United States
Environmental Protection
Agency

Environmental Research
Laboratory
Duluth MN 55804

Research and Development

EPA-600/S3-84-011 Mar. 1984

EPA

Project Summary

Watershed Sensitivity Measurement Strategy for Identifying Resources at Risk from Acidic Deposition

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The objectives of this research include a review of existing literature on the use of indices for quantifying resource status and predicting long-term trends in relation to acidic deposition, a review of options regarding the appropriate form of a sensitivity index or a loading tolerance model for determining resources at risk, and identifying validation steps needed to complete testing of the measure or model and to begin its application.

One section of the full report describes the suite of measures which, when taken together, best identify areas potentially sensitive to acidic inputs. Each of the component measures, when viewed separately, has certain limitations which prevent it from being an adequate measure of sensitivity; when the components are considered as an integrative measure, however, the limitations are less significant.

For non-agricultural systems, forest site index appears to be a well-established integrative measure capable of responding to altered soil and water chemistry. The extent to which site index is related to changes in cation nutrient storage (due to cation stripping by acid precipitation) or other pollutant impacts is incompletely documented, however. Measurements of aquatic sensitivity have been developed more fully, and a number of experimental and field data-based approaches exist. These include the Calcite Saturation Index, the Henrickson nomograph, the Almer/Dickson relation and an additional measure proposed here based on pH shock effects during acid flushing events. This integrative response property appears to describe a complex environment leading to species and population effects associated with periodic but physiologically important exposures to H^+ and Al^{3+}.

This Project Summary was developed by EPA's Environmental Research Laboratory, Duluth, MN, 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 and Objectives

In August, 1979, a federally funded acid rain assessment program was established by executive order. At about the same time, the Environmental Protection Agency awarded a Cooperative Agreement to North Carolina State University to conduct a program of subcontracted studies on biological effects of acid precipitation. The Institute of Ecology (TIE) was awarded a subcontract entitled *"Assessment of the Sensitivity Index Concept for Evaluating Resources at Risk from Atmospheric Pollutant Deposition (Acid Rain),"* to be carried out in support of studies at the ERL-Duluth, U.S. Environmental Protection Agency.

The study focused on developing sensitivity measures for evaluating terrestrial and aquatic resources at risk

from atmospheric pollutant deposition (oxidants as well as acid rain). The main objectives were:

(1) To review existing literature on the use of indices for quantifying resource status, predicting long-term trends in ecosystem and resource responses to acidic deposition, and for assessing overall risks from atmospheric pollutant deposition in relation to air emissions management;
(2) To consider options regarding the appropriate form of a sensitivity index or pollutant loading tolerance model for use in determining resources at risk and to outline how such a measure would function in a regional inventory of risk from pollutant deposition or in the assessment of benefit from acid precursor control;
(3) To identify validation steps needed, data required (existing data or new measurements), and the steps required to complete testing and begin application of the sensitivity measures or loading tolerance model in regional and national energy development decisions.

Approach

Early in the study, possibilities were explored (see Loucks *et al.* 1981) for compressing various acid rain indices (i.e., the McFee soil sensitivity measure, the Calcite Saturation Index) into one sensitivity index. This was eventually recognized as an unsound approach because too many dimensions of chemical mediation in the environment were being expressed in a single dimensionless index number. Instead, it was determined that the first part of the report should examine and define the scope of the processes involved in deposition and acidification in both the terrestrial and aquatic components of watersheds. To this end, the relationships involved in formation, deposition, and subsequent effects from the input of acidic substances were summarized in the form of a descriptive flow model (Figure 1). The model makes explicit the processes by which watersheds incorporate and respond to the multiple pollutants in rural landscapes and to acidic deposition in particular. It also relates the transfers between air and land, and between land and water to subsequent effects.

Implicit in this approach is a relatively formal systems structure used as a guide to the evaluation of the otherwise fragmented information base. The qualitative model of known relationships between the chemical and biological subsystems, and controls operating on the ecosystem as a whole is, in effect, a suite of hypotheses that ultimately must be tested sequentially in a comprehensive research program. As such, it represents both theory and the general outline of a report evaluating the prospective significance of acidic deposition for terrestrial and aquatic resources. It also outlines the principal properties of these systems most likely to function as measures or indices of the sensitivity of the resources involved.

Results

Quantifying pollutant impacts on resources such as streams, lakes or forests requires making a distinction among properties of the system with varying degrees of sensitivity to pollutant exposures. Two general groups of measures can be distinguished: *indicators*, defined as individual high-resolution response measures of components within a complex system (i.e., a chemical nutrient stock); and *integrators*, defined as measures which reflect the combined action of several environmental properties governing a more aggregated response. Both types of measures are necessary to present fully the combined effects of pollutants on the landscape, and both groups are examined in detail through the report.

One major section of the report, entitled "Sub-Components of Lake/Watershed Sensitivity," contains the background material on pertinent characteristics of acid precipitation effects on soils, lakes and watersheds, and lays a foundation for both the recommended sensitivity measures and the outline of research and data needs in later sections (see Loucks 1982a). This section also provides an understanding of the various processes occurring within the system, information that is required for developing and evaluating measures of watershed/lake sensitivity. Topics of interest include hydrologic flows, the nitrogen and sulfur cycles, alkalinity relationships, interactions of acids with organic material, nutrient stripping, H^+ toxicity, the mobilization and toxicity of aluminum and heavy metals, and synergisms between H^+, aluminum and heavy metals

Particularly important are results from the detailed review of the mobilization of potentially toxic metals by the elevated H^+ concentrations in soil water. Mercury, copper, lead, cadmium and aluminum are all considered in some detail, but the most thorough coverage is devoted to the known plant and animal toxicities from ionic free aluminum (Al^{3+}). For terrestrial systems, aluminum toxicities (in crop species) are expressed in the formation of stubby and brittle roots with reduced fine-root branching, and acute foliar phosphorus deficiencies, possibly the result of strong immobilization by soluble Al^{3+}. In aquatic environments, effects on animals are expressed in the altered ionic balance of materials in the bloodstream in the presence of AL^{3+}, and in oxygen deficiencies as Al^{3+}-induced mucus on the gills clog normal gas exchange with the bloodstream.

The section principally focused on new results, entitled "Methodologies for Identifying Sensitive Terrestrial and Aquatic Areas," describes the various options for measures that best identify potentially sensitive areas. Three separate measures are employed for the terrestrial component: McFee's soil sensitivity classification based on cation exchange capacity, the soil sensitivity classification based on base saturation, and the forest site index. The site index (SI) concept has been accepted as a measure of forest productivity for many decades and is examined here as an integrative methodology for measuring changes in potential forest growth due to long-term acidic inputs (see Loucks 1982b). The magnitude of site index changes due to a combination of oxidants, changes in cation nutrient storage (resulting from cation stripping by acidic precipitation), and aluminum toxicity effects still is in completely quantified, however Further studies using available data bases on oxidant exposures, apparent changes in total nutrient stocks and aluminum mobilization in relation to acidic inputs will be required.

Integrative measures for expressing aquatic sensitivity have been developed more fully, and a number of experimental and field-data based methods exist. These include the Calcite Saturation Index, the Henrickson nomograph and the Almer/Dickson relation. An additional measure, based on pH shock effects during acid flushing events, attempts to identify species/population impacts associated with short-term, physiologically important exposures of critical life stages to H^+ and Al^{3+}. Research on brook trout and Atlantic salmon has provided a broad understanding of the response of several pH-sensitive fish species to both long-term and short-term elevated H^+ exposures Mortalities of fish eggs, sac fry and adult fish are viewed as a response to continuing chronic pH depression. Effects on egg viability, hatching success, and adult survival are known to occur as a response to short-interval acute H^+ and associated

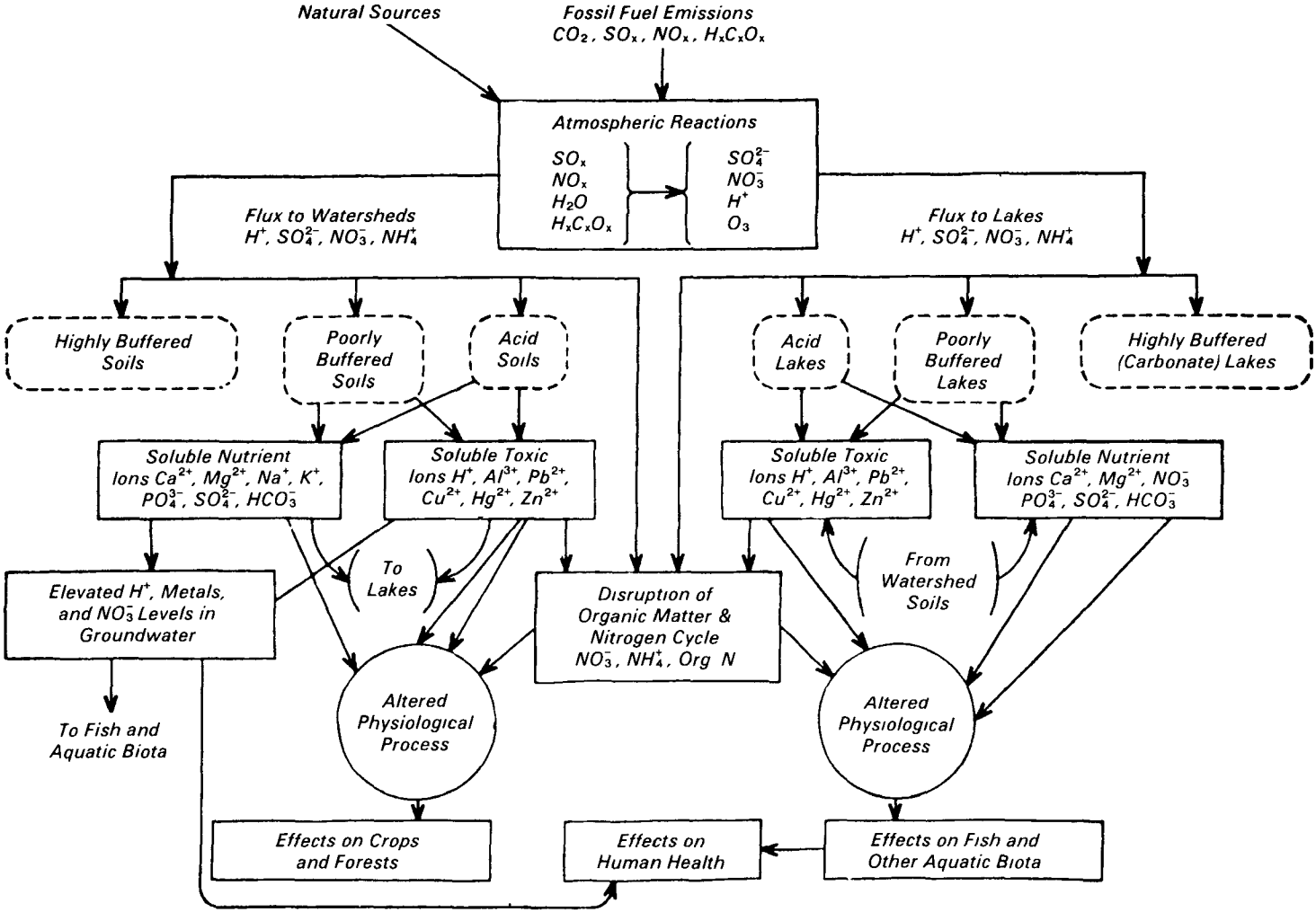

Figure 1. *Flow diagram showing system linkages for acid precipitaton formation, deposition and effects as a consequence of nitrogen and sulfur oxide emissions from fossil fuel combustion*

Al^{3+} exposures. The experimental data base supports two findings:

(1) The short-term acute exposure, or shock effect, can be expected when pH drops in the order of 0.5 to 1.5 units of the pH scale within a background environment of pH 5.5 to 6.5; and

(2) Episodic shock exposures are significant even at pHs above the level at which chronic effects ordinarily would be produced.

Taken together, these data suggest that for waters normally in a range of pH 5.5 to 6.5, a pH depression of 0.5 to 1.0 produces a physiologically significant, acid-induced alteration of water chemistry and biological response. Given this dose/response relationship, an acid loading tolerance, or loading threshold, can be defined as the annual SO_4^{2-} loading which, when subjected to a defined flushing event (e.g., snowmelt or first major rainfall following drought), leads to the minimal biologically-significant short-term H^+ and Al^{3+} exposure.

Present data on pH depression during flushing events (Table 1) indicate a range in responses, from 0.8 units during snowmelt in northern Minnesota to more than 2.0 units in the Adirondacks. Pending further testing, a significant shock event response (defined as a Δ pH of 0.5 to 1.0 unit) may be a useful basis for estimating the annual SO_4^{2-} loading which produces only a marginally unacceptable level of pH depression. This estimate must be defined for watersheds within a specified alkalinity range, a specified range of hydrologic dilution (i.e., stream size), and a defined return interval for episodes. Recurrence at an average of once a year during critical life-cycle stages would be consistent with the physiological data base described above. Present results suggest that a wet-deposition sulfate loading of 5 to 7 kg/ha·yr produces a physiologically critical episode response (Δ pH) in the range of 0.5 to 1.0 for the most sensitive streams in poorly buffered regions. As with the other models, the applicability of the episode shock model still is relatively untested at this time, and research is continuing

The final section, entitled "Concluding Comments and Research Needs," is a brief description of the data needed to achieve a full validation of the sensitivity measurement options. Insufficient data presently exist for quantifying fully the hydrogen ion or sulfate fluxes through a wide variety of watersheds or the aluminum mobilization during peak H^+ concentrations. Nutrient stripping effects

Table 1. *Episode Δ pH Data for Flushing Events at Sites Representing a Cross-Section of SO_4^{2-} Loading Intensities in the Eastern United States an Canada, 1977-79*

Site	Flushing Event Date	pH Observed Before (During) Episode	Δ pH	Annual SO_4^{2-} Deposition (wet only) (kg/ha)
Little Moose Lake, N Y (Outlet)	*March 9-13, 1977*	*6.8 (4 8)*	*2.0*	*38*
Sagamore Lake, N Y. (Outlet)	*March 25 - April 20, 1978*	*6.4 (4.9)*	*1.5*	*38*
Harp Lake Inlet, Ont. (No 3)	*Mid-March - Mid-April*	*6.1 (5.1)*	*1.0*	*30*
Harp Lake Inlet, Ont (No. 4)	*April 10-20, 1978*	*6.4 (5.4)*	*1.0*	*30*
Filson Creek, MN	*April 12-24, 1979*	*6.6 (5.8)*	*0.8*	*14*

on forest productivity, effects from metal mobilization on plants, from food chain alterations on mammals and predatory birds, and the role of organic matter in mediating acidic deposition effects are all too poorly known to have a fully reliable, locally applicable sensitivity measure at this time. The need for continuing research on many of these questions is acknowledged

Publications

Loucks, O.L., R.W. Usher, R.W. Miller, W. Swanson, and D. Rapport. 1981. Assessment of Sensitivity Measures for Evaluating Resources at Risk from Atmospheric Pollutant Deposition. Final Report to the U.S. Environmental Protection Agency, Environmental Research Laboratory-Duluth. The Institute of Ecology, Indianapolis. 87 pp.

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The complete report, entitled "Watershed Sensitivity Measurement Strategy for Identifying Resources at Risk from Acidic Deposition," (Order No. PB 84-141 209; Cost: $11.50, subject to change) will be available only from:
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