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Project Summary

Analyzing Natural Systems: Analysis for Regional Residuals-Environmental Quality Management

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Information on approaches for analyzing natural systems for regional residuals-environmental quality management (REQM) was developed. The natural system components analyzed are land surface runoff; surface receiving water, and atmospheric systems. Detailed summaries of several operational natural systems models are provided along with a discussion of the factors that must be considered in selecting a model in a given REQM context. Information is included on incorporating modified and new models into an existing REQM framework.

***The report is intended for individuals* in government and private organizations who make the analyses necessary to the development of strategies for achieving and maintaining environmental quality. The information is not intended to replace other published material on analyzing particular natural systems. Rather, the purpose is to guide the use of such material in a residuals planning and management context.**

This Project Summary was developed by EPA's Environmental Research Laboratory, Athens, GA, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Over the past several decades, various models have been developed to analyze natural systems. The development and use of these tools has greatly intensified, primarily in response to the planning requirements mandated in federal, state, and local environmental legislation. The various planning mandates have required that parts of the natural system--for example, surface water bodies, groundwater systems, atmospheric systems--be analyzed to *evaluate the impacts of human activities* on the ambient quality of the respective systems and to assess the effectiveness of strategies for achieving and maintaining an acceptable level of "quality." In other words, the primary emphasis of natural systems analysis has been within some "management context," however that context has been defined.

A particularly useful framework for describing this overall management context is Residuals-Environmental Quality Management (REQM). The REQM framework is well-suited to this purpose because it explicitly incorporates all of the activities required to achieve and maintain specified levels of ambient environmental quality. These activities and their residuals generation determine the natural systems analyses that are to be undertaken.

The REQM Concept

"Residuals" are those materials and energy flows that have no value in existing markets or a value less than their costs of collection, transportation, and use in the same or another activity. Thus, a residual is defined in an economic sense. Whether a material or energy flow is a residual depends on the relative costs of alternative materials and energy for use in the same or another activity. These costs in turn depend on the level of technology in the society and on various governmental policies, both

of which change over time. The term residual, then, is used rather than such terms as waste, pollutant, or contaminant. An unwanted material or energy flow may or may not be characterized accurately by any one of these terms, depending on the specific material, the environment into which it is discharged, and the effects on environmental quality and subsequent uses of the environment. Not all discharges of unwanted materials or energy into the environment will have adverse impacts on ambient environmental quality; some in fact may have positive effects on receptors.

The analysis approach emphasizes (1) the interrelationships among the three forms of materials residuals--solid, liquid, and gaseous--because one form of material residual can be transformed into one or more other forms by the addition of materials or energy or both, and (2) the interrelatedness of the receiving natural systems or environmental media. For example, modification of sewage in a sewage treatment plant results in the generation of a semi-solid residual, sludge, plus various types of liquid residuals. If the sludge is incinerated, gaseous residuals will be generated that may be deposited in surface receiving waters. The material and energy inputs required for the modification themselves become residuals. Modification is undertaken under the assumption that the discharge of the modified residual and the discharge of residuals generated in its modification will have fewer adverse impacts than the discharge of the original residual. This may not always be the case. The natural systems analysis to be conducted in any given context must be devised with explicit recognition of these interrelationships.

The concept of an REQM system is illustrated in Figure 1. Within any given region (however defined) at a given point in time, there is a spatial distribution of activities: industrial, mining, residential, agricultural, commercial, transportation. For each activity there are (1) alternative combinations of factor inputs and related production technologies to produce the desired goods and services of specified characteristics, with a set of types and quantities of residuals associated with each combination, and (2) alternative ways of handling the residuals after generation. Activities as sources of residuals can be classified as point sources, such as a power plant, a manufacturing plant, or a residence; line sources, such as traffic flow on a major street; and dispersed or area sources, such as a logging or agricultural operation.

From each activity some residuals are directly or indirectly discharged into natural systems--air, water, and land environments. In the natural environment, these residuals are affected by and may affect various physical, chemical, and biological processes, such as transport, sedimentation, absorption, adsorption, volatilization, decomposition, accumulation. These processes transform the time and spatial patterns of residuals discharged from the various activities into the resulting short-run and

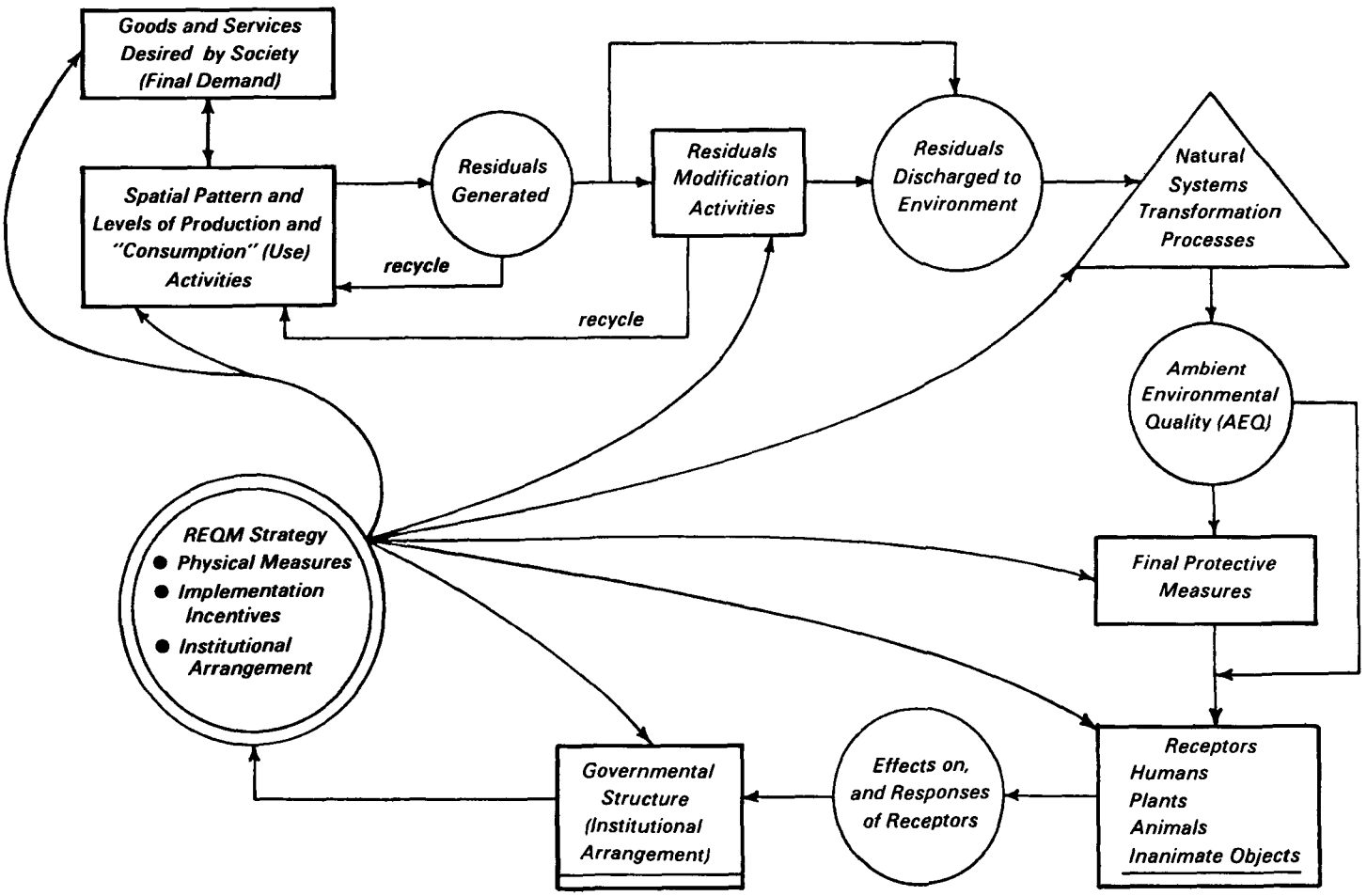

Figure 1. *Concept of a residuals-environmental quality management (REQM) system.*

long-run time and spatial patterns of ambient environmental quality.

The resulting time and spatial pattern of ambient environmental quality impinges on receptors--humans, plants, animals, and inanimate objects. The impacts on the receptors, as perceived by humans, and the responses of individuals and groups to the perceived damages, provide the stimulus for action. The extent and form of action, as expressed in a selected management strategy, depend on the institutional structure, culture, and value system, and on competing demands for scarce resources for other desired goods and services.

Developing an REQM strategy usually involves (1) estimating residuals generation and modification activities, termed "activity models"; (2) understanding the processes that affect, and are affected by, the residuals after their discharge into the environmental media, termed "natural systems models"; (3) specifying an explicit objective function, which includes environmental quality indicators in the function itself, or as constraints, or both; (4) selecting a computational procedure; and (5) developing and applying criteria for evaluating strategies. This report provides guidelines and procedures for selecting one or more appropriate natural systems model.

Natural Systems Models

The types and quantities of residuals discharged at specific locations and times comprise the inputs into the natural systems models, along with the relevant hydrologic, geomorphologic, meteorologic, and pedologic variables such as temperatures, wind velocity, precipitation, soil characteristics, topographic slope, stream channel characteristics, and sunlight. Major types of natural systems models (NSMs) include (1) physical dispersion models such as for suspended particulates, sulfur dioxide, and total dissolved solids (salinity); (2) physicochemical dispersion (or transport) and fate models such as for photochemical smog in air or pesticide movement and modification in ground water aquifers; and (3) biological systems models such as terrestrial and aquatic ecosystem models.

The time and resources available and the relative importance of the environmental media--in terms of the relevant environmental quality problems--determine the degree of complexity necessary for the NSMs. For example, a water quality model may consist of a set of simple linear transfer coefficients or it may be a multicompartment aquatic ecosystem model. NSMs transform the time and spatial pattern of residuals discharges into the environment into the resulting time and spatial pattern of ambient environmental quality as measured by whatever indicators are of interest in the particular situation.

Selecting Natural Systems Models

An approach was developed for selecting NSMs in any given REQM context, relative to three environmental compartments--land runoff (urban and rural), surface water, and the atmosphere.

An NSM translates the time and spatial pattern of residuals discharged into the resulting time and spatial pattern of ambient environmental quality or delineates the on-site changes in the state of a natural system as a result of on-site production processes and residuals discharged from a source. The report (1) identifies and describes the principal approaches and associated analytical techniques presently used to analyze natural systems, (2) provides detailed summaries of a number of operational NSMs that are currently available, (3) indicates the factors which must be taken into account in selecting a NSM in a given REQM context, and (4) describes how to select an appropriate operational NSM.

Two attributes are necessary for a NSM to be considered operational. The first is that it has been successfully applied to and verified for at least one natural system and that it can be used to model another different, but roughly similar, system without extensive internal modification. The second is that sufficient written documentation must be available about the model to enable a potential user to apply the model in a location other than that for which it was verified.

The three basic analytical approaches to analyzing natural systems, whether they represent a surface water body, land area, or atmospheric system, are physical modeling, conservation of mass and energy, and statistical. Three characteristics common to all NSMs are temporal variation, averaging time and spatial dimensionality. NSMs may be steady-state or nonsteady-state depending on whether variables change over time. Nonsteady-state models may be characterized as either nonstochastic (or deterministic) or stochastic.

The report discusses setting up the natural systems analysis portion of an REQM analysis. The factors determining the scope and the type(s) of natural systems analysis include the questions to be answered, the residuals of concern, the conditions of relevant natural systems measured in terms of ambient environmental quality indicators, the available analytical resources, and the relative importance and characteristics of residuals-generating activities. Figure 2 depicts the NSM selection procedure.

Regardless of the category or type of NSM, a number of common problems exist with respect to adoption, operation, and utility of models. The most important problems relate to determining the appropriate level of complexity necessary for the analysis, calibrating and verifying the candidate NSM, determining background levels of residuals, linking NSMs and residuals generating activities, and interpreting modeling results including the use of sensitivity analysis.

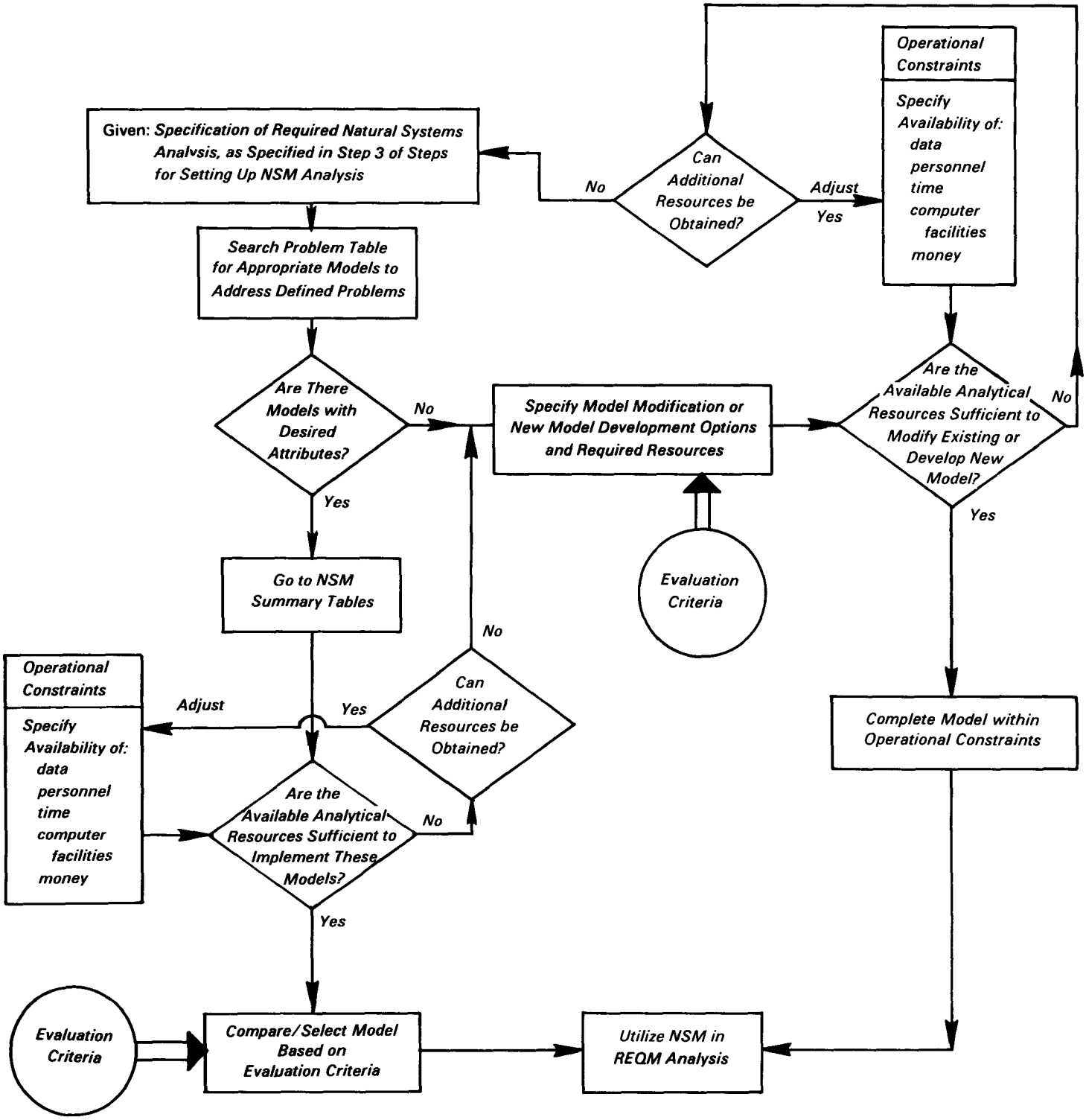

Figure 2. *Flow chart to NSM selection procedure.*

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The complete report, entitled "Analyzing Natural Systems: Analysis for Regional Residuals-Environmental Quality Management," (Order No. PB 83-223 321; Cost: $38.50, subject to change) will be available only from:
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