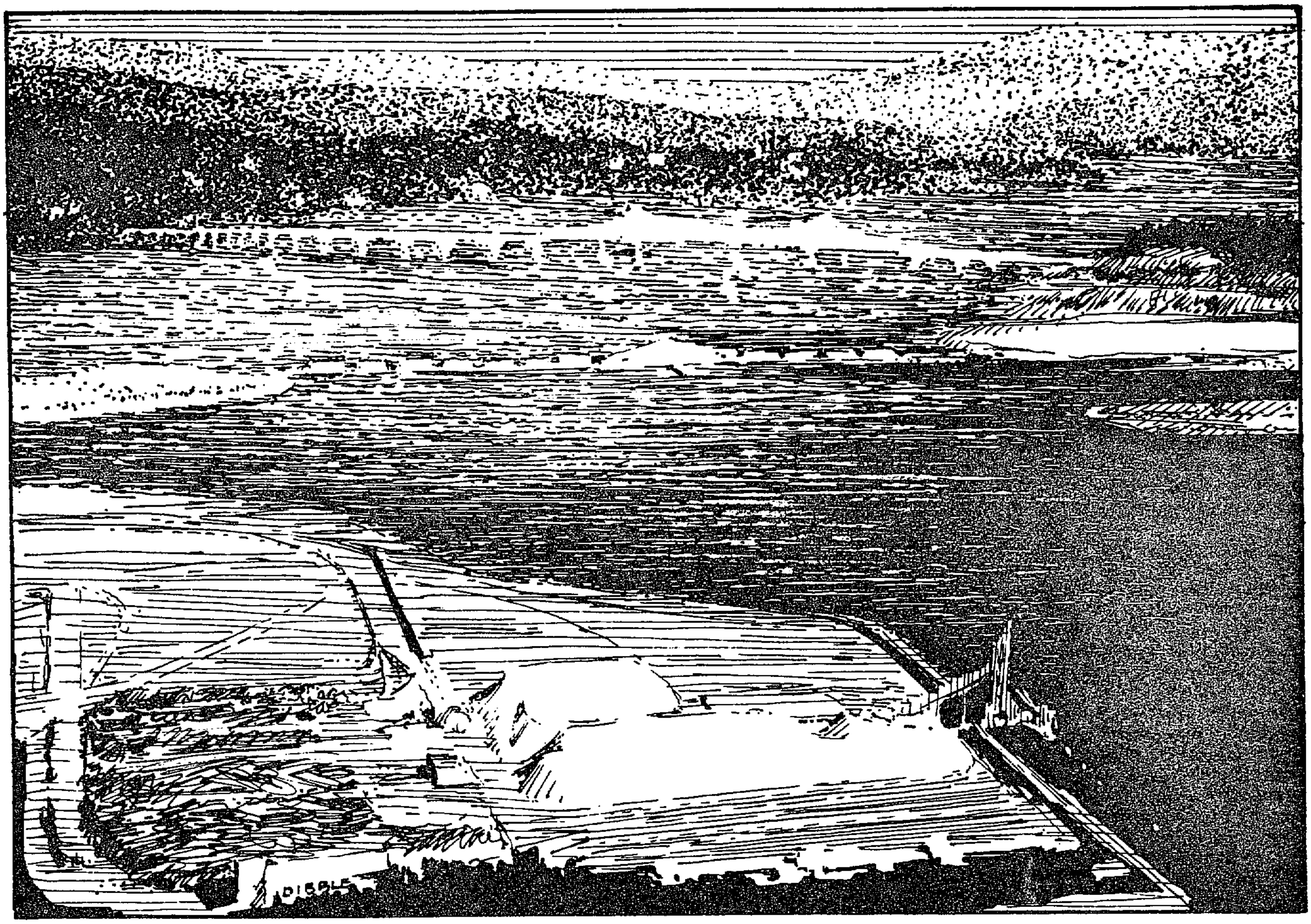

6. Economics

D. H. K. Farness

TABLE OF CONTENTS

6.1. SCOPE OF STUDY

Explanations made in other parts of this study on the scope of the study bear repeating. The economics sections are addressed to the comprehensive assessment which is necessary from the standpoint of the project decision process. The economic information requirements are large, however all information need not emanate from a single document. Environmental impact statements (EIS's) may provide some or all of the necessary information. What is included is a matter of both current institutional arrangements and the conceptual judgments of facilitators of particular EIS's. If a particular EIS for a particular project at a particular point in time does not require a comprehensive assessment of the economic impacts, certain categories of information can be excluded. Inasmuch as current requirements vary by institution, political jurisdiction and administrator and can be expected to change over time, the coverage in this manual has not been restricted to any particular current institutional requirements. Further, whatever the scope of a particular EIS, it is desireable that the individuals involved in its preparation and review have a broad understanding of all the economic impacts that are relevant to the project decision process. Consequently the reader is urged to examine the entire chapter even though parts may not directly relate to a particular EIS.

Also, it should be recognized that the social impacts are derivative from the economic impacts. Consequently, if social impacts are required in the EIS, regional economic impacts must be ascertained in order to facilitate the social impact assessment even if they are not desired for their own sake.

6.2. INTRODUCTION

An economic impact statement purports to report the economic consequences of a project. Obviously a definitive statement is not possible. A project's total impact in all of its dimensions can not be known. Highly interdependent social and natural systems are involved. Through these systems initial project impacts are transmitted over space and time and among industries and individuals. At best, only the largest and most immediate impacts can be accounted for. Futher, these economic impacts cannot be reported in their fullest detail. Selective quantification, aggregation and various summary measures in terms of time, place, industries and individuals are necessary if the myriad individual effects are to be comprehensible. It should be understood that the decisions that determine which effects are quantified, and how they are aggregated and summarized, are decisions that influence the relevance of a study for informing the decision process.

6.2.1. Impact Selection

Many different types of economic impacts may arise from a project. They include production impacts, income impacts, employment impacts, efficiency impacts, fiscal impacts, price impacts and income and wealth redistribution impacts. All are relevant. It should be understood that the degree of relevance is a matter of point-of-view. In effect, many different constituencies are involved, the world, the nation, the directly impacted region, and groups and individuals within the directly impacted region. As far as possible the effects should be studied and reported in a manner in which the economic consequences can be assessed for as many of these constituencies as possible. At a minimum, the assessment process should address the impacts from the point of view of both the nation and the directly impacted region.

The distinction among constituencies is very important for making economic equity judgments as contrasted with economic efficiency judgments. The benefits and costs which result from any project are not distributed uniformly among geographic regions, industries, groups and individuals. What may be a good project from a national point of view is not necessarily a good project from the standpoint of the directly impacted region, and conversely, what is a good project from the point of view of the directly impacted region is not necessarily a good project from the standpoint of society. The same can be said with respect to impacted industries, groups and individuals.

This chapter will be concerned with the economic impacts from the point of view of (1) the national economy and (2) the directly impacted region (and any other impacted region where the effects are large and identifiable). The objectives are to explain (1) what impacts are relevant and why, (2) what analytical techniques are appropriate for the assessment of these impacts and (3) what problems are associated in implementing the various analytical techniques and what to look for in judging whether they have been properly employed.

6.3. IMPACT ACCOUNTING FROM THE POINT OF VIEW OF SOCIETY

The selection of impacts and the appropriate methodology depends primarily on the constituency point of view. From the standpoint of the national economy economic efficiency measures and benefit-cost analytical techniques are appropriate. The test of a project is whether society is better off with it than without it. If the benefits exceed the costs the presumption is that society would be better off if the project were undertaken, however it should be recognized that another project might have an even more favorable benefit-cost ratio in which case it should be preferred to the project under consideration. At issue is whether the increase in production which the project enables is great enough to justify the resources utilized in its completion.

The impacts of a dredging project include both intended and unintended effects. The intended effects are the economic efficiency effects which would occur from the use of the project channel (rather than the best alternative which would be used in the absence of the project). The unintended effects result primarily from the environmental consequences of a project. They can be favorable but more typically they are unfavorable. They pose problems for identification, measurement and evaluation. Some are susceptible to being known, measured and valued at the time of the project assessment. The environmental impacts which are known and subject to evaluation in dollar terms primarily involve resources of current commercial or recreational value. They include damage or enhancement to recreational and fishery resources. Various techniques can be utilized to convert these favorable and unfavorable consequences into dollar measures which are comparable with the calculated intended efficiency effects. Except where mitigation (TM 5.12.) is involved the remaining impacts are not susceptible to being known and/or are not susceptible to measurement and/or are not susceptible to evaluation in social welfare terms. Although they are not quantifiable in measures comparable with the other project impacts they must be given consideration in the project selection process.

6.3.1. Intended Benefits

The channel created by a dredging project makes possible more direct and/or safer transportation routes which result in savings in real shipping costs. Fewer man hours are used in moving cargoes between origins and destinations. Fewer ship hours or days are expended per trip. Smaller stocks of output are tied up in transit, and hence the percentages of output in inventories and therefore costs of inventory financing are smaller. Possibly lower costs are incurred in damage to and loss of ships and even men.

It must be recognized that the benefits attributable to the project are net benefits. For traffic diverted from other routes they are the differences in shipping and inventory costs which would occur with and without the project (the without project costs being the costs which would be incurred in transporting goods via the best alternative route). Estimation of the net benefits from any net additional traffic (traffic which is induced by the decrease in transport costs in addition to the diverted traffic) requires a slightly different calculation. It is the difference between the transport costs incurred over the improved route and what shippers would be willing to pay for rights to use the improved route.

After shipping, fishing is the industry most likely to benefit from a dredging project. However, it should be recognized that the channel requirements for fishing boats are generally different from cargo vessels. All fishing activity must not automatically be treated as a benefit, only that component which is dependent on the particular channel resulting from the dredging project. Also the benefit accounting should follow the practices described for shipping. Only net benefits should be counted. Fishing activities which are diverted from other ports are benefited only to the extent that their costs of operation are lowered as a result of reduced distances between the fishing grounds and home ports, safer harbors, fresh water morages, etc. Net additions to fishing activity (fishing activity in addition to the relocated activity) which result from the project should be treated in a manner similar to the treatment of the net additions to shipping traffic. The net gain is the difference between the fishing transportation and associated moorage costs which would be incurred when utilizing the project and what fishermen would be willing to pay for the rights to use the project channel and related facilities.

Any other intended direct benefits should be assessed in a similar manner. Again only net benefits are allowable when the accounting is from the point of view of society. For example, any recreational and aesthetic benefits, intended or unintended, should be measured for the net increases in satisfaction. It should be recognized that the next best alternative is not likely to yield zero satisfaction.

Other benefits may accrue from disposal of the dredging materials which enhance the desireability of land adjacent to the channel. The relevant gain is the increase in land values which presumably reflects the increased desireability of the land and therefore an enhancement of its productive qualities. These can be expected to be small from a national point of view.

6.3.2. Intended Costs

The principal intended costs are the production costs incurred in the actual dredging and channel maintenance operations. Other public costs necessary to achieve the objectives of the project, for example navigation aids, which are not fully financed by charges to channel traffic must be accounted for either as costs or through a downward revision of the estimated user benefits.

6.3.3. Unintended Benefits and Costs

Other costs and benefits may occur as a result of unintended effects. These effects are frequently referred to as externalities or neighborhood effects. Economic activities may be displaced as well as enabled. Fishery and recreational resources may be damaged or enhanced. The environment may be altered in irreversible ways, the consequences of which may not be immediately known in their significant technological, geographic and time dimensions. Again, if a national point of view is maintained only the net loss or gain can be counted. Obviously only a part of these unintended effects can be accurately quantified in dollar measures.

Adverse or favorable effects on fishery resources require the estimation of the capitalized value of the lost or enhanced resources. It should be noted that the stream of benefits which is appropriately capitalized consists not of the values of the catch, but of the values of the catch less the costs incurred in its harvesting. Even with these adjustments, over-statement of the resource value occurs if it is one which is sufficiently abundant that more remote but unharvested alternative sources would be utilized in its place, in which case the value of the lost or enhanced resource is the capitalized annual differences between the costs which would be incurred in harvesting the impacted resource and the next best alternative sources.

In the case of a loss of a fishery resource or any other resource or adversely affected activity, an additional cost may be incurred as a result of undepreciated and unsalvageable plant and equipment.

Gains or losses to other activities, including recreational and related activities which yield aesthetic benefits, should be treated in a manner similar to fishery resources. In cases in which preferences for the activity are not directly registered through the market process as in the case of many recreational and aesthetically pleasurable activities, the derivation of dollar values for the lost or enhanced resources is more difficult. To date the various analytical techniques which are employed are generally agreed to be less than fully satisfactory. Where market processes are involved, values are indicated by what buyers are willing to pay as revealed by their behavior. The objective of the various techniques for estimating values in nonmarket situations focus on estimating what users would be willing to pay if user fees were charged for recreational, aesthetic and other amenity creating experiences. The reader is directed to the bibliography at the end of this section for detailed explanations of these various techniques and their shortcomings, particularly the monograph by Jack Knetsch which is a state-of-the-art piece.

Other environmental effects which do not involve resources which are currently of commercial, recreational or other amenity producing value are even more difficult to assess. In cases in which mitigation is required certain cost information is available, although these costs do not necessarily represent the correct social costs of the impact which is subject to mitigation. The remaining environmental impacts which are either unknown or not amenable to measurement or not susceptible to evaluation in social welfare terms, constitute one of the major evaluation problems besetting the project selection process. When known, they must enter the decision process measured in scientific terms not economic terms. They should be identified and quantified as fully as possible. Beyond this, without the introduction of a particular criterion, the impact statement has nothing to say about their desireability. Evaluation must necessarily be made at the project decision level.

6.3.4. Opportunity Costs

The emphasis on net rather than gross benefits and costs is based on the assumption that there are no net increases in resource utilization which arise from a project. The only benefits assumed are those resulting from efficiency increases. None are assumed to occur as a result of the employment of otherwise idle resources. If this assumption is incorrect, allowance can be made by adjusting project costs downward. From the standpoint of society, if resources are unemployed the opportunity costs of the unemployed labor and other production inputs are zero. No output would be given up by employing these otherwise unemployed resources. The reviewer is not likely to encounter this treatment of costs, however he may encounter employment benefits included among the total benefits. This should not be allowed, for it disguises a decision which treats labor inputs as having zero opportunity cost (when generally they do not), and may justify an otherwise economically inefficient project on employment grounds. Such a decision should be an explicit high level decision.

6.3.5. Discounting

In addition to the correct identification and quantification of costs and benefits, it is necessary to determine in what years they will be experienced. For reasons of comparability they must be converted to present value terms. This requires the selection of an appropriate rate of discount. Public agencies and economists typically disagree over the discount rate. Economists are concerned with overall economic efficiency in the national economy and advocate policies which result in an optimal use of the nation's resources. For this reason they favor a rate of discount which reflects society's rate of time-preference. This is a rate which is higher than the rate of interest at which the government can borrow and which is typically the rate used by agencies in the discount of project benefits and costs. If economists are correct, the consequence is that resources which would yield greater benefits in alternative uses are committed to public projects.

6.4. IMPACT ACCOUNTING FROM THE POINT OF VIEW OF THE DIRECTLY IMPACTED REGION

Evaluation of a project from the point of view of the directly impacted region requires a different set of measurements. Unlike assessment from the point of view of society, there is no single authoritative measure or analytical technique such as benefit-cost ratios and benefit-cost analysis. Three basic differences in impact accounting for the nation and for the impacted regions should be recognized. First, those net benefits and costs relevant to an accounting from society's point of view predominantly accrue to individuals and areas outside of the directly impacted region. Second, it is the consequences of the gross economic impacts rather than the net benefits and costs that are important from the standpoint of the directly impacted region in which a project's gross impacts tend to be most heavily concentrated. Third, many of these regional impacts cannot be identified as either costs or benefits on an *a priori* basis.

Because of the project, production, employment and income increase in the impacted region. Tax rates may increase or decrease, prices of land and other fixed supply resources tend to increase, availability of other goods and services may increase and their prices decrease if the size of the community is significantly increased, etc. These consequences are viewed differently depending on a persons status and values. Whether they represent costs or benefits is a matter of perspective. Hence, there is no simple criterion by which they can be aggregated and evaluated.

None the less, the regional impacts which are relevant to the project decision process are these quality-of-life impacts. Note, it is not the production impacts *per se* that are relevant. If they were aggregated for all affected regions they would cancel out except for the efficiency gains that are accounted for in the assessment of benefits from a national economic efficiency point of view. This assumes a full employment or near full employment economy. Resources are assumed to have many alternative uses. If not utilized in a particular project it is assumed they would be used in other production activities. Conversely, because they are used in a particular project they are not available for use in other activities. The particular production gains from a project are offset by production decreases elsewhere.

Although conditions of full employment do not always prevail, the assessment accounting from the point of view of the impacted regions should be as if full employment prevailed. Any necessary policy adjustments in response to a less than full employment economy should be made at the project decision level, not in the impact assessment process.

The fact that the production effects virtually cancel out when all the affected regions are taken into account should not be construed to mean that other production related effects also cancel out and therefore can be ignored. It is recongized that in terms of certain social and economic characteristics all communities are not equally adapted to accomodate production changes. In order to assess these nonproduction but production related effects it is necessary to estimate the regional production impacts even if they are not relevant *per se*. In fact, much of the regional impact assessment process must be directed to estimation of the production impacts which, in conjunction with appropriate baseline data, constitute the basic information inputs for assessment of the regional quality-of-life impacts. Accordingly, much of this section is devoted to techniques which are appropriate for estimation of the aggregate regional production impacts. This material is then followed by a discussion of the derivative quality-of-life effects.

6.4.1. Aggregate Production Impacts

Figure 6.1. classifies the aggregate production impacts and indicates their interrelationships. Estimation of these impacts is generally accomplished in several stages involving two general types of impacts and several different techniques of estimation. Typically the impacts are classified as direct and indirect. Here the indirect will be classified into two categories, indirect-expenditure-linked and indirect-supply-and-structure induced and these in turn will be divided into a number of subcategories.

6.4.1.1. Direct Impacts

The direct impacts arise from the dredging operation itself and from the activities that are the immediate intended beneficiaries of the channel, for the most part waterborne shipping and the associated land-side cargo-handling and transportation activities, and possibly commercial fishing. The derivation of the direct effects requires estimation of the probable volumes and types of traffic which would occur as a result of the project. If the project involves maintenance of an existing channel, recent traffic is a relatively good indicator of future traffic, however other developments which may have a bearing on the port's service area must also be considered. Where the dredging involves a new channel or a channel of enlarged dimensions, estimation must be made for traffic which would be diverted to the port in response to the cost savings which the more direct or safer route would afford as well as estimation for growth in the traffic involved. It is important that these estimates be limited to probable traffic and not potential traffic.

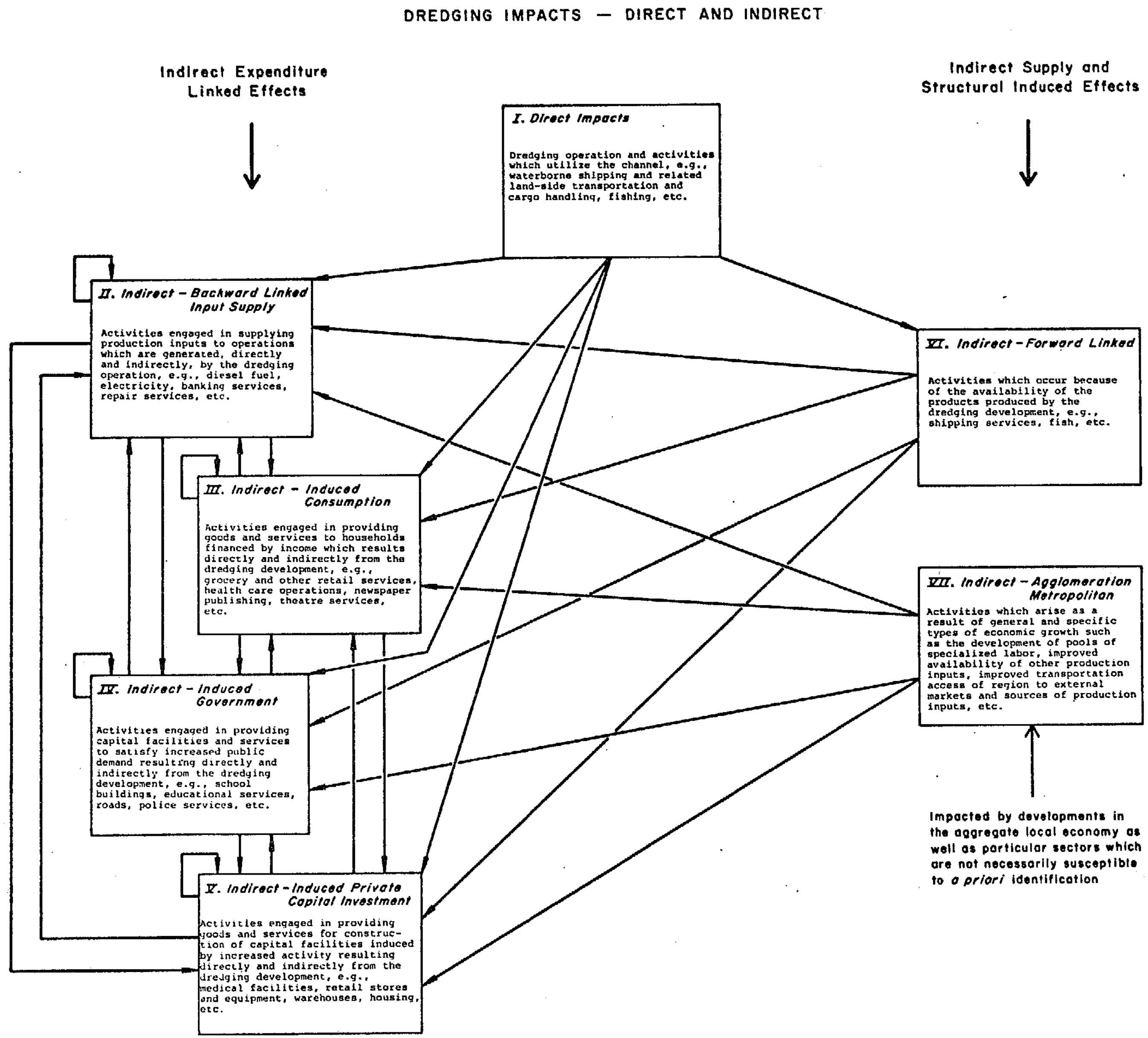

Figure 6.1. Summary of Dredging Economic Impacts and Their Relationships

6.4.1.2. Indirect Impacts

The direct impacts give rise to indirect impacts. These are of two general types. One type results from the flow of expenditures which the directly impacted industries initiate and which are enhanced through the interaction of the indirectly affected avtivities. These expenditure impacts will be referred to as expenditure-linked impacts. The second type results from changes which occur in the supply conditions and structural characteristics of the regional economy. These impacts will be referred to as forward-linked and agglomerative-metropolitan impacts.

6.4.1.3. Indirect Expenditure Linked Impacts

The indirectly affected activities identified as expenditure linked include (1) activities engaged in supplying production inputs to the directly impacted and indirectly impacted activities and wholesale suppliers and/or manufacturers of fuel, banking services, fishing nets, etc.), (2) activities engaged in supplying consumption goods and services to the labor force and owners of the directly and indirectly impacted industries (wholesale and retail suppliers and/or manufacturers of medical services, groceries, haircuts, etc.) (3) activities engaged in supplying capital goods and inputs for construction, expansion and maintenance of private capital facilities (retail and wholesale suppliers and/or manufacturers of pilings for docks, pile driving services, cargo handling machinery, shipbuilding and repair services, lumber, cement, plumbing and electrical supplies for housing, construction services, etc.) and (4) current local government activities to meet the needs of new households and industrial activities (police and fire services, education and other public services and wholesale and retail suppliers and/or manufacturers of traffic tickets, light bulbs, uniforms, etc.), and activities engaged in supplying capital goods and inputs for construction, expansion and maintenance of public capital facilities (retail and wholesale suppliers and/or manufacturers of steel and cement to build roads and buildings, snowplows, sewage treatment plants, etc.).

These impacted activities vary in their relative magnitudes, timing, and predictability. The first two, impacts involving retail and wholesale suppliers and/or manufacturers of production inputs and consumption goods, are the largest, they occur with the shortest time lags, and their correct magnitudes are the most susceptible to prediction. For example, an operation which utilizes a gasoline engine requires fuel in some fixed relation to the time of the engine's operation. Purchases of food and other consumer goods are directly related to income, which in the example depends on whether or not the engine operates and how long it operates. The time lag between the production activity and the resulting purchases is short and the magnitudes of the purchases are predictable with a high degree of accuracy.

The effects of a project on the other two types of expenditure induced activities are quite different. An increase in economic activity and population increases the demand for private capital facilities and public services and capital facilities, and tends to increase production in both of these types of activities. The magnitudes and timing of the production responses are somewhat uncertain however. Police services can be spread more thinly. Schools can be used more intensively. Replacement of machines and other production facilities can be delayed. Despite their lesser importance and greater uncertainty as to timing and magnitudes, these impacts should not be ignored. For proper project evaluation both short run and long run effects must be accounted for.

Typically the expenditure-linked impacts are derived by plugging the direct effects into an analytical model which then spells out the indirect effects (or the total effects including both the direct and indirect). The most common models are economic base, intersectoral flows, input-output and econometric. It should be understood that these impact models do not all estimate the same indirect effects. Typically economic base and econometric models account for all of the four indirect expenditure-linked impacts. Intersectoral flows models are generally structured so that either some or all of the impacts can be derived depending on whether the objective is to measure short run or long run impacts. Input-output models typically account for only the consumption and indirect exports.

6.4.1.4. Indirect Supply and Structure Induced Impacts

The second type of indirect economic impacts which are identified as forward-linked and agglomeration-metropolitan impacts tend to be the most difficult to predict. Forward-linked activities are those activities which are induced to locate in a region because the availability within the region of the products produced by the directly impacted industries. Industries for which these products are important inputs in their production processes are attracted to the region. A dredging project results in the regional availability of shipping services. In addition to the economic activity associated with movement of goods through a port, the availability of shipping services may render the port desireable for the location of nonshipping activities for which water transport is the most economically efficient for the movement of either or both their inputs and outputs. A smelter which processes channel-dependent waterborne ore is a forward linked industry as is a fish processing plant utilizing fish that are landed by channel-dependent fishing boats. These forward-linked activities also give rise to expenditures in the region. These expenditure linked impacts can be estimated by the same techniques used with respect to the direct impacts.

Agglomeration and metropolitan effects pose even more difficult estimation problems and probably can be ignored for small dredging projects or dredging projects which have a relatively small aggregate production impact on a region. However, if the impacts are large they should be considered.

The agglomeration and metropolitan effects operate in a way similar to the forward-linked effects. If developments arising from the directly and indirectly impacted industries alter the availability of certain specialized production inputs in the region, for example the availability of labor of particular skills, or if overall growth occurs in the economy of the region as a result of the project, for example growth which results in the development of new or improved transportation access to the area, the locational desireability of the region may be enhanced. Industries which locate in the region as a result of changes in the region's locational desireability may engage in production for either internal or external markets. If they serve the regional market, their impacts may be picked up with the indirect-expenditure-linked effects depending on whether the parameters of the impact model utilized make sufficient allowance for import substitutions as the regional economy grows. If, however, the attracted activities are oriented to external markets, the more typical case, their direct impact on the region must be estimated independently and their consequent expenditure-linked impacts derived by means of the same techniques used with respect to the other exogenous impacts.

6.4.1.5. Exogenous and Endogenous Impacts

These impacts also can be classified as exogenous and endogenous. From a strictly analytical point of view they are different by reason of the origin of the decisions and financing which give rise to them. Exogenous impacts result from decisions which are made by authorities, businesses and individuals who reside outside of the impacted area and which are financed by funds orginating outside of the area. The exogenous impacts include (1) the direct impacts, (2) that part of the indirect-expenditure-linked-input-supply production which is embodied in the area's exports (indirect exports) and (3) the supply-and-structure-induced impacts insofar as these induced activities engage in production for external markets. The endogenous impacts result from decisions which are made by authorities, businesses and individuals who reside within the impacted area and are financed by funds which are internal to the region. The endogenous effects include (1) all of the indirect-expenditure induced effects except for the part of the indirect-backward-linked-input-supply production (indirect exports) which is embodied in the area's exports and (2) that part of the supply-and-structure-induced production which is utilized within the area, likely a very small part of the total.

This is a conceptually correct classification of the exogenous and endogenous elements. However in certain analytical models which are utilized in the assessment of impacts, different classifications may be encountered. The differences pertain to the mechanics of the models, not conceptual differences. When used appropriately, all of the models discussed below enable the estimation of the total long run local production impacts which result from a dredging project. Some of the models in their typical application, do not estimate all of the four types of indirect-expenditure-linked impacts. None in their typical application estimate forward-linked or agglomeration-metropolitan effects. It is therefore important that the members of an impact assessment team and reviewers of impact assessment statements understand both the measurement objectives and the way in which various analytical models must be utilized to achieve these measurement objectives.

6.4.2. Analytical Models

The correct utilization or construction and utilization of the four different types of impact models, at a minimum, requires an understanding of which activities are treated as exogeneous and endogenous. To facilitate an understanding of the differences among the models, all production is classified into four categories based on ultimate use: (1) production for export, (2) production for local consumption, (3) production for local investment and (4) production for local government. These categories are represented by symbols, X, C, I and G, respectively.

All production ultimately reaches one of these ultimate use categories regardless of whether it is (1) an intermediate product (one used in the production of other products as in the case of cans and canned goods) or a final product, or (2) in response to direct (exogenous) or indirect (endogenous) demand, or (3) is induced through indirect expenditure or indirect supply-structural linkages. These four classifications encompass all of the activities which, in Figure 6.1 above, have been classified into seven direct and indirect impact categories. Once the basic models are delineated in terms of these four ultimate-use-production classifications they will be reviewed in terms of how they must be utilized to estimate all of the indirect impacts which, of course, is the objective.

6.4.2.1. Exogenous Components

The exports have strategic importance in determining the level of regional production. Conceptually they are the only exogenous component of demand. In the long run all of the others are determined by the level of economic activity within a region. In the actual structuring of the various models, components other than exports are treated as exogenous, however. If some nonexport production is treated as exogenous, the model does not functionally relate

relate exports to these other model-exogenous components of production activity. Hence, in order to project the total impact of a change in exports (in the case of a dredging project, the activities involved in the actual dredging and direct use of the channel) it is necessary to define relationships in addition to those accounted for in the model.

The structure of the various models can be expressed by means of the multiplier concept even though a single multiplier is not derived in input-output and econometric models. The multiplier is given by the expression $\frac{\text{total activity}}{\text{exogenous activity}}$. Using the symbols X, C, G and I for the four components of the area's production, the numerator in all of the models is X + C + G + I. The denominator depends on what is treated as exogenous.

6.4.2.2. Structure of Regional Impact Models

In the typical usage, the various regional economic models are structured as follows. For the intersectoral flows model three variants are given, short-run, long-run and intermediate-run. The third case requires the disaggregation of local government into current government (G_1) and government investment (G_2) and local investment into business investment (I_1) and housing investment (I_2). The input-output case assumes consumption to be the only endogenous component of final demand however other structures are infrequently utilized.

Economic Base

$$\text{Multiplier} = \frac{X + C + G + I}{X}$$

Intersectoral Flows

$$\text{Long-run Multiplier} = \frac{X + C + G + I}{X}$$

$$\text{Short-run Multiplier} = \frac{X + C + G + I}{X + G + I}$$

$$\text{Intermediate-run Multiplier} = \frac{X + C + G + I}{X + G_2 + I_1}$$

Input-Output

$$\text{Multiplier} = \frac{X + C + G + I}{X + G + I}$$

Econometric

$$\text{Multiplier} = \frac{X + C + G + I}{X}$$

6.4.2.3. Model Implementation Expenditure Induced Impacts

These multipliers or their equivalents in input-output and econometric models are the tools which are utilized in making the expenditure induced production impact estimates. The effect of a change in exports when expanded by the multiplier gives all or some part of the expenditure induced impacts. The clue to what part of the impacts are derived is found in the denominators of the various multipliers. If exports alone appear in the denominator then all of the other expenditure-linked production has been treated as endogenous. If, however, other terms appear in the denominator, then they have not been treated as endogenous. Hence the impact of an export change on them must be independently estimated and then incorporated with the exports to arrive at the total long run impact. In all cases the other exogenous elements (ΔG & ΔI) should be thought of as being functionally related to exports even though the relationships are not allowed for in the model. Unfortunately for the researcher he must go beyond the model and estimate these relationships which are not provided for. The expenditure linked impacts for the various models must be calculated as follows.

Economic Base

ΔX (Multiplier) = Total expenditure induced production impact

Intersectoral Flows

Long-run ΔX (Multiplier) = Total expenditure induced production impact

Short-run

$$(\Delta X + \Delta G + \Delta I)\ (\text{Multiplier}) = \text{Total expenditure induced production impact}$$

Intermediate-run

$$(\Delta X + \Delta G_2 + \Delta I_1)\ (\text{Multiplier}) = \text{Total expenditure induced production impact}$$

Input-Output

$$(\Delta X + \Delta G + \Delta I)\ (\text{Multiplier}) = \text{Total expenditure Induced production impact}$$

Econometric

$$\Delta X\ (\text{Multiplier}) = \text{Total expenditure induced production impact}$$

6.4.2.4. Model Implementation, Total Impacts

These impact measurements pertain only to the expenditure related impacts. Insofar as supply-structure induced changes occur, it also is necessary to calculate the forward linked and metropolitan-agglomeration impacts. These must then be applied to the various multipliers to arrive at estimates of the total production impacts.

Consequently the total impact calculations must include two additional exogenous components if the impact projections are to be complete. For dredging projects with small impacts they may be zero, particularly the agglomeration-metropolitan effects, nonetheless they should be considered for all projects. Symbols FL and AM represent forward-linked and agglomeration-metropolitan effects. These additional exogenous elements should be thought of as being functionally related to exports even though the relationships are not allowed for in the model. Again it is the task of the researcher to establish these relationships not provided for in the models. The total production impacts must be calculated as follows.

Economic Base

$$(\Delta X + \Delta FL + \Delta AM)\ (\text{Multiplier}) = \text{Total production impact}$$

Intersectoral Flows

Long-run

$(\Delta X + \Delta FL + \Delta AM)$ (Multiplier) = Total production impact

Short-run

$(\Delta X + \Delta G + \Delta I + \Delta FL + \Delta AM)$ (Multiplier) = Total production impact

Intermediate-run

$(\Delta X + \Delta G_2 + \Delta I_1 + \Delta FL + \Delta AM)$ (Multiplier) = Total production impact

Input-Output

$(\Delta X + \Delta G + \Delta I + \Delta FL + \Delta AM)$ (Multiplier) = Total production impact

Econometric

$(\Delta X + \Delta FL + \Delta AM)$ (Multiplier) = Total production impact

6.4.2.5. Production Impact Assessment Errors

Incorrect measurement of impacts can occur for two basic reasons. One results from incorrect use of a particular impact model, probably as a result of not understanding the structure of the model utilized. Consequently certain impacts are sometimes assumed to be endogenous to the model when, in fact, they are treated as exogenous and therefore must be estimated by a seperate operation. The second reason results from the poor quality of the model, either for reasons of conceptual or data inadequacies. To guard against the second type of error, impact-assessment team members and reviewers of impact assessment statements should have some understanding of the models involved, particular sources of error and certain rule-of-thumb guides for judgement of particular model parameters. With this in mind, each of the four types of models will be considered in varying detail following a general discussion of parameters and units of measurement which pertain more or less to all four models.

6.4.2.6. Model Parameters

Obviously it is important that the underlying data be accurate and current. Not so obvious is the desireability of a historical dimension to the data base and therefore parameters which are marginals. Frequently the data base is for one point in time and consequently the parameters are averages. The result is to understate the expenditure-induced indirect effects in a typical growing community. Inasmuch as financial constraints often limit the collection of primary data or even the utilization of available secondary data, the selection of the parameters utilized in estimating a project's aggregate production impacts is often drawn from the best model already available. This means the use of models which are somewhat out of date or models developed for other regions which are judged comparable. This is not necessarily undesireable if the researcher is sensitive to the dangers involved. It is preferable, of course, to develop a current model for the subject area. Correct assessment procedures which employ models with inaccurate parameters can lead to errors quite as serious as those which arise from incorrect assessment procedures. If the results of impact assessments are to be meaningfully reviewed it is essential that information be reported on both method and data base.

Data Measures (Units of Measurement). Different data measures also may be employed in measuring production impacts. Value added, personal income, gross and net regional products, jobs and payroll are all legitimate measures, they reflect only regional activity. Sales, on the other hand, are an ambiguous measure for reasons of both double counting of regional activity (for example in-region produced cans may be counted twice, once in sales of the can factory and once in the sales of the cannery) and inclusion of non-regional activity (cans imported into a region are included in the sales of the canneries). Units of physical product of different enterprises are difficult to evaluate and impossible to aggregate and therefore are not particularly useful for assessing impacts. The choice of analytical models resolves the issue of measures in the cases of input-output and econometric models. If an economic base or intersectoral flows model is utilized a choice is necessary. Because of the availability of employment data, jobs are often chosen as the unit of measure. It should be recognized that these are not perfectly homogenous units. They vary with respect to both their rate of renumeration and the amount of associated nonlabor (property) income which along with the job income is part of the purchasing power which gives rise to indirect expenditure-linked impacts. If jobs are used as a measure, it is preferable that they are standardized to reflect these differences. Payroll data only standardizes with respect to rates of pay, not associated property income.

6.4.2.7. Economic Base

Economic base models are the least sophisticated and the least expensive to develop and/or implement. They are, therefore, the most likely to be employed in a dredging impact study. They also require the least technical expertise to implement and therefore may be the most likely to be misused. Consequently the techniques employed in implementing economic base studies will be discussed in greater detail than the other less likely used and technically more sophisticated techniques.

In economic base models all production activity is classified into two categories, basic (export) and nonbasic (local, residentiary, etc.). The basic activity consists of production for buyers external to a region (or buyers within a region who finance their purchases with funds derived external to the region as in the case of tourists, the retired who live on transfer payments and owners of property external to the region who receive income from that property, etc.). The nonbasic activity consists of production for residents of the region who derive their income from within the region.

The classification of production activity into the two categories is typically accomplished by one of four different techniques: (1) survey, (2) location quotient, (3) minimum requirements and (4) others which may be characterized as assumption and intuition.

Survey Method. The survey method which develops primary data is probably the most accurate, yet there are a number of problems which should be kept in mind including (1) representative sampling, (2) accurate reporting, and (3) identification of indirect exports.

Location Quotient Method. The location quotient method utilizes secondary data. If it is applied to all industries for identification of the basic and nonbasic components of production it is a very inaccurate method. It assumes any production in a regional industry which is in excess of the industry's proportion of the national output is necessarily production for export. The formula for the location quotient is

$$\frac{\text{\% of regional employment in industry X}}{\text{\% of national employment in industry X}}.$$

If the coefficient is greater than one, that share of production in excess of one (in excess of the national average) is considered to be export production. If the coefficient is one or less than one, all production is assumed to be for local markets. This method is not very accurate for industries (1) in which crosshauling is common, (2) for which the industrial classifications are broad (include heterogeneous activities), (3) which produce goods or services for which per capita consumption varies widely by region, (4) which produce goods and services for which productivity varies widely by region and (5) which produces capital, military, export or other goods and services which are not purchased by households on some uniform per capita basis.

Crosshauling. Crosshauling occurs in industries which produce goods which are high in value relative to weight, for example bathing suits. Oregon produces Jantzen bathing suits and ships them around the world while at the same time it imports other brand name suits from beyond its borders. This is an example of crosshauling. The location quotient technique assumes that all local demand is met by local production and only when local production exceeds local demand do exports occur. In other words, it allows for zero crosshauling. Other production involves a crosshauling effect because the buyer moves, not the product. Motel services provide the best example. By assumptions implicit in the method, if the regional level of activity in provision of motel services is proportional to the national production of motel services the entire local production is assigned to the nonbasic category. Obviously this is a mistake. Local motel services are primarily used by visitors and the majority should be classified as an export or basic activity.

Grossness of Classification. If industrial classifications are broad (inclusive of heterogeneous activities) equally erroneous basic and nonbasic classifications result. For example, if all foodprocessing is treated as a single industry and the regional location quotient coefficient is equal to one, then all food processing would be classified as production for local markets. Local production is assumed sufficient to meet all local demand. However, suppose all production is in the processing of maraschino cherries. Given the gross classifications and the assumptions implicit in the technique, all processed food consumption in the area is assumed to be met by maraschino cherries.

Consumption and Productivity Assumptions. Similar mistakes occur in cases of air conditioners, snow shovels, and other items for which per capita consumption is not uniform over the nation, or for tanks, missles, exported raw cotton, farm tractors and other nonconsumer items. The assumption of uniform productivity can contribute additional distortion to the classifications in instances in which productivity varies significantly among regions.

Selective Application. Selective use of the location quotient method for industries which are narrowly defined (homogeneous in their activity composition), for which crosshauling is uncommon and for which the products are consumed nationally on a fairly uniform per capita basis can yield reasonably accurate estimates of the basic and nonbasic components of regional production. For industries which do not fit these conditions other methods must be used in order to derive accurate classifications.

Minimum Requirements. The minimum requirements technique also utilizes secondary data. By means of sampling the percentage distributions of employment by industry in a number of regions of comparable size (and possibly comparable in terms of other characteristics) a judgment is made as to the minimum employment requirements necessary to meet the local needs of communities of the particular size class. The minimum requirement can be either the percentage employment in the community with the lowest employment in the particular industrial classification or the community with the second or third lowest, etc. Given this benchmark for the minimum requirements in all industries, all employment in excess of the various industry minimum requirements is assigned to the export category.

This method is not very accurate for industries (1) in which crosshauling is common, (2) for which industrial classifications are too narrow or too broad, (3) which produce goods or services for which per capita consumption varies widely by region and (4) which produce goods and services for which productivity varies widely be region. Although these industry characteristics which contribute to erroneous estimates are the same as those identified in the critique of the location quotient method, the reasons for the errors are generally different. Consequently each of these characteristics must again be considered with respect to the minimum requirements method. The biases in the location quotient method favor the under-estimation of exports. The biases in the minimum requirements method favor the overestimation of exports.

Crosshauling. The region with the lowest or second or third lowest bathing suit production may have zero production and hence all bathing suits produced in other regions are assumed to be exported which is to allow for too much crosshauling. In the case of motels and other industries which primarily serve a nonlocal clientele the error tends to be the same for both the minimum requirements and location quotient methods, too much production is assumed to be for local residents.

Fineness and Grossness of Industry Classifications. If industry classifications are very narrow (such as maraschino cherry processing) the method will result in the assignment of all production to the export category even though some small part would be consumed locally. Broad classifications tend to result in a canceling out of specialized production. Maraschino cherries processing, meat packing, beer manufacturing, and fish packing are all a part of the food processing industry. Using a broad food processing industry classification, the minimum requirements method tends to assign all production to local markets when, in fact, the majority of the output is exported.

Consumption and Productivity Assumptions. The assumption of equal consumption patterns among all regions has the consequence of assigning the entire output of regionally consumed items such as air conditioners and snow shovels to the export category (assuming that the sample of regions utilized in establishing the minimum requirements included unlike regions for which production of these items was zero). Of lesser importance is the distortion which arises in cases of significant productivity differences among regions. Implicit in the method is the assumption that a given number of workers produce the same output whatever their geographic location.

Reliability of Results. Conceptually the method involves assumptions which are difficult to accept. None the less, the method when applied to all economic sectors has yielded better results than the location quotient method. Unfortunately, there is no basis for any *a priori* recommendation of the ideal application in terms of particular industries or particular industrial classifications. It would appear that the industry definitions settled upon in the original empirical work were quite satisfactory for reasons of luck more than design. They happened to be the census classifications by which census data were reported. Significantly finer or grosser industry classifications would have had sizeable effects on the results.

6.4.2.8. Size of Multipliers

In some sense the utilization of the minimum requirements method and the uncritical use of the location quotient method requires a leap of faith. As protection against serious errors, one should be suspicious of multipliers of more than one and one-half for regions with a population of approximately five thousand, or more than two for regions of thirty thousand or more than three for regions of 500,000. These are very rough guides. The size of the multiplier depends on the rate of expenditure leakages from the local income stream. The market size of an area is an important determinant of that rate. Small market areas cannot justify many types of specialized production ranging from daily newspapers and orthodonists to operas and stock exchanges. In addition to size, geographic location with respect to other communities is important. Two communities of equal size but one geographically issolated and the other near a large metropolitan center will develop differently, with the isolated community more likely to develop functions that the other does not for want of good alternatives. Consequently the multiplier for the isolated community would be somewhat larger. Other variables which affect the magnitude of the multiplier include the character of the basic industries, ethnic mix of population and per capita income.

6.4.2.9. Assumption-Intuition Method

The other techniques for implementation of an economic base study, assumption, intuition, etc., also are subject to various types of errors. Much depends on the judgment of the principal investigator. Again one guide to the accuracy of studies employing these methods is the general magnitude of the multipliers they produce.

6.4.2.10. Intersectoral Flows, Input-Output and Econometric Models

Intersectoral flows analysis is an elaborated economic base technique which requires primary survey data for its implementation. The accuracy of the method is primarily contingent on representative sampling and accurate reporting as well as correct data processing and implementation of the model.

It is unlikely that the typical dredging project impact assessment would warrant the development of a model as expensive as an intersectoral flows or input-output or econometric model. If any one of these models is utilized it is likely because it was already available for the area or some other area which is believed to be enough similar to warrant its use as a proxy. In such cases concern should be directed to the quality of the model, its up-to-dateness, and if it pertains to another region, its appropriateness when applied to the subject region. In the case of a dredging project in an estuary not previously dredged or a dredging project which significantly alters the structure of a local economy, for example a project which would enable the siting of a refinery, any input-output or econometric model already available for the area would have to be substantially modified if it were to be used to predict project impacts. In the case of input-output models it would probably necessitate the addition of an industry or industries within the processing sector and the revision of the various coefficients within the model.

In most cases the reviewer cannot be expected to thoroughly assess the quality of particular input-output or econometric studies which may be utilized. This certainly applies to the data gathering and processing stages. However certain tests can be administered which give some indication of a model's reliability.

Input-Output. A particular failing in input-output models arises in the making of consumption endogenous to the model. Sufficient leakages from the local consumption spending stream must be allowed for. These leakages occur as a result of savings (including monthly payments on housing loans, insurance payments and pension fund contributions), tax payments, commuter and migrant wage leakages, profit leakages to absentee property owners, and direct import purchases which bypass the local economy (payments of tuition, mailorder purchases, magazine subscriptions, vacation expenditures, shopping expeditions to external communities, etc).

The aggregate leakages allowed for in the model can be calculated by examining the value added row or rows in the gross flows (transactions) table and the coefficients in the household payments row and consumption column in the technical requirements (direct coefficients) table. Coefficients for the household payments enable determination of the component of the value added which local consumption is assumed to be a function of. The value added can be reported in a number of different ways and the part which is reflected in the household payments coefficients in the technical coefficients table can range from the entire value added to only that part which is spent on locally procured consumption goods and services. The difference between the total value added and the share which is reflected in the household coefficients (that part of value added which consumption is functionally related to in the model) represents an allowance for leakages from the local value added (that part of the value added which is not spent on consumption goods and services). For example, if the total value added is 100 and the household payments reflected in the technical coefficients table are only 80 then the consumption is functionally related to only eighty percent of the value added, possibly the wages and salary component. A leakage of twenty percent has been allowed for in the partitioning of the value added. A second allowance for leakages can be found by summing the consumption coefficients which pertain to purchases from local industries. Suppose these sum to .7, then of the eighty percent of the value added that is not "leaked out" in the partitioning of the value added, leakages of thirty percent are allowed for in the consumption coefficients, or another twenty-four percent of the total value added which brings the total leakages allowed for to forty-four percent.

This may seem large, however recent national income data reveal that consumption purchases financed with labor and property income (excluding transfer payments) amount to only approximately fifty-four percent of the gross national product (GNP) and sixty percent of the GNP less indirect business taxes. If an area is typical of the national economy then its consumption expenditures which are functionally related to local income can only account for approximately sixty percent of its value added (assuming indirect business taxes are not included in the value added).

Of course all of these consumption expenditures will not occur in the area in which the value added occurs. Commuter labor and nonresident recipients of property income can be assumed to make the majority of their consumption purchases elsewhere. Inasmuch as property income (proprietors income, rents, dividends, and interest) comprises approximately twenty percent of the total disposable income in the nation, property income leakages resulting from nonresident ownership of property may be large.

An even larger source of leakages results from the direct purchases of consumption goods and services which are made outside of the region, thus bypassing the local service and retail sector. Mail order purchases, vacations, shopping trips to adjacent regions for consumer durables, automobiles, and high fashion clothing result in obvious leakages. Less obvious are tuition and support payments for higher education, specialized medical care and magazine and book club purchases. If the market size of a region is small or if it is readily accessible to other market centers, these leakages will be sizeable.

Because of these many sources of leakages and their general magnitudes, any small area input-output study which does not allow for very large leakages should be questioned. It may be correct because of peculiarities of the region, however it is more likely to be incorrect. Depending on the area size (assuming it to be typical) the leakages should range from fifty percent upwards. For most areas immediately impacted by dredging projects, leakages of less than sixty percent should be questioned.

It should be noted that the concern is for consumption demand which is functionally related to the area's production activity (value added). Other consumption expenditures also may occur in the area but they are financed by transfer payments, commuter labor income, property income earned external to the region, etc. If these consumption expenditures are mistakenly confused with expenditures which are functionally related to locally generated value added and reflected in the model's endogenous consumption coefficients, the model cannot be used for impact assessment purposes inasmuch as it overstates the consumption impacts. Unless, of course, it can be demonstrated that these sources of personal income which do not arise from local production are functionally related to local production in a way that they change in proportion with the local value added.

Econometric Models. The best summary tests of reliability of econometric models are the statistical measures of correlation, autocorrelation and data distributions.

6.5. ECONOMIC QUALITY OF LIFE CONSEQUENCES FOR DIRECTLY IMPACTED REGIONS

By the correct use of accurate models, total production impact measures can be derived. It is worth repeating, these aggregate production impacts are not the relevant local impacts which should be considered in the project assessment process. If they are considered, it also would be necessary to consider the offsetting reduction in production which occurs elsewhere (other areas, industries, etc.) as a result of the commitment of resources to the project and project dependent activities. The various regional production impacts tend to cancel out except for the net production increases which are accounted for elsewhere in the assessment process (they are the economic efficiency consequences of the project).

Despite the assumed offsetting regional production impacts, a case can be made for giving special attention to the directly impacted area (and possibly other impacted areas in which effects are large and identifiable). All areas do not have the same capacity to absorb a project's impacts without serious social and economic disruption or conversely, with the same beneficial effects as in instances of seriously depressed areas. To include these impacts in the project assessment process is to recognize that however beneficial a project may be from a national point of view, if it has significant adverse consequences for the directly impacted community, society may not be justified in undertaking it out of regard for improvement in the general welfare, or not unless appropriate compensation is made which would then increase the costs of the project. Conversely, if a project has very beneficial consequences for a particularly depressed area, society may be justified in undertaking an otherwise undesireable project. In the later case, except for the preferred geographic distribution effects, the resources would be better utilized elsewhere.

The regional impacts which are relevant pertain to the project's impact on the region's quality-of-life. These impacts can not be measured in a definitive way, and certainly the various impacts can not be denominated in a single measure. Each area is unique. The impacts in all of their dimensions can be neither fully known nor analysed and reported without selective aggregation and quantification by type of effect and affected individuals, groups, industries, geographic places and by time periods. Individuals, groups and industries are affected differently by any particular impact. None the less, the relevant information must be generated. The objective of the impact statement should be to identify and quantify as many of these effects as fully and accurately as possible and report them in a manner that reveals the consequences for as many constituencies (individuals, industries, neighborhoods, income groups, etc.) as possible. At the project decision level, criteria must be introduced by which this information on the local quality-of-life impacts is weighted relative to the national economic efficiency and environmental impacts.

The production impact measures will generally be in terms of value added or jobs depending on the type of regional model utilized. Both of these as well as other aggregate impact measures should be derived. If income measures are used they should be converted into employment impacts. The employment impacts should be disaggregated by occupation and industry where possible. Employment impacts should be converted to population impacts which in conjunction with personal income impacts enable the estimation of household consumption activity impacts. The population-household consumption impacts combined with the production activity impacts enable estimation of the resulting impacts on (1) the environment, (2) public services and facilities and (3) tax and other local government revenues. Relevant impacts include (1) outputs of solid waste and sewage, and noise, air, water and other pollutants, (2) requirements for educational, police, fire protection and other local government services, (3) requirements for residential, commercial and industrial land, and (4) requirements for housing, transportation services and facilities, energy, water and other public and quasi-public services and facilities.

6.5.1. Fiscal Impacts

The fiscal impacts pertain to the incremental local public expenditures and incremental tax and other local government revenues which are directly and indirectly attributable to the project. The expenditures vary according to the amount of excess capacity within the community infrastructure and the additional public service requirements. Revenues vary in accordance with the net additions of real residential, commercial and industrical property and changes in activities subject to local taxes, fees and transfers. This is one impact which can be evaluated with little disagreement. Assuming the same level of public services, if a dredging project is responsible for an increase in the tax rate over the rate which would have prevailed in the absence of the project, the fiscal effect is considered negative. A decrease in the tax rate would indicate a positive fiscal impact.

6.5.2. Employment and Unemployment Effects

Employment effects are more ambiguous. There obviously will be an employment increase in the directly impacted region even though no employment change is expected in the nation as a result of the project. It is a different distribution of employment that results. In rare cases the employment redistribution effects of a project may occur among activities within the impacted region, but typically the redistribution is between regions. If labor mobility were perfect, then it would be a matter of indifference as to where the jobs occurred. Inasmuch as this is not always true, the geographic location of jobs warrants some consideration. For example, certain areas may be particularly depressed because of labor immobility and fairly rapid declines in industries which were major employers. Consequently high unemployment rates may persist over long periods of time. In cases such as these, unemployment rates rather than aggregate employment, may be the better indicator of favorable regional employment effects.

If a region prior to a project has an unemployment rate which approximates the national average then positive employment effects from a project are difficult to establish. The project would merely rearrange the geographic location of jobs and the labor force inasmuch as both the employed and unemployed components tend to respond fairly readily to new job opportunities. The unemployment rate would be likely to remain at the national level, however as a result of growth in the impacted region the absolute number unemployed could be expected to increase.

On the other hand, depressed areas which have experienced persistant high unemployment rates may experience a reduction in the rate as a result of a project. A geographical rearrangement of job opportunities which has the effect of reducing structural unemployment is generally viewed positively. Success in reducing structural unemployment also depends on the occupational characteristics of the unemployed labor and the incremental jobs.

6.5.3. Price and Local Supply Availability Effects - Land, Housing, Goods & Services

Price consequences also pose assessment problems. For fixed supply resources such as land, water, housing in the short run, and possibly local energy resources such as hydroelectric, project induced economic expansion will tend to raise prices. This consequence is favorable for sellers of these assets and the goods and services produced in conjunction with these assets, and unfavorable to buyers and renters. The long run price effect on produced goods and services (those not significantly affected by higher land or other fixed resource prices) will tend to be downward if the project induced expansion signficantly increases the local market size and thereby enables retailing and other production economies of larger scale operations to occur or justifies local production of goods and services which prior to the project was not economically feasible.

6.5.4. Transportation

Transportation consequences may take a number of forms. Increased demand may have little impact if excess capacity exists prior to the project. If additional capacity is required to maintain levels of service or travel-times which prevailed prior to the project, the result may be (1) congestion and no additional capacity, (2) additional capacity in the public sector with either favorable or unfavorable fiscal or price effects, or (3) additional capacity in the private sector and either favorable or unfavorable price effects. Reduced service is possible but increased service is more likely to occur if changes in the household and commercial traffic generated justify new routes or more frequent trips by public carriers. Various combinations are, of course, possible.

6.5.5. Other Amenity Consequences

Amenity consequences also should be considered when relevant. These can occur through environmental effects and more intensive use of fixed supply resources such as wilderness and seashore resources. These effects shade into the other non-economic social impacts which will be addressed in the chapter on social impacts.

As a ways of getting at the quality-of-life consequences of a project residents are sometimes queried as to how they perceive its effects on them. The implication is that weight is being given to how the project affects people and how they feel about it. Unfortunately, at the time an impact assessment is made, which is prior to the project, most who will be affected by it have an incomplete understanding of its consequences for them. If this kind of information is to be given weight in the decision process, at a minimum it is necessary that the individuals who are sampled are fully informed of the anticipated impacts reported in the statement.

6.5.6. Evaluation and Reporting Quality of Life Effects

To repeat, the assessment of these economic quality of life effects experienced in the directly impacted area is difficult because they cannot be fully identified or quantified in terms of a common measure which will enable aggregation, and they are not always clearly identifiable as either costs or benefits. To facilitate the assessment process it is desireable to report them in a manner which is as clear and comprehensive as possible. One way would be to report both the expected "with project" and "without the project" conditions and possibly percentage differences by various impact indicators. These should include (1) property tax rates, (2) unemployment rates, (3) per capita income, (4) land and housing prices, (5) auto travel time within the area, (6) availability and level of transportation services including passenger services within the area and between the area and important external points, (7) local prices and availabilities of various goods and services including electricity, water and sewage charges, (8) air quality, (9) water quality, and (10) noise levels. Of course for particular projects some may not be relevant whereas others should be included.

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7. Sociology

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TABLE OF CONTENTS

7.1. INTRODUCTION AND DEFINITION

"Social Impacts" are impacts of the proposed project on people. On the one hand, this definition might be seen as encompassing a large number of impacts, since even impacts on fish and wildlife are often described in terms of how they impact people. However, "social impacts" refer to a somewhat narrower range of topics, specifically those dealing with human interaction and human society.

"Social impact assessment" is the process of looking at the way in which the proposed project is likely to impact or change human interaction and human society. In some instances, the results of this analysis are published in a separate "Social Impact Study." More likely, however, is the summarization of analysis in the section of the Environmental Impact Statement titled "Social Impacts" or "Impacts on the Human Environment."

Obviously, trying to understand how a dredging or jetty project will change "human interaction and human society" is complicated by our awareness that things are always changing (which makes it difficult to get at the amount of change that can really be assigned to the proposed project), that it is often difficult to predict what people, or a community, will do in a new or somewhat different situation (people are pretty complicated beings), and that we may have far better information about fish in the estuary than people on the shore.

Despite these limitations, people in the social sciences (anthropology, economics, geography, history, political science, psychology, and sociology) have developed frameworks and techniques for studying human interaction and human society, and many of these are applicable to the task of looking at potential impacts of estuary-related development.

7.2. A SUGGESTED FRAMEWORK FOR SOCIAL IMPACT ASSESSMENT

Analysis of social impacts begins with an understanding of the present situation. This is possible only by using some framework or package of variables which is likely to lead to a relatively complete and comprehensive overview of the present situation.

Guides for analysis of the present setting range from complex social theories to compilations or "checklists" of specific social factors, variables, or indicators. There is no single "best" list. The relative completeness or comprehensiveness of the description of the setting is far more important than the variables or factors which were used to "measure" the social setting. The following discussion should therefore be seen as an introduction to a possible framework for understanding social impacts.

One of the most basic sociological concepts is "social institution." Put simply, a social institution is an organized way of carrying out one of the basic functions of society. This concept is helpful because it directs one to the six things that every society (nation, county, community, social group) must do to survive. The "functions" and the corresponding institutions are as follows:

1. produce and distribute needed goods and services--the economic institution,
2. teach people how to relate to others, train people for jobs, produce new knowledge for the society--the educational institution,
3. develop and enforce rules governing how people relate to each other, deal with conflicts over social power--the political institution,
4. provide a "reason" for certain rules (it's a sin), help people understand things not explained technically--the religious institution,

5. help take care of youngsters, establish setting for male-female relations, provide close emotional support environment--the family
6. defend the society against natural and man-made (war) threats--the military institution.

The researcher who uses this basic framework would therefore begin analysis by asking how the community (or larger unit) carries out these basic functions. While it is obviously the case that all of these functions do not occur within specific community boundaries (a "bedroom" community is one where a major economic function (employment) occurs elsewhere), the social institution framework is helpful because it direct attention to these basic social functions, and serves as a very basic "checklist" for social impact analysis. The focus of impact analysis, therefore, is <u>how proposed estuary-related changes will impact the way in which society (community, neighborhood, social groups) carries out these basic social functions</u>.

The following discussion uses the concept of social institution as the key organizing concept. Potential social impacts are outlined for each of the six social institutions. The rest of the section is devoted to a discussion of six other categories or clusters of social impact variables. Taken together, they offer a sociological framework for social impact assessment. It is <u>not</u> claimed that this framework is <u>the</u> framework within which all social assessments should be prepared. There is no single "best" framework and there is no single "best" list of variables. What is important is that those preparing the social impact sections of Environmental Impact Statements approach their task objectively and systematically, This means that they remain open to consideration of a variety of specific variables, even though consideration of certain impacts may reduce public acceptance of the Proposed Action. It is <u>not</u> suggested that an adequate impact assessment will require mention of all of the variables discussed in this section. It is suggested that some systematic review of these variables (or those on any other comprehensive list) occur early in the assessment process, and that selection of those variables to be included in the Environmental Impact Statement be based on some systematic discussion of likely impacts, reference to agency requirements, and anticipation of those variables of greatest concern to impacted publics.

7.2.1. Impacts on Social Institutions

7.2.1.1. Education

Estuary projects could impact local school systems through changes in property tax base, project-related population changes (especially those which are temporary or seasonal (fishing fleet population or jetty construction)), and alterations of the availability of the estuary for educational (field trips, laboratories) and scientific purposes.

7.2.1.2. Political Systems

Probably the most important impact would come from project-related changes in the governmental units (Port-District, Corps of Engineers) directly involved in estuary management or modification. Secondary impacts on governmental units include creation of new governmental units to service estuary-linked industry (economic development district, water or waste disposal district).

A second category of political system impacts are those where the project results in changes in estuary-related rules and regulations. Jetty alteration could change the need for rules governing operations of pleasure craft or commercial fishing boats. Change can include reduction of regulations (a deeper channel means less supervision of traffic) or new rules for previously unregulated behavior (access to the jetty campground is now restricted).

A third category includes potential impacts usually considered the most "political"--party politics. The potential influence of estuary projects party politics is greatest where political parties are split on their feelings about the project, or where population changes could involve a change in the existing balance between the parties.

Finally, estuary projects could change the "power structure" of the community (the formal and informal "who's in charge"). Typically, projects are initially supported by a segment of the local power structure. (This is especially true where, as with most Corps of Engineers projects, the agency cannot begin project planning unless there has been some expression of local interest.) However, the resulting impacts may be more diverse, and could include displacement of the existing group and changes in the relative power of local, regional, or state levels of government (officials of the new shiploading facility become involved, regional interest in the estuary increases, and decisions are moved to the multi-county or state level).

7.2.1.3. Family System

Impacts on the family occur in two major categories. The first is through economic changes which influence the family as an economic unit. Thus, estuary-related economic changes in employment (new jobs for full-time workers, new part-time or seasonal employment opportunities), income, and the price of availability of consumer products may impact family economic viability. These impacts would usually be treated as part of the economic analysis (TM 6.5.).

The second, primarily "social," category of impacts encompasses a number of variables under the heading of "family characteristics." These include marital status, family composition (number of children, single-head households), and the composition of household units. In general, it is extremely difficult to establish linkages between estuary-related projects and family characteristics variables, except where the project includes significant population change. For example, a tradition of marriages within an isolated, relatively "closed" community (typical of small coastal communities) could be changed where project-related industry brought in a new "supply" of potential mates. And, impacts on family household units could occur where the project increased the demand for housing.

A major problem with assessing impacts on family characteristics is that it is extremely easy to move into making evaluative statements about impacts on the "health" of the family. That is, authors of Environmental Impact Statements may be tempted to assert that family stability may be influenced by project-related employment opportunities for women, or that a possible reduction in unemployment may similarly reduce sources of family conflict. The problem with these assertions is that they often make implicit assumptions about what is "good" for the family or what the "ideal" family should be. In a rapidly changing society, people disagree about characteristics of the "ideal" family and even whether traditional indicators of "family problems" (divorce, separation) should be viewed negatively.

7.2.1.4. Economic Institution

The simple sociological definition of the function of the economic institution as responsible for the "production and distribution of goods and services" conceals the complexity of this fundamental social institution. For impact assessment purposes, it is helpful to distinguish between what might be called "standard" or "basic" economic features of society, such as employment, income, and the production and distribution of goods, and the several "infrastructure" systems which support activities in all of the social institutions.

Assessing impacts on infrastructure systems bridges economic and non-economic social variables. On the one hand, analyses of "social" impacts sometimes stop with consideration of infrastructure impacts; the "social" is synonymous with infrastructures. Obviously, impact analysis which is limited to infrastructures is extremely limited. On the other hand, infrastructure impacts are sometimes included as part of economic analysis. (Figure 6.1 (Introduction) shows several infrastructure systems as "Quality of Life Economic Impacts" (Box 11). They are briefly mentioned as part of the discussion of "Indirect Expenditure Linked Impacts" (TM 6.5.).

Approaches to environmental assessment differ as to which systems should be labeled as infrastructures. Most approaches would probably include the following: transportation, utilities, housing, communications and media, health, law enforcement and emergency preparedness, and social services (public assistance). Regardless of how these impacts are treated in the Environmental Statement, two point are critical. First, economic analysis must extend to estimates of population impacts so that discussion of infrastructure impacts can include population-linked changes (TM 7.4.3.). Economic analysis which is limited to employment projections does not provide this information. Second, social assessment must not be limited to infrastructure impacts. A discussion of impacts which was limited to housing, utilities, transportation, and law enforcement, for example, would probably not constitute an adequate social impact assessment. The following discussion presents some examples of estuary- or dredging- related impacts on infrastructures. It is intended to supplement discussion of infrastructure impacts in the chapter on Economic Impacts (TM 6.5.).

Environmental Statements sometimes fail to consider impacts on the transportation system, other than those transportation facilities (roads, trails, parking areas) which are part of the project. The key to examining impacts on the transportation system is focussing on how different features of the project (use patterns, etc.) impact the transportation system outside of the project boundary. For example, providing new public access areas may increase use of "feeder" roads. Improvement of the road along a jetty could increase off-road vehicle use of nearby dunes or beaches. Construction of new recreational facilities could increase use of adjacent county or state roads. Recreational trails along the shore of the estuary could result in the need for additional parking areas and "connecting" trails.

Impacts on two other infrastructure systems are very closely tied to population change. Relatively rapid changes in population typically have fairly direct impacts on public utilities and housing. From a sociological perspective, the most significant impacts on public utilities are those which result in a major expansion of the system (new capital investments, economists would say). Placement of dredging material may permit development of former marshland, and utility services must therefore be extended to this new area. (Utility impacts are important from an environmental perspective also, where land use changes impact factors such as water supply and water table, and the "capacity" of the area for septic tanks.)

A type of utility impact which could be especially relevant for coastal areas is that concerning "special districts." Special Districts are quasi-governmental units which are organized to take care of specific community services (water, electricity, fire protection, sewage). Increases in population in unincorporated areas often generate pressure to establish special districts. Attention to situations in which dredging projects could lead to such pressures is important for several reasons. First, the formation of special districts is often the first step in the direction of incorporation of annexation. Second, special districts may have significant symbolic meaning to persons who feel strongly about potential population growth and development of an area. Strong opposition to the formation of special districts may be indicative of sentiment against growth and development.

Of all of the infrastructure systems, impacts on housing (TM 6.5.) are perhaps the most sensitive to population change. Changes in the size or composition of the population (age, marital status, household composition) can have a significant impact on the supply and quality of housing. Unfortunately, the prediction of impacts on housing may be difficult, since nearly all housing is supplied by the private sector. Assessment of impacts should therefore attempt to take into account local conditions influencing the likely response of the housing industry to population change.

Another important infrastructure system likely to be impacted by natural resource projects is law enforcement. Potential impacts include changes in what behavior is considered "illegal" (will tourist parking near the new marina require additional parking regulations?), different demands on local law enforcement and justice system (who will patrol the beach area which will be accessible by the jetty road?), and changes in illegal behavior (will theft and vandalism near the port increase?). A more general impact occurs through project-related increases in population.

Three additional infrastructure systems may be impacted by project-related population change. These are health (will a reduction in population make it likely that the town will lose its only doctor?), social services and public assistance (will new port-related opportunities alter the number of people receiving public assistance?), and communications and media (will population increase make it likely that the town will have its own newspaper?).

It is *not* suggested that all analyses of social impacts cover the entire "laundry list" of potential infrastructure impacts. In general, impacts on transportation, utilities, housing, and law enforcement will be more easily identified than those on other infrastructure systems. EIS reviewers should look for some discussion of infrastructure impacts, especially where the project could lead to significant populaton change (TM 7.4.3.). It is also necessary to be watchful of analyses that place the entire "need" for major expansion of any infrastructure on impacts of the project. The local fire chief may have wanted that new truck for years -- the need to fight dock fires may simply provide the needed trigger to finally justify its purchase.

7.2.1.5. Religious Institution

Because of concerns about church-state separation, EIS' seldom mention impacts on the religious institution. However, from a sociological perspective, analysis of social impacts may be incomplete without including potential impacts on this social institution.

Impacts on the religious institution occur within two broad categories. The first is where the project impacts places or values which have symbolic, religious meaning to people. Since most American religions do not place much emphasis on specific places (e.c. shrines, etc.), the impact seldom occurs. (It may be more probable for places which have symbolic value to coastal Indians (TM 7.2.7.)). Impacts on religious values may occur whenever the project is likely to attract persons whose values conflict with those held locally. For example, a dredging project which transforms a small community with a strong religious base into a port or recreational town may impact the values underlying religious institution.

The second category of impacts are those which occur primarily through project-related population change. Significant population change may impact a number of characteristics of the religious institution, such as church membership and attendance, enrollment at parochial schools, church camps and other recreational facilities, and the place of religion in the local power structure.

Impacts on the religious institution are most easily identified in those communities where religion plays a major role in daily life. Typically, such communities are small and somewhat isolated. These are, of course, attributes of many communities located near estuaries.

7.2.1.6. Military Institution

Although social scientists differ on whether the military should be considered one of the five or six key social institutions, it is certainly true that dredging- and estuary-related projects have the potential to impact military installations.

The most probable impact is where project-related land use changes (road access, recreational developments) in turn impact the operation of military facilities. Examples are changes in public access to radar and communications installations (tighter security may be required if public access is improved), naval use of dredged channels, and changes in emergency demands made on organizations such as the National Guard.

Because of the military importance of ports and coastlines, analysis of land use impacts should include lands which are part of military installations or reservations. It should also be recognized that military use of land also has impacts; expansion of navigation or communications systems in coastal areas may require an increase in military landholdings, with a corresponding decrease in public access.

7.2.2. Impacts on Population Characteristics

There are a number of ways in which estuary projects could influence the population of a community or region. And, there are several key indicators which express population impacts.

Four factors or components determine population size--births and deaths and in- and out-migration. Ordinarily, estuary projects would not impact birth or death rates, except where they also influence the age structure of a community (employment opportunities which would attract younger people mean a higher birth rate for the community; a recreational development which attracted retired persons would increase the role of the death rate in determining community size). Thus, analysis usually focuses on project-related influences on in-migration (primarily new employment opportunities or special residential attractions) and out-migration (reduced community desirability or declining in employment opportunities (especially for more mobile younger persons)).

In general, employment opportunities have the most immediate impact on migration patterns. Therefore, analyzing project impacts on community size must begin with analysis of employment impacts (TM 6.4.1.). This is the most direct link between "economic" and "social" impacts. However, employment impacts must, in turn, be linked to total changes in community size.

A major problem with many discussions of population impacts is that people forget that most communities will grow or decline even without the project. Thus, it is essential that project-related population projections are compared with existing population estimates, and that impacts are expressed as the difference between with and without project population estimates (TM 7.4.3.).

Analysis of impacts on population size should include both estimates of community growth or decline and discussion of community attitudes about population growth. Although communities seldom agree on what is "desirable" growth, estimates of project population impacts should be contrasted with prevailing sentiment(s) about growth. (Social surveys are probably the best way of obtaining systematic community opinion on growth--see TM 7.3.).

In addition to population size, estimates can be made of potential impacts on population density (will dredging facilitate use of floodplains for high density residential development, will jetty-related recreational developments lead to high density recreational parks), rural-urban-suburban population distribution (will increased population size increase the need to annex suburban areas, will recreational opportunities stimulate development of recreational or retirement oriented "rural neighborhoods"), and age and sex population structure (will port-oriented occupations (warehousing, shipping) increase number of males in specific age groups, will recreation attract more older persons, will employment opportunities reduce out-migration of younger people).

7.2.3. Impacts on Land Use Patterns

Probably the major type of community impact of estuary projects is land use change. Projects may result in changes in existing land use patterns, either directly (land used for port facility construction, sources of fill materials, areas for depositing spoils) or indirectly (expanded port facilities lead to conversion of nearby lands to industrial use, residential areas gradually became recreational housing). Further, estuary projects have the potential to actually "create" new lands (flood plains become suitable for use because of channel diking, dredging materials are used to fill marshes), or flood existing lands (reservoir projects "take" existing lands).

When examining impacts on land use, it is difficult to separate natural environment, social, and economic factors. In a sense, all land use changes are "social" or "economic" in the sense that it is people who are using the land. (Obviously, concern includes how plants and animals "use" the land, but even here impacts are usually described in terms of how they relate to people.) The discussion which follows focusses on "social" aspects on land use patterns. It does not include those "economic" aspects, in which land use impacts are reflected in prices, or "environmental" aspects, which include impacts on the suitability of land for development (drainage, utility services, etc). "Social" aspects of land use impacts can be grouped into three major areas: land use compatability, aesthetics, and land use regulation.

Compatability refers to the extent to which different activities can occur in adjacent areas. Concern over land use impacts often includes questions on whether new activities associated with the the project (increased shipping activity, expansion of port or tourist facilities) will "fit" or conflict with existing activities or with other activities likely to be associated with the project. Concepts such as "compatability," "fit", or "land use conflict" include both evaluative and "practical" considerations. They are evaluative in that people vary in their perception of the impact of a nearby activity. "Practical" considerations would be those where the impact of one activity makes it almost impossible to carry out another, regardless of the perceptions or attitudes of those involved. Heavy shipping activity may make it impractical (and dangerous) to permit simultaneous pleasure-craft traffic, even though "weekend skippers" may find that their enjoyment increases when channels are shared with large commercial boats.

Despite the evaluative character of these concepts, some effort should be made to identify land (or water) use changes which are likely to lead to incompatible activities, or to reduce present land use conflicts.

The second major type of land use change involves aesthetics or landscape quality. The specific concern is the "visual quality" of project-related changes (a jetty, spoils deposition area, port facilities), and of those indirect changes which occur because of the project (motels, recreational vehicle parks). Visual impacts are similar to those involving land use compatability, in that both include a perceptual factor ("beauty is in the eye of the beholder"). However, major public concern over the visual impacts of activities such as clearcutting and road construction has led to development of a "landscape management" speciality within the field of landscape architecture. Wherever estuary projects are likely to have a major visual impact, the project design should include consideration of aesthetic factors, and impact analysis should include discussion of potential changes in visual quality.

Two additional points are relevant. First, decisions as to the "importance" of visual impacts should include issues such as how many people see the area (will the spoils area now be visible from a major scenic highway?), for how long will the area be visible (will the jetty become a permanent part of the view from homes bordering the estuary?), and the relative abruptness of the visual change (an "untouched" shoreline becomes transformed within nine months). Secondly, people sometimes assume that any "man-made" change reduces "natural" beauty, and that nearly all visual impacts of large-scale developments will be negative. While it is true that most people prefer a "natural" environment to one which is obviously "artificial," it is also the case that careful application of a variety of techniques can "improve" the visual quality of "natural" landscapes.

The third type of land use impacts are those where the project leads to changes in <u>land use regulations</u> such as long-range plans, zoning, conditional use permits, and building codes. There is often confusion about whether it is appropriate to assess impacts on land use regulations. Resource management agencies point out that they are limited in their ability to control uses of adjacent lands. Obviously the area within the project boundary is usually under the control of the sponsoring agency, and changes in zoning, and alterations of long-range plans for the project area are really an integral part of the project -- they are so "close" to the project that they cannot really be considered as impacts.

Assessment of land use impacts should also include examination of the compatability between the project and local land use plans. This is particularly important since it is often assumed that federally owned lands do not come under local land use regulations. While this may be true, it is also the case that major impacts can occur where the project involves land uses which would not be permitted under existing comprehensive plans or zoning regulations. Another consideration is the extent to which project impacts are likely to lead for pressure for zone or plan ammendments. Increased commercial activity in the port area may lead for an expansion of this zone into adjacent single- or multiple family dwelling areas.

7.2.4. Impacts on "Lifestyles"

One of the major challenges of social impact assessment is to use a cluster of variables and indicators which somehow tap impacts on daily life in impacted communities. Although the usual economic and social indicators (employment, income, infrastructure impacts) certainly do relate to daily interaction, they usually fail to portray many other changes which have importance to people. "Lifestyles" or "ways of life" are labels which have been used to cover a range of specific variables or indicators which get at how people go about their daily activities. In part, while it is obvious that some reason could be found for including nearly all social and economic indicators in either category, many of these indicators are best grouped under some other category. This means that some of what is included within "lifestyles" or "ways of life" are variables which do not belong in other categories -- "lifestyles" becomes a "leftover" or "catch-all" category. This is seen in the following discussion of three major lifestyle dimensions.

7.2.4.1. Recreational Opportunities

There is often confusion over how Environmental Statements should discuss recreational opportunities. On the one hand, most estuary-related projects would include some provisions for recreation. In some cases, recreational facilities may be a major reason for the project, and, in others, projections of the "outputs" or "uses" of the estuary or project facility could include estimates for the usual indicators of recreational activity (recreational visitor days), or facilities (number of day use and overnight camping places, parking lot capacity, miles of trail, etc.). In some Environmental Statements, analysis of recreational impacts is limited to this information. Critics of this approach argue that these indicators are such an integral part of the project that they cannot be considered as "impact" variables, and that adequate impact analysis would include consideration of more broadly defined recreational opportunities. This second approach could result in analysis of project impacts on the following four general recreational variables.

Non-Project Recreational Lands and Facilities. The most important impact would be on recreational lands and facilities outside the project boundary (or outside of the immediate concern of the project). Thus, an increase in recreational access to a jetty could mean increased use of an adjacent state park with overnight facilities. Increased recreational use of federal and state campgrounds often means that heavy use "spills over" into county or city facilities, and that local people feel "displaced" from federal and state areas. Port-related projects could increase available land where a new road opened up an area for state or private recreational development. In other cases, the project may utilize existing recreational areas for construction of new industrial facilities. All of these impacts could occur in addition to the actual "recreational outputs" of the project.

Recreational Demand. The second type of impact would be on recreational demand. Inclusion of demand as an impact variable is somewhat unusual since it is usually assumed that projects respond to, rather than "create," demand for recreational facilities. It is precisely because of the way in which new or expanded facilities can generate additional demand that project impacts on additional recreational demand should be considered. There are two key aspects.

First, will project-related recreational facilities be adequate for the demand likely to be generated by the project? Construction of a major jetty in an area which has long experienced navigational and recreational access problems will probably attract more recreationists than the facilities which are to be constructed as part of the project can handle. A key factor is the relative "visibility" of the project, and how it complements existing similar facilities in the area.

Second, expected project-related recreational facilities may generate demand for complementary facilities which are not included in the project. A project which includes access and parking for recreational boaters will probably generate demand for overnight facilities, a picnic area near the launching area, and facilities for those who want to watch the launching of small boats. What is important about both aspects of recreational demand is that it is the project which is generating a demand which, in turn, must be met by a governmental unit other than that sponsoring the project.

Recreational Carrying Capacity. The third and fourth variables are somewhat unusual ways of expressing recreational impacts. Although both are experimental, they may have some use in special situations. The first is the concept of "recreational carrying capacity," which expresses the "capacity" of a variety of recreational facilities in terms of indicators such as the total number of visitor days per acre per year. The figures express an average level of use and indirectly include the fact that recreational use is highly seasonal and concentrated on weekends and holidays. The underlying concept is usually that of natural environment carrying capacity, defined as the level of use above which environmental degradation would occur. Ideally, carrying capacities could be estimated for psychological or sociological limits as well. The Bureau of Outdoor Recreation has derived some preliminary estimates of carrying capacity for six or seven key types of recreational areas. Although these are very tentative, general estimates, recreational carrying capacity could be used as an impact variable by asking one or two key questions.

First, will either direct (part of project) or indirect recreational improvements changes in recreational facilities involve a change in the recreational carrying capacity of land or facilities? Most "improvements" in recreational facilities also increase recreational carrying capacity. Road improvements, surfaced overnight camping spots, water, and toilet facilities all usually increase recreational carrying capacity.

Second, will expected recreational use exceed existing carrying capacity? This is often an unanticipated impact which, in turn, forces modifications in facilities to increase capacity. An alternative is restriction of use. This is, or course, most likely to occur where adjacent areas have very different carrying capacities (a fragile dune area near a large picnic ground, a beach and marsh area near a major road access and parking lot, a narrow jetty or small dock near a major highway or on the road to a large campground or favorite ocean viewpoint). As mentioned above, efforts to precisely define carrying capacity are still in their infancy, and even the basic concept is somewhat controversial. However, comparing rough estimates of carrying capacity with (equally rough) estimates of recreational use is one way to express impacts on recreational opportunities.

The "Optimal Recreationist". In an effort to insert a "quality of life" element into our understanding of the relationship between population size and recreational opportunities, researchers have tried to estimate the "optimal" annual number of visits per person to different types of outdoor recreation areas. Where, for example, estimates of the "optimal recreationist" would include two visits annually to a free flowing river, some general estimate of optimal recreation demand can be estimated by multiplying optimal visits by total population. (The resulting figures are, of course, very general estimates. Total recreation demand obviously includes participation by those outside of the area, and it is misleading to assume that people will wish to find all of their recreational opportunities within a local area.) Despite the series of assumptions which must be made when using "optimal recreationist" estimates, this can be an effective way of highlighting potential impacts on the availability of different types of outdoor recreation. When used in an impact statement, total (or a "local" portion) optimal recreation demand could be matched with the carrying capacity of project related and other recreational facilities to provide a rough indication of likely "shortages" or "surpluses" of recreational opportunities. This technique could be especially effective where large population increases were likely.

7.2.4.2. <u>Leisure and "Cultural" Opportunities</u>. Social scientists often distinguish between "leisure" and "recreation." The key feature of leisure is that it involves "discretionary time." The assumption is that any activities which might be carried out during leisure time are done so "voluntarily" or at the discretion of the individual. Employment, housework, and routine chores are not leisure activities. Watching TV, engaging in recreational activities, and "just sitting around" can be considered leisure time activities if the individual has some discretion over them.

Within what has become a complicated subject for social science research, there are a few key leisure time variables which might be used in impact analysis. One is the actual amount of leisure time available to individuals. Estuary-related projects could impact this variable if employment changes influenced commuting time, employment patterns (will economic conditions likely increase "moonlighting," or alter seasonal unemployment patterns?), or transportation time. A second type of impact could involve opportunities for leisure time activities, other than those traditionally described as "recreation." Definitions of impact would depend on those activities which were considered important locally.

"Cultural" opportunities are those which typically come to mind under the popular meaning of "culture." These include art, music, theater, libraries, and special educational programs. (This meaning of culture is more limited than that used by anthropologists when they speak of "culture patterns" or "community culture.") Nearly all impacts on cultural opportunities occur through population change, and, in general, more population means more opportunities. However, there are at least two instances where this may not be true. First, expansion of cultural opportunities in a small town sometimes means that persons who formerly took advantage of limited opportunities cannot enjoy expanded opportunities, even though the total number of people served significantly increases. Low cost community concerts and theatrical productions may become inaccessible when semiprofessional groups must charge higher prices. Second, communities may benefit from special cultural opportunities which often accompany expansion of recreational facilities, even though population increase may not be significant. Resort communities typically offer a range of opportunities far beyond that expected on the basis of community size. Estuary-related projects which could move the community in this direction may therefore have the indirect impact of increasing the availability of "culture."

7.2.4.3. Security and Anxiety

One of the most frustrating aspects of social impact assessment is that specific indicators, whether quantitative or qualitative, somehow fail to effectively communicate what many people feel are the more important quality of life features. A good example of the problem is in the use of security and anxiety as social impact variables. Each of these interrelated but distinct concepts speaks to how people view their social environment.

Security includes notions such as predictability, a sense of control over one's destiny, stability, and the achievement of a personally or socially defined minimal level of material well-being. The most general impact on security is the rate of social change. Estuary-related projects which are likely to accelerate the rate of change in a community may reduce a sense of security for many people, even though certain features of the project, such as employment opportunities, may increase the security of others. A second general impact is change in the degree of personal or local control over the future.

On a personal level, this is usually associated with changes in the rate of change. For a community, "local control" may diminish as the community grows, particularly where growth attracts "outside" economic interests. A good example is where dredging increases outside investment in and use of port facilities.

In part, anxiety is the opposite of security, and includes concepts such as uncertainty, insecurity, and the lack of predictability. Anxiety has an additional meaning where it is associated with mental health problems. Anxiety also differs slightly from security in that it is a very likely response to a perceived decline in one's personal situation. Thus, a project alternative which reduced channel use by freighters could lead to an uncertain future for port-related employment. Another aspect of anxiety is fear of the "unknown", and this, of course, is why rapid social change can increase anxiety.

Environmental Impact Statements seldom include assessments of impacts on security or anxiety. A systematic discussion of these impacts would require collection of respondent-contact information (TM 7.3), and even the design of the questionnaire or interview schedule would require consideration of the complexities of "measuring" individual perceptions. And, it may be extremely difficult to develop a credible analysis which links a natural resource change (dredging) to a psychological state or condition. Except in those unusual situations where such an investment in data collection is justified, consideration of potential impacts on security and anxiety will probably be limited to a general discussion of community change. (An alternative method of including these impact variables is through a discussion of impacts on the health infrastructure system (TM 7.2.1.4).)

Changes in the social class composition of a community can also have implications for levels of cohesion and conflict. "Social class" is a concept that combines factors such as occupation, education, and income into a sense of the relative social position occupied by individuals within a community. Social class position relates to cohesion and conflict because sociologists often find that class position is one of the better predictors of a wide variety of attitudes and lifestyles. Thus, a project which alters the distribution of individuals within a community on factors such occupation, education, and income is likely to affect the class composition of the community, and this, in turn, can change community cohesion and conflict.

Project-related impacts on patterns of cohesion and conflict which are related neither to attitudes toward the project nor social class characteristics occur as an indirect consequence of a relatively direct impact. For example, a project-related impact involving an increase of retired persons in the community could have an indirect impact on attitudes and values relating to the educational institution, which, in turn, may be communicated through a reluctance to pass school budgets.

7.2.5. Impacts on Conflict and Cohesion

Impacts on this aspect of society are difficult to determine. The key question is whether the project will increase or decrease levels of community (or inter-community) cohesion or conflict. Analysis of impacts works best when several different dimensions are discussed separately. The major areas or types of conflict or cohesion are 1) project-related, 2) social class-related, and 3) non-project value or attitude-related.

Conflict and cohesion surrounding the project are what first come to mind, and, although the situation may change once the project is begun, impact assessment should include a look at whether the proposed project has increased levels of conflict within the community (is there a "Committee to Save..."?), placed one community in competition with a neighbor (where will the new state park be located?), or served as a focal point for increased cohesion (the community is, for the first time, united in its support for the project). This aspect of impact assessment is little more than judging relative community approval or rejection of the project. The actual impact is the extent to which the project itself has stimulated new forms of cohesion or conflict.

7.2.6. Impacts on Cultural Values and Symbolic Meanings

One of the most difficult aspects of social impact assessment is that some of the most important impacts cannot be quantified. Further, descriptions of communities which rely on the "cold, hard facts" often fail to portray the "sense" or "meaning" of the place. Many of these more qualitative factors can be grouped under the general headings of values and symbolic meanings.

"Values" are general perspectives or orientations which usually have a "good" or "bad" aspect. Values are more general, enduring, and less susceptible to change than attitudes or opinions. Whether an individual likes the proposed jetty extension is an attitude, while one's views of the appropriateness of major alterations of the natural environment (man over nature) is closer to a basic value. Ideally, of course, one expects a high degree of correspondence between general values and attitudes on a range of specific issues. However, it is also true that one's attitudes about an issue conflict with his or her values, especially where the issue has a direct impact.

Despite the highly qualitative nature of values, social scientists have developed questionnaire items and other research strategies to measure value orientations. Where a social impact study includes gathering respondent-contact data, some of these items might be included in a questionnaire or interview schedule.

Because values are by definition general and difficult to change, it is seldom possible to assert that a project will actually change individual values. Probably the most likely way for this to occur is where the project is viewed as "expressing" or "manifesting" certain values. A major re-channeling project may be seen as a strong assertion of "man over nature," in contrast to an alternative which involves only minor modification. The linkage of the project, alternatives, or the "No Action" option, to basic values means that the final outcome may reinforce the basic values of different groups within the community. Opposition to a project may crystallize those with "submission to nature" values, while implementation may reinforce those beliefs held by people who identify strongly with the project.

A frequent source of conflict with those who seek change in a community, whether through some alteration of the natural environment or by other means, is the degree of "rationality" or "objectivity" displayed by those sponsoring or supporting the project. This is especially true where proposed projects are analyzed for their economic consequences and the many "improvements" which will result from the project.

In any community, there are many places, practices and things which have a special symbolic meaning for people. This meaning is labeled "symbolic" because it includes aspects which may be different from those apparent to the outsider or "objective" observer. The old lighthouse may be inefficient and sadly in need of repair, but it is a permanent part of the landscape for many people, and is a special reminder of pleasant times. The old dock may be considered dangerous by some, and may fail to meet federal public fishing area standards, but spending a warm afternoon sitting and talking with friends is an important part of what makes life worth living for many, even for those (perhaps the vast majority) who have never actually found the time to enjoy the sunwarmed, but rotting, wooden planks.

Environmental Statements often ignore places, practices, and things which have symbolic meaning. Paradoxically, it is often public concern over conflict between the Proposed Action and widely held symbolic meanings that triggers more general opposition to the project, and, in some cases, legal action which eventually brings the project to a halt.

Enviornmental Statements should therefore include an effort to determine those places, practices and things which have symbolic meaning and are likely to be impacted by the project. Often, written documents provide good clues. What places are pictured on brochures or maps describing the community-- what are the "must see" places for visiting relatives? What estuary-related places appear to be frequently used for a function other than that for which the place was intended? What are the port-related special activities that are important to people? The emphasis is obviously on those meanings which are widely held, or which hold special importance to a group within the community (elderly, ethnic minorities, etc.).

There are a number of ways in which estuary-related projects could impact symbolic meanings. The most obvious is some change which would destroy the place or thing which was the focus of these meanings. A second would be changes in patterns of access to such places. In many instances, projects could enhance or reinforce these meanings by taking steps to protect special places, although the way in which this occurred would be crucial. Use of the old lighthouse as the Jetty Visitors Information Center would probably remove much of the symbolic meaning, although it might become an attractive facility. A third general way in which symbolic meaning impacts might be felt is through the project-related activities which have the potential to "create" new places, practices, or things which have symbolic meaning. Construction of a new dock may allow the existing dock to become that "special place in the sun."

Clearly, symbolic meanings have a special quality, and it is easy to see why they are so often ignored in Environmental Statements. Some places and things are given special attention because of federal (P.L. 93-291 - Preservation of Historic and Archaeological Data) and state legislation. When applied to Environmental Statements, these laws usually require the agency to undertake some archaeological exploration or to consult some list of historic places. Although this does provide some consideration of potential impacts on places and things which could have symbolic meaning, it is equally likely that many would be ignored. Therefore, additional treatment of symbolic meaning impacts is essential.

7.2.7. Impacts on "Special Groups"

In the past several decades, society has frequently focussed on the problems of "special groups" within society, such as racial and ethnic minorities, the physically disabled and handicapped, and the aged. Concern with employment and other opportunities for women has been a parallel concern.

These concerns are related to social impact assessment in two ways. First, some federal agencies require those preparing Environmental Statements to include assessment of impacts of these groups. Thus, it may be appropriate to expect some mention of these groups in the discussion of social impacts. Second, because society's concerns are frequently reflected in federal legislation, natural resource programs of federal agencies may present special opportunities for improving the situation of these special groups. Equal employment opportunity and affirmative action programs, special considerations for "minority" businesses, and special training and rehabiliation programs are examples.

In general, estuary- or dredging-related impacts on these special groups would not differ from those associated with any natural resource change. In such cases, impacts are most likely to be translated through employment opportunities and recreational facilities. Special attention should be paid to those port-related occupations in which minorities predominate, both in terms of likely additional employment opportunities and impacts on existing occupational groups. Although it may be difficult to predict whether a type of employment which is totally "new" to the community will be filled by minorities (or women), attention should be given to this possibility.

The second general type of impact is on access to recreational opportunities. There are several ways in which this impact might occur. The most obvious is when the project involves the actual area used by special groups. (Except in the case of the physically handicapped, the recreational areas involved will not be designated for special group use; observation of existing use patterns is therefore very important (TM 7.3)). A second way these impacts occur is through project-related changes in the cost of recreational access, such as campground fees. A more elaborate campground near the jetty will probably have higher user fees, thereby reducing access for those on limited or fixed incomes.

A third category of impacts includes those related to the actual physical design and layout of the project-related recreational facilities. Features which increase access for the physically handicapped, transportation facilities (access to public transit) for those who are "transit-dependent," and other special facilities are ways in which impacts on special groups might be reduced.

A fourth type of impact can occur where the project impacts lands which are used or owned by special groups. Examples would include impacts on minority groups neighborhoods (often located near port facilities because of lower costs and indirect discriminatory practices), and Indian lands. The latter is especially important in those coastal areas which include current or former (currently disputed) tribal lands. These impacts would hopefully be identified as part of assessment of impacts on land use patterns. Minority group involvement in these lands is an additional reason for special attention.

Several additional points should be kept in mind when examining impacts on special groups. First, questions about the degree to which a special group should get special treatment raise difficult value issues. One position is that groups which have been poorly treated in the past (racial minorities) should receive special emphasis to compensate for past conditions and to accelerate their movement toward "equal" status. A different position is that such special treatment is really "reverse discrimination". A related issue is whether special programs should emphasize integration of minority groups into the larger society (with the probable loss of the cultural features which are unique to the group), or work toward equality of access to opportunities and better economic opportunities while encouraging minority groups to retain special values and cultural themes.

A second important point is that most governmental units have individuals whose jobs involve programs for these special groups. In addition, many government agencies collect information which is broken down by special group status (minority group membership, sex, etc.). Thus, persons preparing Environmental Statements should make contact with these individuals and data sources when assessing impacts on these special groups.

7.3. COLLECTING SOCIAL DATA

A major part of the job of doing social impact assessment is collection of a variety of information about the current social setting. As indicated previously, this information is helpful as an introduction to the area which is likely to be impacted, and as the basis for making predictions of possible impacts.

There are several ways to describe different types of social data. The distinction between "primary" and "secondary" data is one way. Primary social information is that collected directly from the individual through a self-administered questionnaire or social survey or through the use of an observer or a mechanical device (traffic counter). Interviews with community residents, port officials, or employees of port-related or port-dependent industries would yield primary social data. Secondary data is the label applied to social information which results from a counting or tabulation of information which was not originally collected for social data purposes. For example, analysis of newspaper articles and letters to the editor to determine community attitudes or concerns, tabulation of shipping volumes from port records, analysis of campground registration slips to determine where recreationists come from, or studying tax and property assessment records to better understand land use changes all utilize "secondary" data. ("Secondary data" may also refer to an analysis of information originally gathered by someone else--thus the persons actually preparing the Environmental Statement may wish to re-analyze information collected earlier in a "community goals" social survey.)

Another way of sorting out the different types of social data is to refer to statistical, observational, written, and respondent-contact social data. Statistical information is quantified, usually published by a unit of government (U.S. Census, State Employment Office), and often organized by some time interval (annual, every five years, every ten years). All government agencies publish some type of statistical data, and, because the information is quantified, statistical information is frequently used in Environmental Statements. Major disadvantages of statistical social data are infrequency of data collection (the Census occurs every ten years), problems of understanding people's motives and attitudes from such statistics (we know that 8% are unemployed, but we don't know what jobs they are looking for, why they left their other job, etc.), and the difficulty of getting a picture of a community simply on the basis of "the cold, hard facts."

Observational data result from the reporting by a trained (or untrained) field observer. Observational studies can get very complicated. An observational study of jetty recreational use would want to include time of day and seasonal differences. This type of information may also be quite simple--a "memo to the files" which reports an afternoon of patrolling by port police. A major advantage of observational data is that the person collecting the information is, literally, "on the scene," and is therefore capable of adding to our understanding of the meaning of the information. Two major disadvantages are the difficulties (time, money, and expertise) in carrying out a systematic observational study, and the possibility that those being observed will change their behavior because of the presence of the observer.

Written or documentary social information has legitimacy because the act of committing something to print has social importance. Thus, letters to the editor or to the port manager, written (and transcribed oral) testimony at public meetings, and descriptions of "our community" are all potentially useful forms of written data. To approach the scientific calibre of other types of social data it is often necessary to carefully analyze and tabulate a large number of separate examples of written data. This method is called "content analysis" and is a way of converting written documents into data which can be counted and further analyzed. This process can be time-consuming and expensive, and, in many situations, the number of cases may not be sufficient to justify such an elaborate analysis (less than a dozen people may write port- or estuary-related letters to the local newspaper in a year). The primary advantage of using written data is it's "richness," and it's ability to describe feelings in the words of the person. It also gives the person a chance to express the "why" behind an attitude (a letter to the editor is far more complicated than simply answering "agree" in a questionnaire). The major disadvantages are the complexity of converting written documents to a form which can be analyzed statistically and potential problems with the extent to which the documents analyzed reflect the range and distribution of public concern.

Respondent contact social data are what usually come to mind when people begin to think about gathering social information. Social surveys, interviews, informal discussions with community residents, and systematic anthropological "ethnographic" fieldwork are examples of techniques which produce respondent contact data. In all cases, individuals (respondents) are aware that they are providing social data, and this means that they must agree to do so. In most cases, information is obtained through the use of semi-structured or closed-form questions (one would not use a question as general as "What do you think about the estuary?") and opinions are sought from a larger number of persons. (An extremely rough rule-of-thumb is that a social survey must have at least 300 respondents to have any meaning--of course, they way in which the 300 are chosen is also of critical importance.) The major advantage of respondent contact data is that, properly collected, it can be used to make general statements about the characteristics or attitudes of a large number of people. The use of somewhat standardized items makes it possible to compare the responses of persons in different communities or other social settings. The major disadvantage is cost. A well-designed social survey, in which interviewers are asked (and paid) to make several visits to the homes of potential respondents (so as to not bias the sample in favor of those who happen to be home at certain times of the day), can easily average thirty dollars per respondent, including data collection and analysis. Another disadvantage is that federal agencies cannot undertake social surveys unless the questionnaire or interview schedule has been approved by the Office of Management and Budget. While this procedure does screen out some poorly designed studies, it can be very time consuming to obtain this approval. An additional disadvantage is that it is both difficult and expensive to undertake repeated social surveys, especially in a small community where people may discuss their responses with others. In a rapidly changing situation, people's attitudes may change rapidly, and the social survey only describes their views at a single point in time.

7.4. STRATEGIES FOR DOING SOCIAL IMPACT ASSESSMENT

Unlike assessments of impacts on natural environment features (sedimentation, dissolved oxygen, etc.), estimates of social impacts are usually less precise. There are few reliable formulas which can be "plugged into" a data base to yield estimates of social impacts. Limited knowledge, the complexity of human beings, and the many factors which combine in unknown and unpredictable ways with project-related changes to impact daily life in a community all make social impact assessment less than an exact science.

Nonetheless, it is possible to identify several major "strategies" for carrying out social impact assessment. Some understanding of these is important to EIS reviewers. The following discussion examines six major strategies, in addition to the role of establishing baseline characteristics.

7.4.1. Understanding the Baseline--Description of the Setting

An essential part of any social impact assessment is a description of key social and economic characteristics of the present community or region. Obviously, there are no set standards for the extensiveness of this primarily descriptive section of the Environmental Statement. On the one hand, and EIS is not the place to present a complete community study (agencies will sometimes publish a separate Socio-Economic Overview). On the other hand, it makes little sense to make predictions about the future without presenting any information on the present. Further, the present cannot be understood without some minimal reference to the past.

The Guides Manual lists several key features of an adequate Description of the Setting (GM 3.3.2.). All of these point toward an analysis which provides the EIS reader, and the decision-maker, with a detailed introduction to the social and economic characteristics of the area. In many ways, it is in this section that discussion of social variables is the most "scientific," since techniques are available (random sample surveys, social indicators, attitude scales, specialized methods for describing social characteristics of communities) for obtaining and analyzing present characteristics. For this reason, although some tolerance for judgement error is essential when evaluating estimates of the future, EIS reviewers can pay close attention to the appropriateness and scientific respectability of methods used to collect "present condition information".

7.4.2. Project the Future of Current Trends

In some ways, this strategy encompasses the whole of impact assessment. However, it stands as an identifiable social impact strategy where it 1) focuses primarily on trends or issues which are of primary concern to impacted populations (variables of interest to decision-makers may not always be those of greatest interest to impacted populations), and 2) describes social impacts in terms of how the project will change current expectations or attitudes about these issues or trends. Use of this strategy can be seen in sentences such as:

> "Because jetty construction will increase recreational boat traffic, the project is likely to further increase conflict between commercial and recreational traffic."

> "The rapid increase in population over the past ten years is expected to continue with deepening of the main channel."

Admittedly, there is nothing especially "scientific" about this strategy, and many EIS' rely almost exclusively on it. Hopefully, estimates are based on more than simply common sense judgements of engineers with no social science background. The adequacy of this strategy increases where 1) estimates are based on a careful analysis of past and present conditions, 2) there has been some systematic analysis to determine the importance ("salience") of certain issues to the community ("Please rank the following topics in terms of the extent to which you feel they are important community problems..."), 3) estimates are made by more than one person, and 4) estimates are made without regard to whether they will influence the acceptability of the project.

7.4.3. Use Population Multipliers to Quantitatively Estimate Social Impacts

It is often difficult to distinguish between economic and social impacts. While it is fairly clear that some impacts are clearly economic (employment, income) and others are primarily non-economic (family, cultural values), the lines become blurred for many other variables, especially those dealing with infrastructure systems (see TM 7.2.1.4.).

The primary link between economic and non-economic social impacts is through project-induced population changes. Use of population change estimates as a separate assessment strategy occurs because anticipated impacts on many aspects can be expressed in terms of some social variable unit per population unit. Put simply, whenever it is possible to express some characteristic of the social setting in terms of per 1,000 people (doctors, hospital beds, police cars, classrooms, etc), estimates of social impact can be similarly expressed:

> "Likely industrial activity associated with port expansion could bring up to 5,000 new persons into the community in the next ten years. This could require an additional five doctors, 2.4 hospital beds, etc."

There are several steps which lead to the point at which social impacts can be expressed in this manner. The first steps are the work of the economist, and involve estimates of project impacts on economic activity and employment. These steps are described in detail in the Economic Impact section of this Manual (TM 6.4.1.). This discussion describes several different approaches to estimating multipliers, and also warns of the many problems associated with calculating and interpreting multpliers.

The population multipliers will range between 1.5 and 3.5. These multipliers usually express the total number of jobs per basic job, <u>and include the basic job</u>. That is, a basic/non-basic multiplier of 2.3 means that each new basic job will create an additional 1.3 non-basic jobs. It should be remembered that these figures are <u>very general estimates</u>. Further, one should be suspicious of large (over 2.7) multipliers, especially where it appears that employment is a major justification for the project. (Limits on what might be considered "reasonable" multipliers also vary with the population of the area under analysis. (TM 6.4.2.).)

Persons primarily concerned with economic impacts often limit their analysis to estimates of project-related employment change. Assessment of employment-related impacts on other aspects of the community requires <u>three additional steps</u>. Usually, these are performed by a population analysis specialist (demographer). The <u>first step</u> is to estimate the ratio of people (spouses, children, retirees) not in the labor force to the number of workers. This is important for calculating the total number of "new" people in the community for each new project-related basic and non-basic job. Two different techniques can be used to provide rough estimates. The first is to use census data to calculate the average number of workers and non-workers per household. The second is to use employment statistics to calculate a modified labor force participation rate (the percentage of the total population which is in the labor force). (Note: Labor force participation rates are usually based on the population 14 years of age and over. For the population multiplier, those in the labor force should be compared with the total population not in the labor force.) Both of these techniques yield <u>extremely rough estimates</u>, but they do allow one to estimate total population impacts of employment change.

The second step is to compare population change attributable to project-related employment (primary and secondary employment plus worker/non-worker ratio) to that expected without the project. Unfortunately, many Environmental Statements which do link employment change to total population change and their analysis with estimates of the total population change which can be expected because of the project (and alternatives). This is typically expressed in total number of persons (1,679). This figure has little meaning unless 1) there has been some estimate of the rate at which these people would be expected to move into the community (the project will probably not create 500 new jobs overnight and some (not all!) new jobs will be taken by currently unemployed locals), and 2) the likely rate of population change (1.5% annually) expected because of the project is compared to that expected without the project (1.0% annually). This second step is especially important since all communities will experience some change even without the project. To omit this second step is actually to assume that the only factor contributing to population change is the project!!! This is both false and extremely misleading.

The third step is to estimate social impacts in terms of the additional population expected in the community as a result of the project. A variety of indicators are available which express community services in terms of units (classrooms, doctors, police cars) per 1,000 population. (Some examples of per 1,000 multipliers used in recent social impact studies are: 1 police car, 2.0 police officers, 2.6 full-time law enforcement personnel, 3.63 hospital beds, 1.3 physicians, .5 dentists, 2.7 Registered Nurses, and 10 acres of urban open space.)

These indicators may be provided by local organizations. When using these estimates, it is very important to distinguish between the current situation (0.5 doctors/1,000 persons) and some "ideal" or standard (1.0 doctors/ 1,000 persons).

On the one hand, some communities may have to make special efforts even to "catch up" with a state standard, which means that project-related population change poses an additional burden. In other cases, officials may find it tempting to attribute long-needed equipment needs (a new ladder truck) to the specific demands of the project.

The end result of these steps is an expression of social impacts in terms of additional service needs, such as 1.3 doctors, 2.5 police cars, and 3.67 new classrooms. Social impact studies which rely almost exclusively on population multipliers are extremely interesting to those concerned with fiscal impacts (city council, hopital boards, school boards), and fairly uninteresting to those who want to know how their town will be different if the new dock is built. That is, although citizens can identify with population multiplier impacts if expressed in additional taxes, people generally do not easily relate to a discussion of community change in such quantitative terms. For this reason, while any project with significant employment impact should include estimates of total population and social services impacts, Environmental Statements should also portray social impacts through a more qualitative strategy.

7.4.4. Ask a "Social Impact Variable Expert" to Estimate Impacts

One of the curious things about social impact assessment is that planners whose expertise is in natural resource management (civil engineer, hydrology, forestry) sometimes provide estimates of social impacts on the basis of minimal information. An obvious solution to this problem is for natural resource planners to systematically incorporate the opinions of persons with expertise in, and responsibility for, certain aspects of social life.

Use of the "expert estimate strategy" involves agency consultation with "outside" experts such as law enforcement planners, demographers (population specialists), school personnel, and highway planners. Ideally, the first contact with these experts would occur early in the planning process, during the preliminary selection of impact variables to be included in the Environmental Statement, and long before the preparation of the Setting Description. Although small communities and counties may not have an elaborate network of people whose formal responsibility is in planning, contact with local agencies will usually lead to someone with above average interest in planning or in how estuary-related activities might impact their area of social concern. Information from these persons could be included in the Setting Description, and would hopefully form part of the background information for design of the Proposed Action.

The next contact would occur after the agency had designed the Proposed Action and alternatives, at the point at which some estimates of project outputs and population impacts had been estimated. Experts would then be asked to estimate impacts on their areas of expertise, and their estimates would be included (properly footnoted) in the Environmental Statement. Following publication of the Draft Environmental Statement, experts could be again called in to evaluate public concerns in certain social areas, and to assist in any modifications in the Proposed Action and impact assessment.

The above "strategy" may appear to be nothing more than applied common sense. Further, natural resource agencies may feel that they already use a version of this "strategy," since Environmental Statements are routinely distributed to other governmental agencies for review and comment. (Their comments are usually published in the Final Environmental Statement.) Although this interagency communication process may have been designed to encourage the "expert estimate" strategy, in most cases it does not. Environmental Statements are usually reviewed by persons whose primary job is reviewing other agencies' Statements, the review takes place after the Draft Statement is written, the local agencies which review Statements are typically those with a general interest in planning (the city planning office, zoning commission or city council) rather than those with specific interests in the social environment. Further, reviewers often pay more attention to process (was the list of historic places consulted?) than substance (did the agency make a meaningful attempt to get at potential impacts on locally defined places of historic importance?). For these reasons, most agencies could make far more systematic use of the "expert estimate" strategy.

7.4.5. Ask Citizens to Estimate Impacts

Social impact studies sometimes give the impression that the agency or a group of "experts" see themselves capable of deciding "what's good for the people." Even though agencies do provide opportunities for "public input," they often occur in a highly formalized situation (a public hearing), or relatively late in the planning process (people may make written comments on the Draft Environmental Statement).

One way to increase the involvement of potentially impacted publics is to use questionnaires or social surveys to solicit citizen views of likely social impacts of the project and alternatives. Involving the public in the estimation of social impacts could occur in addition to soliciting public input for the Setting Description ("we want to know about special inventory information you feel should be included") or project design ("we want your ideas about the proposed channelization and jetty construction").

Use of the "citizen estimate" strategy usually takes the form of a social survey (mailed questionnaire or interviews). The questionnaire includes some information about the Proposed Project and alternatives. People are then asked questions about their feelings on project impacts on population growth, housing, educational opportunities, community attractiveness or any other of an infinite list of possible variables or items. Typically, questionnaires included a number of "closed form" items (strongly agree, agree, etc.), since it is very difficult to analyze the responses of 300 people to an open-ended question such as "Do you think the dredging project will change your community?" Analysis of responses usually involves tabulating the responses to the items, and hopefully would extend to "crosstabulation" of items to discover if groups within the community differ in their perceptions of likely impact.

"But what do the people know?" Although agencies have obvious reasons for finding out whether people like the project (not really a social impact), they may have much less confidence in the ability of citizens to understand the complex linkages between project outputs and social impacts. There are several possible responses to this. First, because of personal and professional or occupational experiences, many citizens <u>do</u> bring a level of expertise to bear on social impacts, particularly if they are intimately concerned with the future of their neighborhood or community. Second, survey respondents may have lived in the community longer and had more experience with the estuary than outside persons hired to do the social impact study, or agency personnel who moved to the community several years ago, and will probably be transferred out before project completion. Third, social psychologists who have studied the "self-fulfilling prophecy" tell us that if people believe that something is likely to occur (land values will go up near the jetty) they may alter their behavior (land <u>is</u> subdivided into recreational lots) in response to what they believe will happen in such a way that what they believed will happen becomes reality (land values <u>do</u> go up even though the project is still tentative). For this reason, it is important to understand citizen perceptions of likely impacts, even though they may differ from those provided by "experts."

A number of social impact studies have used this strategy. In part, this is because questionnaires are a major data gathering tool for many social scientists (see discussion of Respondent Contact Data, TM 7.3). (Anthropologists may be less inclined to use structured questionnaires and generally prefer somewhat more open-ended, indepth interviews with a smaller number of "key informants.") Because of governmental concern over the quality and number of questionnaires distributed by federal agencies, current regulations require Office of Management and Budget approval of any document (questionnaire, response form) that asks the same question of more than 10 people. For this reason, many agencies are reluctant to use questionnaires, and therefore this impact estimate strategy is seldom used. Hopefully, more experience with questionnaires will result in more widespread use of this basic information gathering tool.

7.4.6. Compare Impacted Areas with the "Most Similar Other Project"

A strategy which is particularly appropriate for large "lump" projects (construction of a new jetty, major deepening of channels, large-scale industrial development) is to locate similar completed projects and to examine community characteristics in that setting as a basis for estimating future conditions in the area under study. While it is true that one can never match the expected "post-project" situation exactly, focus on a community or region which currently displays some of the characteristics expected to emerge as a result of the proposed project is an effective impact assessment strategy. Selection of the comparison communities (ideally, several different communities would be selected to correspond to the "future" under the Proposed Action <u>and</u>

different alternatives) is based on estimates of changes in population size, and the scope and impact of the project. Thus, this is more of a technique for displaying the results of impact analysis than a strategy for actually doing impact assessment.

A major advantage of the comparison community strategy is that it provides a living example of what the community under analysis might be like. People can visit the comparison community, and learn first-hand about how people dealt with similar project impacts. A major disadvantage is that it may be difficult to identify such communities. This can mean that people become unduly concerned about characteristics of the comparison community which have little to do with project impacts.

7.4.7. Prepare "Scenarios" which Portray "Alternative Futures" of the Impacted Area

What people want to know is what their town will be like if the project is implemented. Unfortunately, most impact strategies fail to provide this information in an integrated manner. Of the five strategies discussed above, the "comparison community" comes closest, but people may not easily relate to this strategy, because, after all, the comparison community is "someone else's hometown." The other four strategies tend to fragment analysis into a series of variables and indicators, and fail to present a wholistic, integrated picture in which key features of social life are described in terms which are meaningful to local people.

"Scenarios" can provide this sense of reality. A scenario is a description of an area (community, estuary, etc.) at some future time. Two key features of scenarios are: (1) the future is described using local names, landmarks, and features and (2) the future is described by using an "historical" writing style which takes the perspective of a writer who looks "back" on how the community has been transformed by the project. The presentation might include a sentence such as:

> By 1985, the view west from the Bay Bridge included the new jetty, a blacktop access road, and the revegetated spoils area.

Ideally, separate scenarios would be prepared for the Proposed Action and each alternative. The aspects or features of the community mentioned in the scenario would be those most likely to be changed by the project. Hopefully, the scenario would present an integrated view of the community, much like that which should also be found in the Setting Description.

Effective, realistic scenarios are obviously based on a data set which includes projected changes in employment, population, land use, and other social characteristics. Writing scenarios requires imagination, creativity, and a good sense of those local features which would most effectively portray the setting.

In many ways, both the scenario and comparison community strategies are ways of "packaging" the results of impact analysis, rather than basic analytical techniques. Both rest on a systematic effort to establish impacts in terms of specific variables. Scenarios have been used to present broad alternatives for multicounty regions and large metropolitan areas. The more elaborate scenarios include land use and transportation maps showing possible future conditions. To date, scenarios have seldom been used in Environmental Impact Statements. The reason is probably that they appear to be more "speculative" or "subjective" than population multipliers or trend extrapolations. However, continuing progress in the application of these more quantified techniques should make it easier to use a scenario to summarize likely impacts in a manner which gives a good "feel" for the future of a community.

7.5. THE RESEARCH AND KNOWLEDGE BASE FOR ESTIMATING SOCIAL IMPACTS OF ESTUARY DEVELOPMENT

Ideally, one would point to a large and comprehensive list of studies which were able to monitor over time a large number of estuary-related projects. Further, it would be helpful to have access to a literature on a series of resource-people relationships. Unfortunately, the knowledge base is somewhat inadequate, and even in those areas which have received some attention, results are sometimes contradictory. Further, relatively few social research projects are able to monitor changes over a long period of time, and even relatively short-term "before-after" studies are extremely limited.

The following sections list literature in five categories; 1) handbooks and systems for social impact assessment. examples of social assessment in 2) Environmental Impact Statements on dredging projects, 3) water resource-related community impact studies, 4) studies of port-related occupations, and 5) studies of specific social impact variables.

7.5.1. Some Examples of Handbooks and Manuals for Social Assessment

Social Impacts: A Guidance Manual for the Assessment of Social Impacts Due to Highway Facility Improvements. Prepared by Skidmore, Owings and Merrill (and subcontractors) for the U.S. Department of Transportation, Washington, D.C., 1975.

Since many people are usually impacted by major highway projects, it is not surprising that the most comprehensive (as of early 1977) impact assessment system has been developed for the Department of Transportation. The Social Impacts Notebook is part of a seven volume "package" developed by Skidmore, Owens, and Merrill, a large architectural and planning firm. (Those interested in social impacts would probably also find the Economic Impact Notebook (Number 3) helpful.) The Social Impacts Notebook discusses several general groups of social variables, such as community cohesion and aesthetics. The document gives many examples of specific ways of measuring particular indicators, and also supplements the discussion with photographs and drawings. Wherever a dredging project included construction or relocation of a major highway, this document may assist in the assessment of likely social impacts. Despite its somewhat technical style, interested citizens will find it helpful in understanding highway-oriented social impacts.

Social Impact Assessment Manual: A Guide to the Preparation of the Social Well-Being Account. Prepared by Stephen J. Fitzsimmons, Lorrie I. Stuart, and Peter C. Wolff, Abt Associates, Inc. for Bureau of Reclamation, Denver, July, 1973.

This manual is one of a series of reports prepared for the Bureau of Reclamation by Abt, Associates. It is designed to assist planners in assessing social impacts of water-oriented projects, such as small reservoirs, irrigation projects, and flood control programs. Although Bureau of Reclamation projects typically involve inland areas and waterways, persons concerned with coastal, estuary-related projects may find this document helpful because of its emphasis on water-oriented changes and its use of the Water Resources Council Social Well-Being Account system to organize the list of possible indicators.

Methodology and Guidelines for Assessing Social Impacts of Development. Prepared by Duncan and Jones in Affiliation with Berkeley Planning Associates for Community Development and Environmental Protection Agency, County of Sacramento, California, July, 1976.

Because this document was prepared for county-level use in the assessment of the impacts of subdivisions and shopping centers, the primary concern is land use impacts on community infrastructure systems and existing neighborhoods. It gives emphasis to the attitudes of potentially impacted populations, and suggests a number of possible variables or indicators, many of which could be used in the Citizen Estimate strategy. The document could be particularly useful to citizens, since it is clearly written and avoids social science "jargon."

A Social Impact Assessment Primer. Prepared by Raymond L. Gold, Director, Institute for Social Research, University of Montana for Region 1 and SEAM (Surface Environment and Mining), U.S. Forest Service (First Draft, June, 1976).

In contrast to handbooks which suggest use of a formal rating system (Bureau of Reclamation) or social surveys (Sacramento County), this "Primer" stresses qualitative information which gets at how people in impacted areas deal with each other on a daily basis. The research techniques suggested are close to those used by anthropologists, and the focus is on the immediate "village" or small community environment. (The authors have done extensive studies of the impact of coal mining and power generating facilities in eastern Montana.) This document effectively points the reader toward making sure that the social impact study does not ignore "the social" (what is important in the daily life of people), and gives too much emphasis to the "socio-economic" (the infrastructure systems which usually get nearly all of the emphasis on "social" impact studies). Although the Primer has relatively few examples, most of which deal with ranching and dryland farming, persons concerned with estuary-related impacts will nonetheless find this document to be extremely informative and very readable.

Social Impact Assessment Notebook, U.S. Forest Service, Washington, D.C., (Draft available, July, 1977). This document was prepared for Forest Service planners. The first part of the Notebook reviews a number of different aspects of social assessment, including data sources, selection of social impact variables, and seeking outside help in preparing social assessment. Part Two consists of a variable-by-variable discussion of over fifty specific variables and components. Data sources are recommended for each. Problems and limitations of the use of each variable and component are also discussed.

7.5.2. Social Impact Assessment Examples in Dredging-Related Environmental Statements

It would be helpful if one could point to several "ideal" examples of social impact assessments which were prepared for dredging-related Environmental Statements. Such examples might be found had it been possible to carry out a thorough search of a large number of appropriate EIS'. It was not possible to undertake the search. However, the results of such a search would probably have led to the following conclusions:

1) The social impact assessment sections of most EIS' generally present only minimal information.

2) The vast majority of information presented in such sections consists of a summary of demographic information from the U.S. Census rather than a discussion of likely future impacts of the project.

3) One occasionally finds more complete social impact analyses in a Supplement published after the initial Draft EIS.

The following represent a range of coverage of social impacts.

1. Fall River Harbor Improvement Dredging Project and Fall River Providence River Harbors Dredging Actions with Ocean Disposal at Browns Ledge Draft Environmental Statement, New England Division, Corps of Engineers, Walthan, Massachusetts, February, 1976.

   This document provides only minimal information on the characteristics of present situation. It emphasizes the economic conditions (unemployment, decline of established industry) which provide the economic justification for the project. The discussion of environmental impacts does not even have a section entitled "social impacts." Instead, there is a five page discussion of "economic benefits attributable to improvement," and several brief discussions of impacts on commercial fishermen.

2. Maintenance Dredging of Existing Navigation Projects, Final Composite Environmental Statement, San Francisco District, Corps of Engineers, San Francisco, California, December, 1975 (Volume I).

One can sympathize with the overwhelming task facing those charged with assessing impacts of the continuation of dredging activity on such a large, complex region. The Setting Description presents a 68 page summary of economic characteristics and a 26 page discussion of social characteristics. Discussion of impacts includes a 25 page assessment of economic impacts. The social impact assessment, however, consists of a brief, superficial 3 page commentary. Assessment of impacts of alternative disposal sites also includes some mention of economic and social impacts. Despite the complexity of the social setting, it is reasonable to expect a fuller treatment of social impacts, particularly on those segments (areas, subcultures) of communities likely to be impacted by a significant change in port activity. The Setting Description approaches "data overkill", with numerous tables providing detailed demographic information. Assessment of social impacts, however, is essentially nil.

3. Corps of Engineers Activities in the Chetco, Coquille and Rogue River Estuaries and Port Orford, Oregon, Final Environmental Impact Statement, Portland District, Corps of Engineers, Portland, Oregon, December, 1975.

This document includes an above average discussion of social impacts. Social and economic impacts of the setting are reviewed in a 54 page section, and, although given relatively brief coverage, social and economic impacts are systematically discussed. Analysis of how different community groups view population growth is particularly interesting. In some ways, the task of assessment was simplified by the geographical isolation of the area. (One shortcoming of the analysis is failure to discuss the interrelationship between different ports which share dependence on tourism and the timber industry.) What is most impressive about the discussion of social impacts is the absence of a strong effort to "sell" the project through a discussion of social and economic "benefits."

4. Coos Bay Deep Draft Navigation Channel, Draft Supplement to the Environmental Impact Statement, Volume II - Background Information, Portland District, Corps of Engineers, Portland, Oregon, February, 1975.

The lengthy coverage of social and economic variables in this document reflects a format which is typical for many recent Corps of Engineers EIS'. That format is to present a more complete social impact assessment as part of a Supplement to the Draft or Final EIS, published as a separate document. Discussion of social and economic impacts is organized into separate sections, with titles such as "Population Characteristics and Changes" and "History of Coos Bay Area." The most significant contribution to social impact assessment is a section titled "Community Attitudes," which is a combined report of a public opinion poll and the results of interviews with a number of local officials. One of the questionnaire items reported is an example of the Citizen Estimate of Impact Strategy (TM 7.4.5.), and asks respondents to estimate both the direct (increase or decrease) and value (beneficial or adverse) of the impact. (Most notable was the large number of persons in the "No Response" category.) A decision to engage in further impact studies and to publish then in a Supplement to the EIS is a mixed blessing. On the one hand, it is encouraging that the agency is willing to invest additional time and money in studying potential impacts. On the other hand, it is unfortunate that such information was not provided as a regular section of the Draft EIS.

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