ENVIRONMENTAL AUDITING

A Synoptic Approach for Assessing Cumulative Impacts to Wetlands

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ABSTRACT / The US Environmental Protection Agency's Wetlands Research Program has developed the synoptic approach as a proposed method for assessing cumulative impacts to wetlands by providing both a general and a comprehensive view of the environment. It can also be applied more broadly to regional prioritization of environmental issues. The synoptic approach is a framework for making comparisons between landscape subunits, such as watersheds, ecoregions, or counties, thereby allowing cumulative impacts to be considered in management decisions. Because there is a lack of tools that can be used to address cumulative impacts within regulatory constraints, the synoptic approach was designed as a method that could make use of available information and best professional judgement. Thus, the approach is a compromise between the need for rigorous results and the need for timely information. It is appropriate for decision making when quantitative, accurate information is not available; the cost of improving existing information or obtaining better information is high; the cost of a wrong answer is low; there is a high demand for the information; and the situation calls for setting priorities between multiple decisions versus optimizing for a single decision. The synoptic approach should be useful for resource managers because an assessment is timely; it can be completed within one to two years at relatively low cost, tested, and improved over time. An assessment can also be customized to specific needs, and the results are presented in mapped format. However, the utility of a synoptic assessment depends on how well knowledge of the environment is incorporated into the assessment, relevant to particular management questions.

In 1988, Bedford and Preston proposed that a qualitative, synoptic assessment procedure could be a useful tool for allowing cumulative impacts to be considered in the wetland regulatory process (Bedford and Preston 1988b). This proposal evolved from a series of papers and a workshop sponsored by the US Environmental Protection Agency's (EPA) Wetlands Research Program (WRP). The papers, which were published subsequently in a special issue of *Environmental Management* (Bedford and Preston 1988a), examined in detail the conceptual, technical, and regulatory issues related to the assessment of cumulative impacts to wetlands. Incorporating cumulative impacts into the regulatory process stems from the need to develop proactive, anticipatory approaches to wetland protection that take a more comprehensive view of wetlands and the factors impacting them. This is necessary to complement the reactive, project-by-project approach taken during permitting under Section 404 of the Clean Water Act, a process that is initiated by and, for the most part, limited to the proposed project (Hirsch 1988, Preston and Bedford 1988).

As Clark (1986) has argued, cumulative impact assessment needs a synoptic perspective so that all potentially significant impacts are considered; this is in contrast to traditional impact assessments, which consider a specific impact. Yet the word synoptic, which is defined as "affording a general view of a whole" (Webster's Ninth New Collegiate Dictionary), also implies that a synoptic assessment provides a broad perspective, rather than a detailed analysis. A synoptic assessment is especially critical if cumulative impacts are to be considered during the permitting process because of a major constraint: Thousands of permits must be processed in a limited amount of time with limited staff. In 1995, 62,000 permit applications were received by the US Department of the Army, Corps of Engineers, up 60% from 1992 (US Army Corps of Engineers 1995). These constraints mean that the majority of annual permit decisions, which mostly involve small or seem-

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ingly inconsequential actions, must be made using readily available information; detailed assessments requiring extensive collection and evaluation of information are limited to major controversial actions (Hirsch 1988).

The Section 404(b)1 guidelines that followed the Clean Water Act require cumulative impacts to be considered during permit review (40 CFR 230.11). However, including information on cumulative impacts has been hampered by the lack of a method that could conform to the constraints of the permit process (e.g., the ability to use readily available information). Although a number of methods have been developed for assessing cumulative impacts that produce an integrated view, none of these are truly synoptic in that they also provide a general view. Bedford and Preston (1988b) argue that a conceptual and qualitative understanding of cumulative impacts, based on comparative risk and relative predictions having relatively low resolution, is a legitimate assessment approach that could improve regulatory decisions during the interim until additional research allowed more rigorous assessments.

Bedford and Preston propose a synoptic approach that would provide relative rankings of landscape units based on the various characteristics that determined wetland functions and their responses to impacts. These characteristics include the wetland's intrinsic attributes, such as its capacity to assimilate various pollutants, as well as extrinsic attributes, e.g., landscape characteristics that control input of pollutants into the wetland. Qualitative evaluations of these various characteristics could be derived and mapped using existing information on climate, topography, soils, land use, etc. The goal is to provide a generally accurate evaluation of the region as a whole (Preston and Bedford 1988); more detailed information could be obtained on a site-specific basis, e.g., through 404 site evaluations.

Since Bedford and Preston's proposal, WRP has developed the methodology for a synoptic assessment. That effort, consisting of conducting a number of case studies to demonstrate the feasibility and utility of the approach and to formalize the methodology, culminated in the release of a report entitled "A Synoptic Approach to Cumulative Impact Assessment: A Proposed Methodology" (Leibowitz and others 1992a). This article summarizes the 1992 approach, briefly discusses technical problems with the approach that are being researched, and reviews some current and past applications of the synoptic approach. A summary of the synoptic approach follows.

Synoptic Indices

The synoptic approach provides a framework for making comparisons between landscape subunits, such as counties, watersheds, and ecoregions, so that cumulative impacts can be considered in management decisions. These comparisons are made by evaluating one or more landscape variables or "synoptic indices" for each subunit. These indices were based on principles from landscape and stress ecology and are discussed fully in Leibowitz and others (1992a).

The purpose of cumulative impact assessment is to evaluate effects, which are the physical, chemical, and biological changes, resulting from an impact (human-generated action) and including direct and indirect changes that can be removed from the impact in time and space (Beanlands and others 1986). When conducting the impact assessment, we are particularly concerned with the loss of valued functions. These ecological functions are aggregate behaviors that arise from the many physical, chemical, and biological processes that take place within ecosystems. For example, a wetland function can include reducing flood peaks, which depends on the processes that determine the wetland's hydrologic budget, such as precipitation, evapotranspiration, surface and groundwater in- and outflows, and tidal input (Mitsch and Gosselink 1986). From a landscape perspective, ecosystem functions can broadly be classified as source or sink functions (Leibowitz and others 1992a). An ecosystem is a source for a given material at a given time if it causes a net increase in the total amount of material being transferred within the landscape (i.e., exports from the ecosystem are greater than imports into it); it is considered a sink if it causes a net reduction in the material flux. We define these terms in the broadest sense, without regard to the specific processes responsible for the functions.

Numerous ecosystem characteristics can be altered by an impact. Lugo (1978) developed a model that described five ways an ecosystem can be stressed. Based on this, impacts can have three general types of effects on an ecosystem: changes in the driving factors that control material and energy flows that originate outside an ecosystem's boundaries; changes in ecosystem processes, such as production or respiration and material and energy distribution; and changes in structure, which is comprised of an ecosystem's physical, chemical, and biological characteristics.

Based on the preceding principles, we defined four synoptic indices for assessing cumulative impacts and relative risk: function, value, functional loss, and replacement potential.

Function Index

Wetlands are capable of performing various functions as a result of physical, chemical, and biological processes. These functions can be divided into three general categories: habitat functions, that is, providing support for wetland-dependent species, including food, shelter, and breeding sites; water-quality functions, such as water-quality improvement and nutrient cycling and supply; and hydrologic functions, such as flood attenuation and moderation of hydrologic flow. The function index refers to the total amount of particular function that a wetland provides within a landscape subunit, without considering benefits. The function index is the rate at which material or energy is added to or removed from the active landscape pool.

Causing a reduction in material flow depends not only on the on-site (intrinsic) conditions, but also on the off-site (extrinsic) factors controlling input of the material into the ecosystem. Thus, the function index consists of two components for sink functions: the assimilative capacity, which is the amount of material the ecosystem could remove, assuming it was available, and the landscape input, which is the amount of material imported into the ecosystem. Phosphorus retention in a wetland provides an example of how capacity and landscape input control sink functions. A wetland's capacity to retain phosphorus depends on factors such as plant uptake; the concentrations of minerals that precipitate phosphorus (e.g., ferric iron and aluminum); soil pH, which affects phosphorus solubility; and adsorption to soil constituents such as clays and organic matter (Mitsch and Gosselink 1986). Factors that determine the landscape input of phosphorus into the wetland include the types of neighboring ecosystems, land-use practices outside the wetland (e.g., fertilizer application rates), and landscape characteristics that control sedimentation rates into the wetland, such as slope.

Value Index

Environmental regulations also recognize the effect of ecosystem functions on public welfare (Preston and Bedford 1988, Westman 1985); therefore, we focused on valued ecological functions as the target of an impact assessment. Wetlands can be valued for the tangible benefits they provide, such as clean water or hunting, or for intangible benefits such as aesthetics. However, values are highly subjective, and a wetland characteristic valued by one individual could be perceived as a liability by another. Whether a particular ecological function is considered valuable is not a technical issue but must be determined by the policy maker initiating the synoptic assessment. Such a decision might be based on law, agency mandate, or public input. For example, by enacting the Endangered Species Act, Congress has affirmed that endangered species are a valuable natural resource (recent discussions concerning revisions to the Endangered Species Act reinforce the need to consider value and function separately, since values are subject to social and political will and can change rapidly). Similarly, an agency mandated with protection of drinking water would place a high value on functions that improve water quality. Values can also be established through public debate. For example, defining watershed protection goals through stakeholder involvement (e.g., citizens groups, industry, and local government) is an important component of EPA's watershed protection approach (EPA 1991b). Public input is also an important element of state wetland conservation plans, for example, through public meetings, workshops, and advisory committees (WWF 1992). Such involvement allows segments of society to air concerns about their interests and values. Including public comments is especially important where proposed actions lack the weight of regulations, e.g., management plans that rely on voluntary participation or the successful passage of local ordinances.

Once it has been decided that a particular function is valued, the relative value of that function within each landscape subunit can be determined using the value index. This index has two components. First, value is related to overall level of function. Second, value is also related to the extent to which that function interacts with some social end point. For example, wetlands could be valued for recreation, in which case the value of wetlands within a particular area would be related to both their level of function (e.g., their habitat quality) and their accessibility to recreationists (note that future value could be included by considering future recreational use). For that case, an index of value could be habitat quality weighted by distance from residential areas. Similarly, the value of flood reduction depends not only on the magnitude of reduction but also on the number of people and amount of property located within the floodplain. Assessing the benefits of an ecological function in this fashion is therefore directly analogous to how risk is defined for environmental stressors (RAF 1992), e.g., risk from contaminants depends on both toxicity and exposure to target populations. Note that this index does not represent economic value because it does not consider market factors. Instead, it provides an estimate of the value provided by a particular function within a landscape subunit relative to the other subunits. We emphasize again that this index is not used to establish whether or not a function has social value; rather, it is used to determine the relative value among subunits of a function whose social value has already been established.

Functional Loss Index

Functional loss represents the cumulative effects on a particular valued function that have occurred within a subunit. This index should include complete loss of function from conversion, in which the ecosystem is changed into a different ecosystem or land use, and partial loss through degradation, in which the impact does not change the ecosystem type but alters its functions. Future loss should also be considered. Functional loss depends on the characteristics of the impact, including the type of impact and its magnitude, timing, and duration, and ecosystem resistance or the relative sensitivity of the ecosystem to the impact, based on the ecosystem's robustness and overall health.

Replacement Potential Index

Replacement potential refers to the ability to replace a wetland and its valued functions. In this case, we are referring to functional replacement performed by people; however, natural recovery could also be considered. Although not a component of a cumulative impact assessment per se, replacement potential is included as a synoptic index because it is a consideration within the 404 permit process and could also be an important component of risk assessment (Leibowitz and others 1992b). Replacement potential depends on many factors specific to the wetland, such as the type of wetland, the function to be restored, and the kind of impact that altered the original wetland (Kentula and others 1992, Kusler and Kentula 1990). In a synoptic assessment, however, we are more concerned with the landscape factors that contribute to the replacement potential. Because it is more difficult to replace a wetland if critical driving factors have been disrupted, this index depends on the overall environmental condition of the subunit. For example, it would be difficult to restore a swamp within a historical floodplain if a levee had been constructed on the river. If restoration did take place, the wetland probably would not be sustainable because natural overbank flooding, which was the major driving factor causing the original swamp, would be disrupted.

Estimating Synoptic Indices

In conducting a synoptic assessment, we must refine the general synoptic indices into a specific set of indices that are most relevant to management concerns within a particular landscape setting. For example, in an application concerned with nonpoint source nitrogen pollution within an agricultural region, the specific indices for capacity and landscape input might be maximum denitrification rate and the nitrate loading rate, respectively. However, quantifying the specific indices accurately for large landscape subunits would be difficult, if not impossible. To evaluate the indices, the synoptic approach uses landscape indicators of actual functions, values, and effects. The indicators are first-order approximations that represent some particular index. For example, data on agricultural nonpoint source nitrate loadings might not be available, in which case, agricultural area could be used as a first-order landscape indicator. In addition, we often take a risk-based approach to estimate specific indices. For example, we may not understand the relationship between a stressor and function, and thus might not be able to quantify the actual loss of hydrologic function caused by cumulative impacts. However, we could assume that loss of function will be greatest in areas where functions and stressors both occur at high levels, compared with areas that have low function and low impacts. Such an approach will undoubtedly make errors in assigning a relative ranking to each landscape subunit. However, a synoptic assessment need not provide a perfect evaluation of cumulative effects. The goal is to provide information that will improve permit evaluation and management decisions overall.

Steps in Conducting a Synoptic Assessment

The process of producing a synoptic assessment involves five major steps (Table 1). Although presented and discussed here sequentially, in actual application, one might have to follow these steps iteratively. We suggest that information resulting from this process not be viewed as the ultimate end product, but that synoptic assessments be updated periodically to reflect changing objectives and environmental conditions and to incorporate better data. By producing an initial assessment and improving it over time, an agency can obtain the desired results over the long term while gaining useful short-term results (that is, processing of 404 permit requests).

Preparation of a synoptic assessment requires the efforts of a team of individuals with different backgrounds and responsibilities. This team should ideally consist of a manager who is in charge of the resource-management program and who has primary responsibility for defining the overall goals of the assessment; a resource specialist who is the ultimate user of the final maps (e.g., a permit reviewer), who is familiar with the

Table 1. Steps in conducting a synoptic assessment (Leibowitz and others 1992a)

- Step 1. Define goals and criteria
  - Define assessment objectives
  - Define intended use
  - Assess accuracy needs
  - Identify assessment constraints
- Step 2. Define synoptic indices
  - Identify wetland types
  - Describe natural setting
  - Define landscape boundary
  - Define wetland functions
  - Define values
  - Identify significant impacts
  - Select landscape subunits
  - Define combination rules
- Step 3. Select landscape indicators
  - Survey data and existing methods
  - Assess data adequacy
  - Evaluate costs of better data
  - Compare and select indicators
  - Describe indicator assumptions
  - Finalize subunit selection
  - Conduct preanalysis review
- Step 4. Conduct assessment
  - Plan quality assurance and quality control
  - Perform map measurements
  - Analyze data
  - Produce maps
  - Assess accuracy
  - Conduct postanalysis review
- Step 5. Prepare synoptic reports
  - Prepare user's guide
  - Prepare assessment documentation

area's wetland resources, and who has primary responsibility for defining the ecological relationships relevant to the particular management objectives; and a technical analyst who assembles the data, makes measurements, calculates the index values, and then maps them. In an actual assessment, these roles need not literally be performed separately by three individuals. In describing the steps below, we include some examples using the Pearl River basin (Figure 1), located in Mississippi and Louisiana (Leibowitz and others 1992a).

Step 1: Define Goals and Criteria

The general objectives of the assessment depend on the overall mission and goals of the particular agency or organization conducting it. The manager should define how assessment results will be applied. The assessment could be used to support very specific decisions, such as a 404 permit review, or it could be used for general planning, for example, to be included in a State Wetland Conservation Plan (WWF 1992). Gosselink and Lee (1989) discuss policy considerations and the importance of goal setting as part of a cumulative impact assessment.

Figure 1. The Pearl River basin, in south-central Mississippi and southeastern Louisiana, and its five subunits. Subunits are USGS cataloging units.

The particular use affects the level of accuracy required and the degree of review the final products must undergo. The overall management objectives and the intended use of the information determine the level of uncertainty the manager is willing to accept in decisions that make use of the synoptic assessment. The manager should also determine whether the assessment is to be purely technical or whether input from the public and potential stakeholders should be included in defining social values and priorities. The manager must estimate the amount of time, money, and personnel hours that can be committed to the project. Regardless of the objectives and needs for accuracy, the effort will be limited by available resources. An example of a management goal for the Pearl River basin would be to provide 404 permit reviewers with information that they can include in the permit review process on the cumulative effects of converting wetlands to agriculture.

Step 2: Define Synoptic Indices

Once the objective has been determined, the resource specialist must define a specific set of synoptic indices that will meet the objectives and intended use of the assessment. This involves replacing the four general

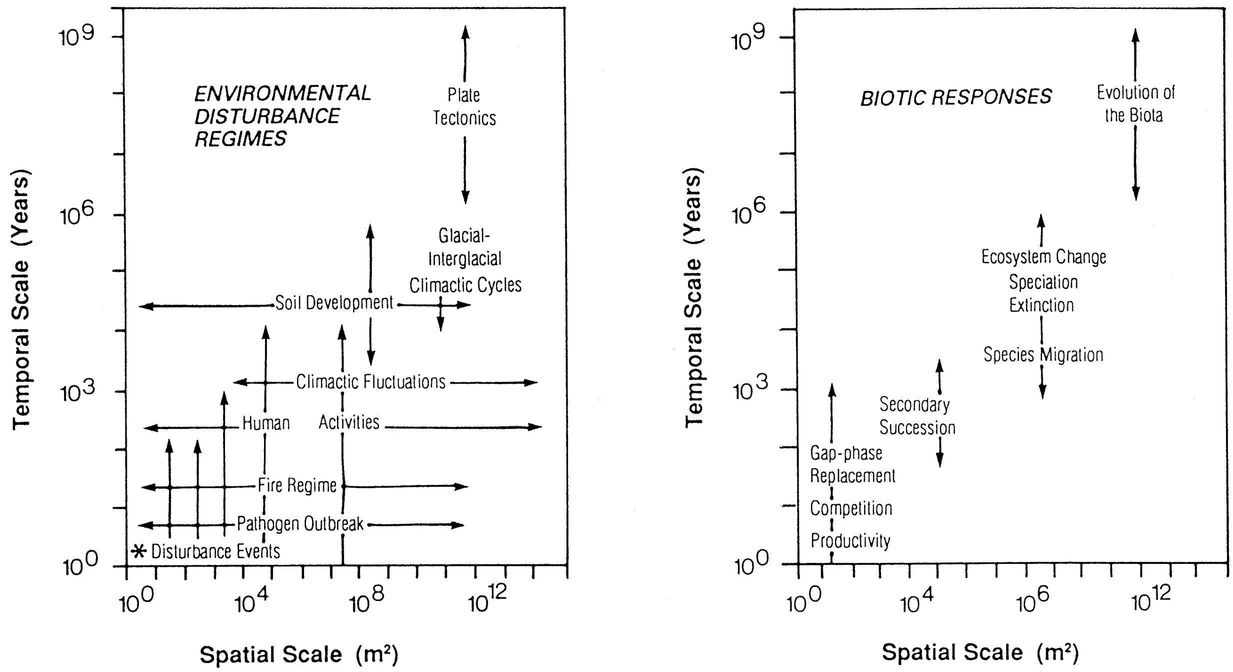


Figure 2. Disturbance (left) and biotic responses (right) occur in many forms and at various spatial and temporal scales (adapted from Delcourt and others 1983). *Disturbance event examples include wildlife, wind damage, clear-cut, flood, and earthquake.

indices (function, value, functional loss, and replacement potential) with a set of indices specific to the objectives. Defining these indices requires an understanding of the relevant environmental processes. A landscape characterization should be developed that describes the following: the wetland types, their functions and values, the natural factors that sustain these wetlands, and the major stressors that are causing a loss of valued functions. Three other factors should also be considered:

- Breadth of analysis. Depending on the specific objectives, the assessment may have to consider environmental processes comprehensively or it could focus on a particular subset of processes. For example, an assessment of stream water quality would need to consider all stressors that were sources or modifiers of pollution, as well as a number of different ecosystems (e.g., streams, riparian zones, urban and agricultural ecosystems). In contrast, an assessment to support a wetland regulatory program might focus specifically on dredge-and-fill impacts to wetlands.
- Spatial scale. Human and natural stressors occur at different spatial and temporal scales, as do the biotic responses to these disturbances (Figure 2). Different management approaches may also have a particular scale; for example, wildlife management units typically range in size from 10,000 to 1,000,000 ha, while 404 permits are usually issued for much smaller areas (Gosselink and Lee 1989). Scale can also have implications for the analysis, e.g., going to a larger scale can result in a loss of detail but may also be more sensitive to emergent system properties (Meentemeyer and Box 1987). The scales of the relevant environmental processes should be considered in planning the assessment and defining the indices.
- Assessment boundaries. The boundaries for cumulative impacts and cumulative effects need not coincide. Some cumulative effects could occur outside a cumulative impact boundary; conversely, cumulative effects within an area could partially result from impacts occurring outside the boundary. If the objective is to determine the cumulative effects within a specific area, the study area boundary should be defined to include the relevant natural factors and stressors that could be operating outside the study area. Even if the actual analysis ignores it, this boundary should be defined so the degree to which the assessment might be overlooking important factors can be determined.

The resource specialist can consult with regional experts for assistance in describing these factors and the specific processes that need to be considered in an assessment. For example, soil scientists from a university or the US Department of Agriculture's Natural Resources Conservation Service (NRCS; formerly the Soil Conservation Service) are familiar with regional factors affecting denitrification capacity and adsorption potential. Hydrologists with universities or the state office of the US Geological Survey (USGS) can provide insight into the hydrologic factors that form wetlands and also can provide information on hydrologic modifications that may affect wetland functions. Biologists with the US Fish and Wildlife Service (FWS), state agencies, or the Nature Conservancy/Natural Heritage Program can provide expertise on wetland habitat and wetland-dependent species, and biologists with the NRCS and other agencies will be familiar with wetlands in agricultural settings, as well as opportunities for restoration. FWS "community profile" reports (e.g., Wharton and others 1982) provide a wealth of relevant information on regional wetland types and often include discussions of geological/climatic setting, natural forcing functions, ecological functions, ecosystem structure, and degradation by human actions or activities.

A specific synoptic index is a mathematical expression that is a combination of several factors. This could include components of an index, such as capacity and landscape input for function or degradation and conversion for functional loss, or this could be a combination of several indices, e.g., function and value. Although a separate index could be defined and separately evaluated for each factor, instead one may want to mathematically combine them into a single index, in which case a set of combination rules needs to be defined. Combination rules should address the following questions:

- Will the factors be combined by addition, multiplication, or some other operation?
- Will the data be normalized, that is, adjusted to a common ordinal scale, before combination? If so, by what procedure?
- Will all factors be considered to contribute equally or should weighting factors be applied to some?
- Will the same combination rules apply to all wetland types and across the entire range of conditions within the study area?

Decisions concerning combination rules are difficult and often subjective and thus deserve careful attention. Mathematical relationships between factors may be available from the literature or regional models. One may have to assume, however, that factors have equal weight or that there is a first-order proportionality between factors. Combination rules are discussed further in FWS (1981), Hopkins (1977), O'Banion (1980), Skutch and Flowerdew (1976), and Smith and Theberge (1987).

For the Pearl River example, the assessment boundaries are the basin itself, since the assessment deals with hydrologic functions (see below) and because the Pearl River basin is a closed drainage unit. USGS cataloging units are used as the assessment subunits, since these units are defined using hydrologic features. To provide information about cumulative impacts within the Pearl River basin, three scenarios were considered: wetland loss from conversion, the effects of that loss on hydrologic function, and the risk of future loss of wetlands from agricultural and urban expansion. To address wetland loss, we defined the percentage of historical wetland area that has been converted as a specific index of functional loss:

$$\%\mathrm{LOSS} = [(\mathrm{AREA_H} - \mathrm{AREA_C})/\mathrm{AREA_H}] \times 100$$

where %LOSS is the percentage of lost wetland area, $\mathrm{AREA_H}$ is the historical wetland area, and $\mathrm{AREA_C}$ is the current wetland area.

In the second scenario, we assumed that loss of hydrologic function would be greatest in areas with high hydrologic input and high rates of wetland loss. We used peak discharge for a 50-year flood event as an estimate of hydrologic input because flood control along the main channel is an important hydrologic function of Pearl River wetlands. Therefore, the index for loss of hydrologic function is defined as follows:

$$\mathrm{LOSS_H} = f(\mathrm{Q_{50}}, \%\mathrm{LOSS}) \approx \mathrm{Q_{50}} \times \%\mathrm{LOSS}$$

where $\mathrm{LOSS_H}$ is the index of loss of hydrologic function and is defined as a function of $\mathrm{Q_{50}}$, the peak discharge for a 50-year flood (Landers and Wilson 1991), and %LOSS, the percentage of lost wetland area. This is a simple index and does not account for wetland influence attributable to position within a subunit or to hydrologic regime. Such factors can greatly influence the cumulative wetland capacity to moderate peak flows. Note also that we did not weight or normalize either variable. Since we do not know the exact relationship between $\mathrm{Q_{50}}$, %LOSS, and $\mathrm{LOSS_H}$, we approximate $\mathrm{LOSS_H}$ by assuming a first-order proportionality and multiplying (i.e., the greater the wetland loss and the greater the flood peaks, the greater the loss of hydrologic function).

The third index was future risk. We based future risk to wetlands on a weighted estimate of agricultural and urban growth:

$$\mathrm{RISK} = (\Delta\mathrm{AGR} \times \mathrm{RF_{AGR}}) + (\Delta\mathrm{URB} \times \mathrm{RF_{URB}})$$

where RISK is the synoptic index, ΔAGR and ΔURB are the expected rates of agricultural and urban growth, respectively, and RF_{AGR} and RF_{URB} are risk factors for weighting the relative importance of these two impacts.

Step 3: Select Landscape Indicators

Landscape indicators are the actual measures used to estimate the synoptic indices; either a single indicator or combination of indicators can be used. Selection of indicators, which depends on data availability, should not begin until goals are defined and the relevant environmental variables are identified. To evaluate the accuracy of an assessment, one must keep the goals and environmental variables distinct from the trade-offs that occur because of data limitations. If data availability is considered too early on, real-world limitations begin to dominate the process before goals and environmental variables are articulated. Goal setting, defining synoptic indices, and selecting landscape indicators should occur iteratively and not simultaneously.

Various federal and state agencies that have jurisdiction over the study area should be contacted to determine what kind of environmental data are available; county agencies may also be included. Other sources could be university experts and state and university libraries. The survey of available data should include both mapped and tabular information for the entire assessment area and need not be limited to data bases. Potential indicator data should be evaluated for adequacy according to a set of criteria determined by the technical analyst. Adequacy of data depends on several factors, including the degree to which an indicator based on the data represents the actual index and the quality of the data relative to the management objectives (Table 2). The technical analyst should assess the time and cost of obtaining better data. Given the adequacy of available data and the cost of obtaining better information, the resource specialist and technical analyst can select a suite of indicators that best balances the level of accuracy needed to satisfy management objectives within existing constraints.

Once indicators have been selected, the resource specialist and technical analyst should carefully determine which assumptions must hold if the indicator is to represent the synoptic index adequately (in this case, adequately is defined relative to the need for accuracy). These assumptions must be stated explicitly, so that it can be determined later whether they were violated. This information should also be included as part of the assessment documentation. After selecting the final indicators, the analyst should reconsider the landscape subunits in light of the type of data available.

In our example of the Pearl River basin, our indicators (Table 3) included: hydric soils and USGS land-use/land-cover maps for historical and current wetland area, respectively; USGS regression equations for peak discharge (Landers and Wilson 1991); and recent trends in agricultural area and human population, as derived from census statistics. Some of the assumptions associated with the use of these indicators follow.

For %LOSS (i.e., wetland loss), the use of hydric soil area as an indicator of historical wetland area assumes that wetland soil retains its hydric characteristics after drainage or conversion; hydric soils are properly mapped; and more permanently flooded wetlands, which could appear on NRCS maps as water and not

Table 2. Example of objectives and related questions for defining landscape indicators (adapted from Leibowitz and others 1992a)

Determine how well the indicator represents the index
- Do comparable data exist for the entire study area or are there gaps that would limit intraregional comparison?
- Do standardized data exist for the appropriate time period, for example, the past 10 years, the entire year, or by season?
- Are data at the appropriate spatial scale or are there major scale differences between data sources?
- Are the classification systems used for wetlands and other landscape variables compatible? For example, the FWS National Wetland Inventory maps, NRCS soils maps, and USGS land use/land cover maps classify wetlands according to different criteria.

Assess the quality of existing data
- What is the source of the data, for example, agency or university?
- Can the originator (person or agency responsible for data collection) be contacted?
- When, where, and how often were the data collected?
- What methods were used for the data collection?
- Was the data collection associated with a quality assurance program? If so, what information is available on the precision, accuracy, representativeness, comparability, and completeness of the data?
- Are there assumptions, limitations, or caveats to consider in using the data base?
- What are the time, personnel, and cost constraints of obtaining better data?

Determine level of confidence in the data
- What are the common assumptions between indicators and indices?
- What evidence would violate these assumptions?
- How should the weighing of variables be adjusted to compensate?

Table 3. Examples of landscape indicators for Pearl River basin (adapted from Leibowitz and others 1992a)

Index component	Indicator
$AREA_H$ (historic wetland area)	Area of hydric soils estimated with dot grid from county and parish soil surveys; hydric soils identified from SCS (1987).
$AREA_C$ (current wetland area)	Area of wetland cover estimated with dot grid from 1:250,000 USGS land use / land cover maps.
Q_{50} (peak discharge for 50-year flood)	Estimated from USGS regression equations (Landers and Wilson 1991), based on watershed drainage area, mainstem channel length, and channel slope.
ΔAGR (agricultural growth)	The percent annual change in agricultural area between 1972 and 1984 based on agricultural census data (US Bureau of Census 1974, 1982a); prorated from county to subunit areas, and set to zero if subunit showed negative growth.
ΔURB (urban growth)	The percent annual change in human population between 1970 and 1980, based on census data (US Bureau of Census 1972, 1982b); prorated from county to subunit areas, and set to zero if subunit showed negative growth.
RF_{AGR} (agricultural risk factor)	A factor of 87/95 is used, based on historical loss of national wetlands by agricultural conversion (Tiner 1984).
RF_{URB} (urban risk factor)	A factor of 8/95 is used, based on historical loss of national wetlands by urban expansion (Tiner 1984).

hydric soils, are either insignificant in an area or are distributed in such a way that bias is uniform across all subunits. Other assumptions are that 1:250,000-scale USGS land-use / land-cover maps adequately represent current wetland area and that the USGS land-use classification of wetlands and NRCS classification of hydric soils agree with generally accepted criteria.

Because the USGS's regression equations for Mississippi were developed using data from watersheds that were not heavily urbanized, channelized, or dammed (Landers and Wilson 1991), the use of these regressions as an indicator of hydrologic function assumes none of the watershed's hydrology has been significantly modified. Using these regression equations also assumes that the stream is unaffected by tides, which would decrease the rate of discharge but increase flood stage. It is also assumed that hydrologic loss is proportional to the loss of wetland area regardless of where in the subunit the loss occurred (e.g., whether or not the wetland is within the floodplain).

For the indicators of RISK, assumptions include: agricultural and urban growth in the recent past are good indicators of future growth; future population growth rates are a good indicator of wetland loss from urban expansion; and historical causes of national wetland loss, as reported by Tiner (1984), will also be the important causes of future wetland loss in Louisiana and Mississippi. In addition, prorating county census data to subunits assumes that agriculture and population are uniformly distributed throughout the area.

These assumptions are violated in certain cases, and it is important to consider how this could affect the outcome of an assessment. For instance, some of the areas adjoining lakes and estuaries are defined as wetlands by USGS but are classified as open water by NRCS. These errors result in an inaccurate depiction of net wetland gain, thus underestimating historic loss. In contrast, some areas commonly considered wetlands are not classified as such by USGS maps. Also, 1:250,000-scale USGS maps omit small wetland patches. These errors would result in an underestimate of current wetland area, causing an overestimate of historic loss. This indicator of loss, however, should be adequate for relative comparisons since classification errors are usually consistent between subunits.

As noted, the use of USGS regression equations as an indicator of Q_{50} assumes that watershed hydrology has not been significantly altered. The Pearl River basin contains a major structural modification, the Ross Barnett Dam near Jackson. However, this dam functions primarily as a reservoir and would have minimal impact on larger floods. Therefore, we chose a 50-year flood event to minimize this effect. An alternative would have been to use a hydrologic model such as TR-55 (SCS 1986) to calculate peak discharge, which would take into account damming and channelization. The assumption of uniform distribution of agriculture and population, related to the risk factors, may be violated where populations of counties are clustered around large cities like Jackson.

Finally, before conducting the assessment, the analyst should ask managers and technical experts to review the overall management objectives, the synoptic indices that were defined, and the selected landscape indicators.

Step 4: Conduct Assessment

Once the landscape indicators have been defined and assumptions have been explicitly identified, maps and data can be obtained from the appropriate sources and the technical analyst can begin the process of producing the synoptic maps. Data for a synoptic assessment typically come from multiple sources and in a variety of formats, including mapped data, tabular data from reports, and computerized data bases. Because reliability of the final product depends on quality control of data processing, a set of protocols should be developed for determining and maintaining data quality. The technical analyst should begin this step even before data are received, using information obtained during the data survey phase. Protocols also should be developed for designing the synoptic data base and for screening, archiving, and documenting the data. In addition to the initial information collected during the data survey, data documentation should include descriptions of the protocols, data-base design, and archiving formats. This information should be included as part of the assessment documentation.

Much of the information used in a synoptic assessment is derived from maps. Examples of information and sources include wetland area and number of wetland types from National Wetland Inventory maps; hydric soil area from county soil surveys; elevations and stream channel lengths from USGS topographic maps; and nonwetland land use from USGS land-use/land-cover maps. Area and length are the two types of measurements often made from maps. If the map is in digital format, a geographic information system (GIS) can be used to generate these measurements. If a GIS is not available, the features can be planimetered or estimated using a dot grid. The technical analyst must keep in mind the difference between the accuracy of map measurement and the overall map accuracy. A map can be measured very accurately but still have unacceptable overall accuracy if the map itself contains errors. Burrough (1986) gives a good discussion of data quality and errors in mapping.

A number of calculations may be required to produce an index for each landscape subunit from the various data sources. Common analyses might include calculating channel slope, prorating areas, and calculating the percentage of streams that support state-designated uses from state water-quality summaries. Final index estimates are produced by completing any other necessary calculations and converting to standard units. After index values are calculated for each subunit, the subunits can be ranked numerically. For example, subunit 4 in the Pearl River basin had the lowest value for %LOSS and therefore was given a rank of 1 (Figure 3). Standard statistical packages can perform these calculations automatically. Rankings for each index should be included as part of the database. Figures 3–5 illustrate rankings of the subunits for the Pearl River basin for the indices of functional loss, loss of hydrologic function, and future risk.

The final synoptic maps can be produced by a computer mapping package, such as a GIS, or manually if resources are extremely limited or if no automated system is available. An important decision in the map-production phase is how to display the data. At a minimum, the map should include the index value for each subunit. In the Pearl River example, it was not necessary to define classes or intervals, since the basin has only five subunits. In cases with a greater number of subunits, the data typically are aggregated into intervals to promote interpretation. People can easily reach erroneous conclusions if the map they are examining contains improperly displayed data. The choice of class intervals is therefore an important decision, since this can greatly affect the visual appearance of a given set of results. One way to design the intervals for map display is to first create a histogram or frequency curve showing the distribution of the numerical data. This will allow the analyst to detect any natural clumpings and also reveal common patterns such as normal or logarithmic distributions. Alternatives include dividing the range of numeric values into equal intervals or assigning an equal number of subunits to each interval based on rankings (for example, quartiles). Figure 6 illustrates rankings, by quartile, of 62 watershed units in the State of Washington for the functional loss index. Many standard texts on cartography, such as Robinson and others (1984), include discussions on the display of mapped data.

Throughout the course of the assessment, the technical analyst and resource specialist should look for evidence that any of the assumptions have been violated and consider the effects this would have on the assessment's accuracy. The assessment team should again seek a technical expert's review comments after completing the data analysis and synthesis. This information will assist the team to derive conclusions and suggest ways that the results can be used. For example, given the assumptions and limitations of the data, results for functional loss for subunits 1, 2, and 5 of the Pearl River basin are probably not significantly different (Figure 3), and should, therefore, be considered as one class. Because there is no method for quantitatively assessing the accuracy of results, this step and the preanalysis review are essential to ensure results that are adequate for the intended use.

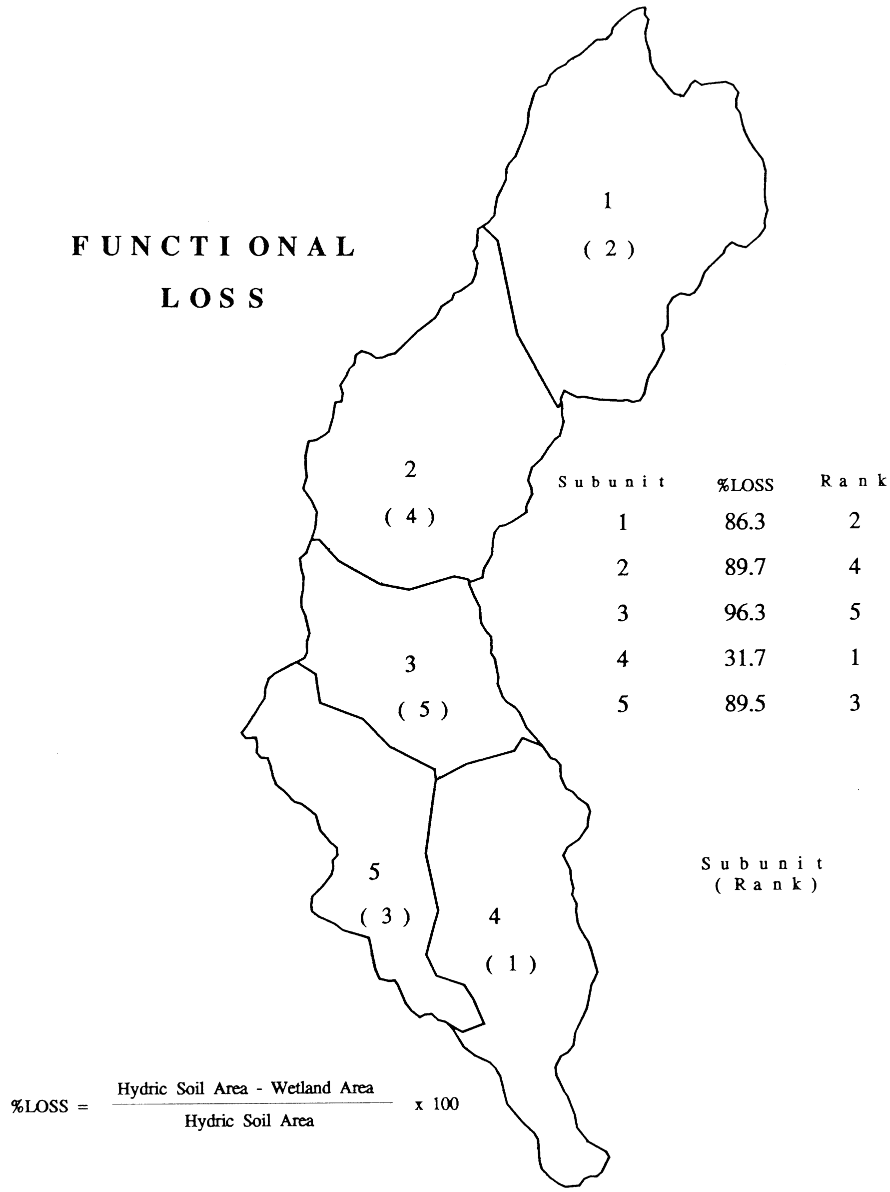


Figure 3. Functional loss for the Pearl River basin. Within each subunit, the upper value is the subunit number and the lower, parenthetical value is the rank. The variables included in the equation for %LOSS represent the landscape indicators, not components of the synoptic index.

Step 5: Prepare Synoptic Reports

The last step in the assessment is to report how the information was derived and how it can be used. Two different documents are appropriate for this: a report for the manager and resource specialist, which would be a user's guide, and a detailed reporting of procedures to serve as a record of the complete assessment process, which would be the assessment documentation. The user's guide should focus on the results of the assessment and how the results can be used to satisfy the original management objectives. This report might include protocols and illustrations of how synoptic maps can be used in 404 permit reviews and should include any important caveats and assumptions. Since maps representing different indices may vary in quality, the report should provide the reader with at least qualitative information on the accuracy of the various components, e.g., which results are based on validated information and which are based on tentative or incomplete information. This will allow decision makers to give the greatest weight to the most reliable results. The user's guide should also make clear that final numeric values are relative rankings and should be treated as such. For example, if the Pearl River subunits were ranked for habitat, the lowest-ranked subunit does not necessarily lack significant habitat. What this means is that the

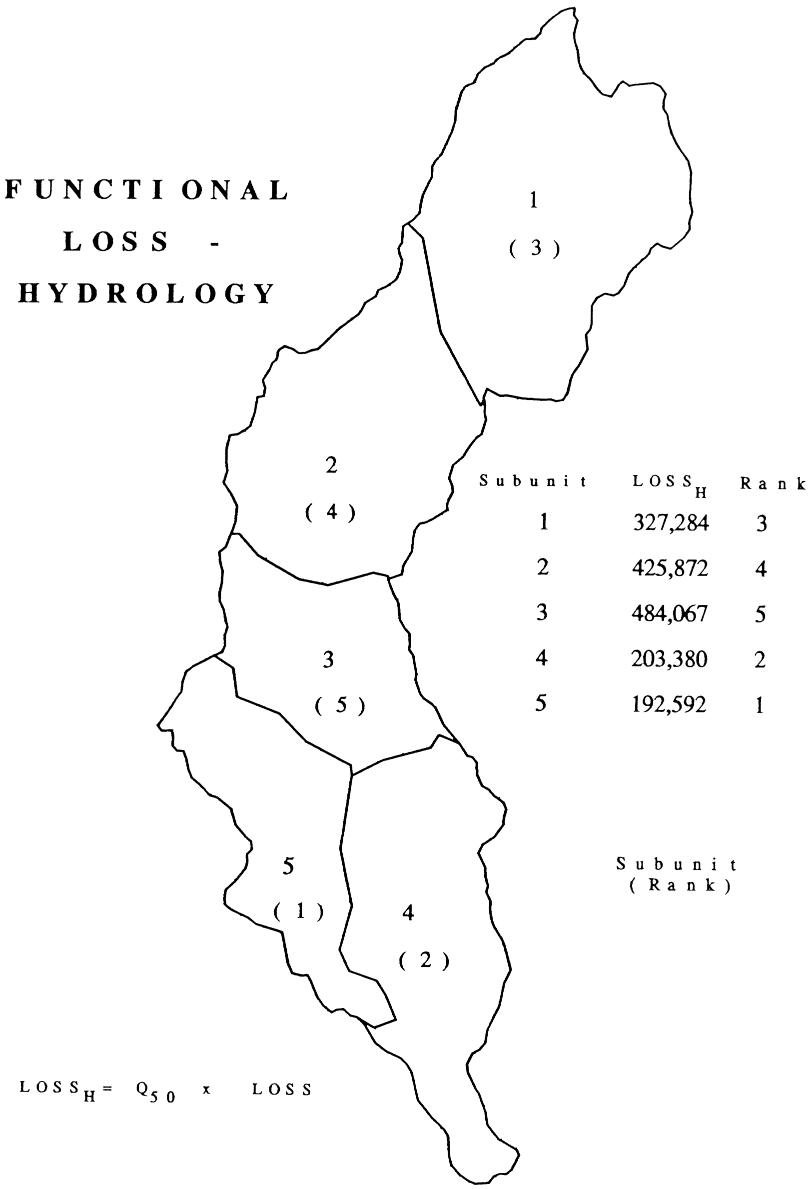
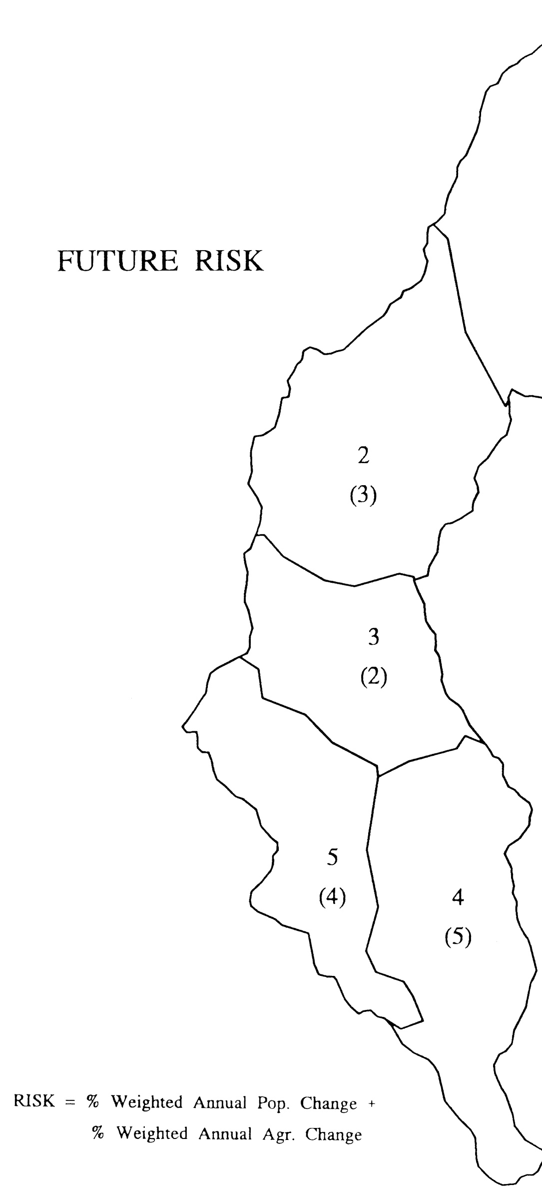


Figure 4. Loss of hydrologic function for the Pearl River basin. Within each subunit, the upper value is the subunit number and the lower, parenthetical value is the rank. The variables included in the equation for $LOSS_H$ represent the landscape indicators, not the components of the synoptic index.

subunit has lower habitat function relative to the other four subunits. The intended audience for this report includes resource specialists who are involved in decision making or planning, resource agencies, scientists, and the public. Because it describes major environmental processes and geographic patterns in an area, the report can provide the public with a broader, regional context for proposed management decisions. The educational value of the report can be especially important if these actions are controversial or are otherwise contingent upon public support.

Each synoptic assessment should include, for internal use or distribution to interested parties, complete documentation of how the assessment was conducted, including the objectives, constraints, rationale for index definition and indicator selection, assumptions related to the indicators, and detailed descriptions of the procedures used in measuring and analyzing data. Any problems encountered should also be described. This report should carefully document the sources and quality of the various data sets and describe where and how the data were archived. The report should also include an overall assessment of data quality and recommendations on how the assessment could be improved in the future. This document is a detailed record of the synoptic assessment process and could be valuable if



Subunit	RISK ($\times 10^{-4}$)	Rank
1	6.90	1
2	19.95	3
3	8.64	2
4	155.74	5
5	58.01	4

Figure 5. Future risk for the Pearl River basin. Within each subunit, the upper value is the subunit number and the lower, parenthetical value is the rank. The variables included in the equation for RISK represent the landscape indicator, not components of the synoptic index.

procedures are forgotten, challenged (such as through litigation), or if the assessment is updated.

Guidelines for Use

A synoptic assessment balances the need for rigorous results and the need to provide managers with timely information. Although the approach has a number of useful qualities—including low cost, flexibility in being adapted to management needs, and results that are geographically mapped—the utility of this information will ultimately depend upon the assessment team's knowledge of the environmental processes relevant to particular management questions. The following guidelines will help maximize the benefits of the approach while minimizing inappropriate use:

- To the extent possible, synoptic indices, landscape indicators, and combination rules should be based on validated relationships reported in the literature. Since many of these relationships will not have been validated and may be speculative, regional and local experts should be consulted throughout the assessment process. It is also critical that the assessment be reviewed at various points to assure that the relationships incorporated into the analysis are

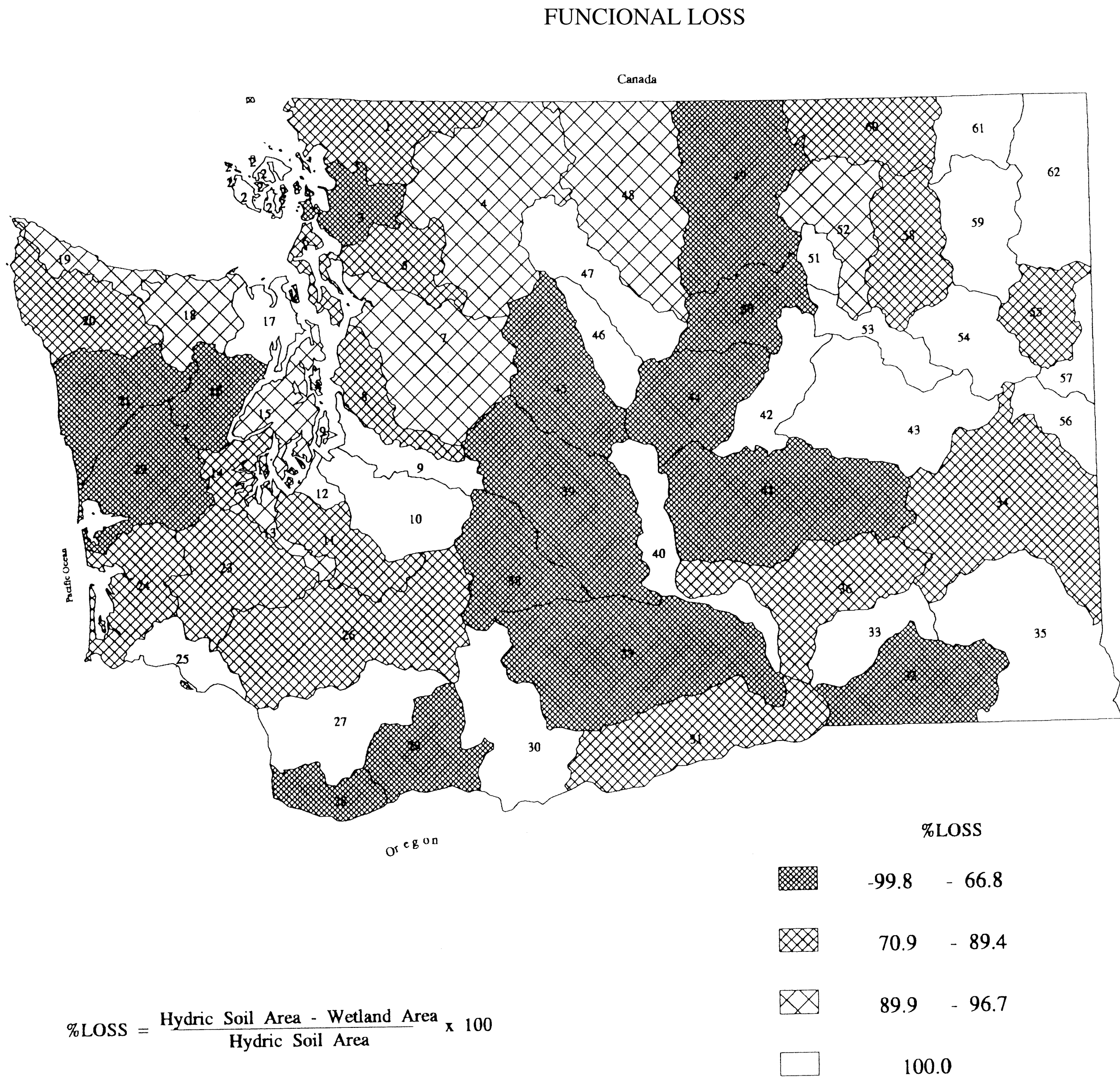


Figure 6. Functional loss for Washington. Values calculated as described for the Pearl River basin (Table 3 and Figure 3). Class intervals represent quartiles of individual rankings. Lighter hatching corresponding to higher loss; a negative value represents a gain in wetland area.

based on the best existing science and expert judgement.

- If there is no clear consensus on how indices and indicators should be formulated, either within the literature or between experts, the analysis should include a sensitivity analysis that examines various alternatives. If results are stable, in that different alternatives do not significantly affect overall rankings, then a synoptic assessment is appropriate. In the extreme case where alternatives produce entirely inconsistent results, it would be inappropriate to continue with an assessment until the major sources of uncertainty can be resolved. In intermediate cases, only the results for the inconsistent subunits need be discarded.
- The accuracy and rigor of the assessment should be qualitatively evaluated, since the overall accuracy determines the degree to which synoptic results can be incorporated into real decision making. Accuracy depends on (1) how well the indices reflect the actual environmental conditions, (2) the quality of the data being used, and (3) the degree to which

assumptions concerning the use of indicators are valid. Results from a simple assessment should be used only to provide broad background information, to serve as an initial screening tool, or to raise "red flags" requiring more intensive consideration. Using such results for critical or controversial decisions would be inappropriate, unless the conclusions were validated with more detailed information. Management decisions can rely more heavily on the conclusions if, for example, better data with higher confidence levels are used. However, we caution that a more detailed analysis is not necessarily better, since the intent of the synoptic approach is to provide a general picture of the environment.
- In evaluating the accuracy of the assessment, weak assumptions and conceptual links should be explicitly identified, along with low-quality data. This could be combined with results from a sensitivity analysis to identify the lowest-quality variables that have the greatest influence on overall results. These variables would be priorities for iterative improvement over time.

Perhaps the most important guiding principle in conducting a synoptic assessment is that the approach should not be followed in a cookbook fashion, since it does not represent a fixed recipe to produce uniform results. The synoptic approach provides a framework for organizing and identifying relevant ecological information. Ecological relationships need to be described, and results require ecological interpretation. Producing maps using the indicators that were provided as examples in our report (Leibowitz and others 1992a) would be inappropriate without going through the process of determining whether the information was justified, given the ecological context of the actual problem. It is, therefore, the burden of those conducting the assessment to assure that the results best fit management needs and resource constraints.

We are continuing to work on improving the synoptic approach. At this time it is necessary to subjectively evaluate the quality of a synoptic assessment, as described above. We are currently working on an approach that will allow a more objective, systematic evaluation and that helps identify components having the greatest uncertainty. We are also in the process of conducting a synoptic assessment of the prairie pothole region, in conjunction with an extensive monitoring study, which will allow us to illustrate how such data can be used to validate and improve synoptic results. Finally, we are working on a more rigorous approach to developing combination rules that also addresses scaling of variables. These developments should reduce the degree to which an assessment relies on specific decisions made by the analyst and should result in a more robust and methodical approach.

Discussion

It has been almost two decades since regulations were first introduced in the United States requiring cumulative impacts to be considered during certain environmental assessments, e.g., during preparation of environmental impact statements under the National Environmental Policy Act (40 CFR 1508.7) and during permit review under Section 404 of the Clean Water Act (33 CFR 320, 40 CFR 230.11). In spite of the recognition that cumulative impacts can represent significant sources of environmental degradation, they are still rarely considered during decision making. This has not been for lack of research, methods, or scientific approaches. In fact, there are a number of tools that have been applied to cumulative impact analysis, including modeling (Ziemer and others 1991), analyses of paired watersheds (Brooks and others 1989, Croonquist and Brooks 1991), and statistical analyses (Gosselink and others 1990, Johnston and others 1990). The main reason these techniques are not widely used is that they are impractical in a regulatory context.

We believe that one of the major reasons for these shortcomings has been an implicit assumption that, to be useful to managers, any assessment must provide precise, quantitative information that comprehensively considers the ecological consequences of cumulative impacts. An example of this viewpoint is provided by Duinker (1987) in an article entitled "Forecasting environmental impacts: Better quantitative and wrong than qualitative and untestable." Duinker argues that impact assessments need to be quantitative, preferably through the use of dynamic system models. His rationale for this position is that quantitative, measurable information would be more useful to decision makers than qualitative information and, secondly, that neither scientists nor managers will learn about systems and improve methods if assessments produce predictions that are untestable. However, we believe that there are situations where Duinker's approach is inappropriate, either because of cost, legal requirements, or intended use.

It would be hard to argue against the assertion that quantitative, measurable information is better for decision makers and for learning about systems if information had no cost. It does, however, with increasing levels of quantitative accuracy usually requiring greater levels of effort (Figure 7). Given a situation where a decision

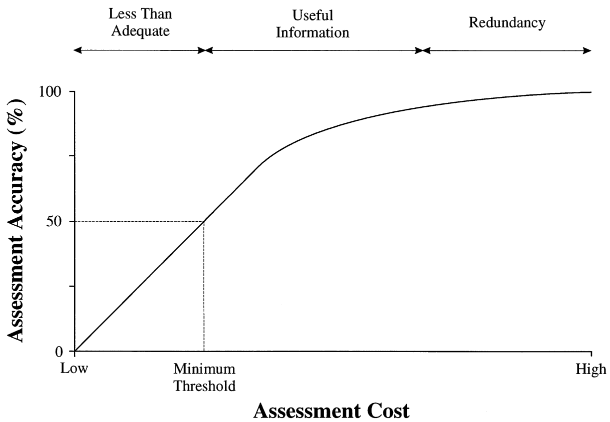


Figure 7. Cost and benefit of information used in environmental decision making. Most situations would be expected to follow the diminishing returns curve, shown here. Some minimum level of effort is required to obtain information that is at least as useful as the flip of a coin. Beyond a certain point, however, costs rapidly increase without providing significant improvements in accuracy (adapted from Leibowitz and others 1992b).

maker has a limited amount of time and money to collect and analyze information, it is not always possible to use highly accurate information. Thus the rigor going into an analysis must be commensurate with available resources; qualitative information may have less accuracy, but it can be adequate as long as the information meets management objectives.

A second situation where using qualitative information is appropriate is when a decision is required by law, regardless of whether scientifically valid assessments are available. In the absence of better information, witholding qualitative information because it was not scientifically testable would be tantamount to saying that there was no impact. However, the law does allow qualitative information to be used in various situations. For example, the law recognizes EPA's authority under Section 404 to include the use of best professional judgement when making a determination of unacceptable adverse effects. Similarly, the law does not require an in-depth analysis to establish a finding that cumulative impacts have occurred. Hirsch (1988) cites two examples where cumulative impacts were included as rationale for EPA issuing a 404(c) action (a veto of permit issuance by the Army Corps of Engineers). Even in these highly controversial cases, information on cumulative impacts was mostly descriptive, for example, general trends in wetland loss, proportions of the loss considered to be due to discharge of dredge and spoil, and identification of aquatic resources within the area that could be significantly harmed or degraded as a result of the loss.

Finally, we note that the distinction between quantitative information that is wrong or qualitative information that is untestable is a false one because results from qualitative analyses can be tested. For example, results from a synoptic assessment could be tested by comparing the synoptic rankings with a subset of rankings obtained through a more rigorous effort. And as we previously mentioned, the availability of monitoring information will allow us to validate and more rigorously evaluate the results of our synoptic assessment in the prairie pothole region.

Although a quantitative, accurate assessment is an important goal to pursue in the long run, day-to-day management decisions can be improved with qualitative information. With respect to the 404 program, Hirsch noted that conducting an actual study of cumulative impacts in response to a permit application would be impractical in day-to-day decision making; thus there was a need for "simple protocols, analytical procedures, or logic flows, some *do's* and *don't's* or rules of thumb" in cases where resources or the nature of the project precluded extensive data collection and analysis (Hirsch 1988). While the constraints of the 404 program may be extreme, the need for such qualitative information is broader.

Given this discussion and the arguments presented earlier, we believe qualitative information, such as that provided by a synoptic assessment, is appropriate in environmental decision-making under the following conditions:

- Quantitative, accurate information is not available.
- The cost of improving existing information or obtaining better information is high.
- The cost of a wrong answer is low.
- There is a high demand for the information (e.g., through a legislative mandate).
- The situation calls for prioritizing between multiple decisions vs optimizing for a single decision.

Information from a synoptic assessment could be used in routine permit evaluations to identify areas where losses were unacceptably high and to support determinations that significant loss had occurred. The approach is appropriate for such use because: (1) a synoptic assessment can provide a landscape context for project-specific conditions and thus serve as a basis for developing descriptive findings; (2) selection of indices and indicators is flexible and can be customized to fit specific needs; and (3) the assessment can be completed for an entire state or region within a year or two at relatively low cost, and subsequently improved following the initial assessment.

Although the synoptic approach could be used to assess cumulative impacts as part of the 404 permit process, we believe that the permit process is not the best mechanism for addressing cumulative impacts to wetlands. By its very nature, the permit process is a reactive form of protection that considers impacts on a case-by-case basis. The process is initiated by a request to fill a specific wetland, and the assessment for the most part focuses on the effects of the particular action and an alternatives analysis. Furthermore, the actions that can be considered under 404 are limited to discharge of dredge and fill materials; other impacts that can degrade or destroy wetlands, such as nonpoint source pollution or drainage, are generally not within the purview of 404. Thus the scope of 404 does not promote a comprehensive view of wetland impacts. For these reasons, and because cumulative impact assessment is best conducted at landscape or regional scales (Bedford and Preston 1988b, Gosselink and Lee 1989), we believe that cumulative impacts are best addressed as a part of regional planning efforts, such as State Wetland Conservation Plans (WWF 1992) or watershed protection plans (EPA 1991b). This is a proactive approach that allows a comprehensive examination of all the relevant impacts at an appropriate scale. The synoptic approach is particularly well-suited for such efforts.

Unlike traditional impact assessment, the synoptic approach was not designed to assess the effects of a particular action within a specific area; instead, the approach makes relative comparisons of functions and impacts *among* areas. Brooks and others (1995) used the synoptic approach to assess patterns of wetland loss in individual stream reaches of four watersheds in Pennsylvania, as part of an evaluation of cumulative impact assessment tools. The authors incorporated spatial indicators, e.g., distance to the nearest neighboring wetlands, as a screening tool to complement synoptic maps of restoration potential. The US Fish and Wildlife Service cooperated with EPA's Wetland Research Program to ground-truth a synoptic evaluation in Illinois watersheds (John Rogner, personal communication, US Fish and Wildlife Service, Barrington, Illinois, 1994). The researchers found general similarity between watershed rankings produced by the two methods and stated that the synoptic approach appeared to be more useful for overall watershed comparison than for site-specific evaluations because of the potential for error associated with broad-scale data.

At the statewide or regional scale, the synoptic approach can be used to identify areas that have experienced high cumulative loss, and these results can then be used by managers to develop specific strategies to prevent further loss in those areas. Several applications of the synoptic approach have been conducted, or are in progress, at the statewide or regional scale, including: (1) the State of Oregon, Division of State Lands adapted the synoptic approach to prioritize watersheds for protection, enhancement, and restoration on a statewide basis (Dagget 1994); (2) the NRCS used a GIS-based synoptic approach, complemented by a field evaluation, to select wetland restoration areas for water quality improvement in the Tensas River basin (Rainer and others 1994); and (3) the EPA Region VII Office of Integrated Environmental Analysis used the synoptic approach to rank the risk of loss to Nebraska's wetland resources as a starting point for the development of a regional wetland inventory and tracking system, and is currently integrating the synoptic model with a similar model for terrestrial systems for the entire region (E. William Schweiger, personal communication, US Environmental Protection Agency, Kansas City, Kansas, 1996).

Management options resulting from these or similar assessments could include conservation easements (USDI 1988), zoning restrictions, establishment of total maximum daily loads to limit nonpoint source pollutants (EPA 1991a), educational outreach, and intensified enforcement within the area. Using the synoptic approach to address cumulative impacts as part of regional planning efforts broadens, and therefore complements, 404 activities. These same properties should make the approach useful as a strategy in regional risk assessments or as a framework for ecosystem management efforts.

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names or commercial products does not constitute endorsement or recommendation for use.

Correction

The method used in Leibowitz and others (1992a) to calculate weighted percent annual population change for a subunit was incorrect. Table H.3 of that report shows that weighted population change was calculated for each county in a subunit by calculating annual population change, using joint county–subunit populations for 1970 and 1980, and then multiplying by the risk factor. The total weighted population change for the subunit was then calculated as the sum of the individual county values. Instead, 1970 and 1980 population values should have been calculated for the subunit by summing the joint county–subunit values for each county; the weighted percent annual population change is then calculated using these subunit population values. The calculations for agricultural change in Table H.3 are similarly incorrect. This error was incorporated into any maps using the risk factor, e.g., Figure 4.13 in that report. Calculations for this article were completed using the correct procedure.

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