THE DESIGN OF INTEGRATED MONITORING SYSTEMS
TO PROVIDE EARLY INDICATIONS OF
ENVIRONMENTAL/ECOLOGICAL CHANGES

R. E. MUNN
International Institute for Applied Systems Analysis, A-2361 Laxenburg, Austria

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Abstract. One of the important goals of the next several decades is to achieve and maintain ecologically sustainable development of the biosphere. However, the management of ecological systems is rather difficult, largely because of uncertainties in long-term predictions of environmental and ecological behaviour. Thus, one of the objectives for integrated monitoring should be to provide early indications of impending changes so that mitigative actions can be taken.

This paper includes a discussion of the factors to be considered in the design of early-warning monitoring systems, and gives some examples. One approach that appears to be particularly promising is that of identifying, quantifying and monitoring the stresses, feedbacks and component lags in the environmental-ecological system being studied.

1. Introduction

One of the objectives for integrated monitoring should be to provide early indications of impending changes in the environment or in the biosphere. These changes are often difficult to detect, at least in their early stages, because of large natural variability in the element or process being monitored. Some of these changes are expected, but with uncertainty as to magnitude and rate of change, e.g., CO₂ greenhouse climate warming and stratospheric ozone depletion. However, other changes are completely unexpected, e.g., forest dieback in Europe, which was not forecast by anyone 20 years ago, and the ozone ‘hole’ in the Antarctic stratosphere.

Although the early detection of discontinuities and jumps is issue-specific in many cases, there are nevertheless some general principles that can be listed. One of these is that monitoring should be undertaken within the framework of integrated monitoring (Izrael, 1980 and 1983). When based on an interconnected picture of the environment and the biosphere (through the notion of biogeochemical cycling of trace substances, for example), the monitoring system is likely to be much more responsive to detecting surprises than if it consisted of several disconnected components (an air monitoring network; a water quality network, etc.).

2. Trend Detection

There are five approaches that might help in getting an early indication of a trend or imminent step-change in the behaviour of an environmental/ecological system:
(1) Historical reconstructions;
(2) Biological indicators;
(3) Statistical techniques, e.g., the mapping of signal-to-noise fields; time series analysis;
(4) Identification and quantification of stresses, feedback mechanisms and component lags;
(5) Creative scenario writing.

These approaches will be discussed below in general terms. Then two practical examples will be given in Sections 3 and 4.

2.1. HISTORICAL RECONSTRUCTIONS

There are many examples of environmental issues that arose too quickly for appropriate monitoring systems to be put in place. This has made it impossible to determine pre-disturbance 'baseline' conditions. Particularly in the case of ecological monitoring, five to ten years of records may be required in order to determine the natural variability of the system. In retrospect, for example, how could we have had the foresight to monitor the European forests in the 1960s, or the exposures of mine workers to asbestos and fluorspar in the 1940s? In some cases, of course, a monitoring network had been operating for a decade or more before the 'disturbance' was noticed. However, the network had usually been established for other reasons and was inappropriate for trend detection. For example, the world stratospheric ozone network was developed in the 1920s and 1930s to get synoptic pictures of the ozone field; the resolution was too coarse to detect ozone depletion by chlorofluorocarbons when that issue arose in the 1970s. The same remarks apply to the Swedish wet deposition network organized by Rossby about 1950 for the purpose of tracing the synoptic motions of air masses. Again the time and space scales of the network made it difficult to detect trends when the acid rain problem arose in the 1960s (Munn and Rodhe, 1971).

It would be useful to undertaken a comprehensive review of an historically documented list of surprises in the environmental and ecological fields. Of particular interest would be a study of reasons why the surprises had not been expected.

2.2. BIOLOGICAL INDICATORS

There has been a long search for biological species that provide first indications of ecosystem damage by pollutants. For reviews, see Phillips (1980), Martin and Coughtrey (1982) and Burton (1986). It has been found, for example, that tree ring widths begin to decrease up to 20 years before there are visible signs of forest dieback.

In the context of early detection of the effects of water pollution on biota, Cairns and Schalie (1980) have produced a useful overview. They first make the point that biological indicators are indeed important in that they integrate the effects of various stresses operating on the system; information on pollution concentrations alone is a poor indicator of potential impact, toxicity being a complex function of water