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Los Angeles, Calif.

April 1-5, 1974

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EVOLUTION OF MONITORING FOR EARTHWATCH

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The basic products of global environmental monitoring are warnings of potentially harmful environmental conditions and possible environmental deteriorations that may lead to natural disasters, predictions of future environmental states that can assist in the day-to-day management of human activities, and assessments of conditions and trends that will allow proper management planning and policy decisions. Using this breakdown of global environmental monitoring by the resulting products--warnings, predictions, and assessments--I would like to first present an overview of the global monitoring efforts of the National Oceanic and Atmospheric Administration (NOAA) as an example of national programs. Secondly, international activities in global monitoring are essential to provide the needed worldwide coverage of environmental processes and I will discuss the major initiatives in this area. Finally, I will review current efforts underway to initiate global monitoring portion of EARTHWATCH--a global environmental assessment under the auspices of the new U.N. Environment Program.

NOAA was created as the national focal point to monitor the current state of the atmospheric and oceanic environment, predict its future state, issue warnings of impending hazards, and assess long-term changes. To discharge its responsibilities, NOAA operates a complex system that involves the acquisition of basic environmental information over wide geographical areas, the processing and analysis of this information into warnings and forecasts, the dissemination of products to users and the assessment of the long-range effects of nature and man-made activities on the quality of the environment.

To satisfy the requirements for data, NOAA relies on a wide range of observing facilities. Weather and hydrological conditions are observed and reported at approximately 1100 land stations. On the ocean, volunteer cooperative observers aboard more than 2000 ships transmit marine weather observations. From the surface to about 100,000 feet, profiles of temperature and moisture are determined through the use of balloon-borne instruments. Data for the strata between 100,000 and 300,000 feet are obtained by meteorological rockets. Above the atmosphere, geostationary and polar-orbiting satellites provide a near-continuous capability to detect, locate and track hazardous phenomena such as hurricanes, tornadoes, sea ice, and solar events. In addition, they provide vertical profiles of temperature, cloud imagery, upper wind data and, in cloud-free areas, sea surface temperatures and related oceanic circulation features. Radar is employed to provide continuous coverage of hazardous phenomena such as tornadoes, severe local storms, and hurricanes and is vital for monitoring on a local and regional scale. In addition, an evolving technology is producing new monitoring equipment and techniques such as data buoys and remote sensing devices. All the above facilities are organized into various network configurations depending upon the type of observation required and the need for its timely availability at analysis and processing centers.

Communications are essential to the effective operation of environmental warning and prediction services because they provide the capability to collect, display, and distribute environmental information rapidly and in sufficient time to permit issuance of short-period forecasts and warnings. For meteorological operations, rapid communications facilities are essential for the timely collections of weather data for centralized processing and for direct application by user groups. Weather communications facilities are also used to distribute information from processing centers. Teletypewriter systems are used as the primary means for collecting and distributing data, forecasts and warnings. Facsimile systems are more widely used to distribute analyses and other processed products from weather centers. Marine environmental observations taken at sea are transmitted to shore stations by radio circuits. Demands for increased amounts of data, greater collection speed, and more products from computers in weather centers have led to an increase in the use of high-speed digital systems as replacements for some teletypewriter and facsimile networks.

There are three types of analysis and forecast centers; primary, area and guidance, and specialized centers. Primary centers produce basic analyses and forecasts and provide basic warning services. NOAA operates four such centers: the National Meteorological Center which provides basic weather analyses and forecasts for the Northern Hemisphere and for portions of the Southern Hemisphere; the National Environmental Satellite Service which has the responsibility for establishing and operating a national operational environmental satellite system; the National Hurricane Center which provides basic forecasts and warnings of hurricanes in the Atlantic and Pacific Oceans, Caribbean Sea and Gulf of Mexico; and the National Severe Storms Forecast Center which functions as the source for severe thunderstorms and tornado watches in the U.S. in support of civil needs. Area and guidance centers using the products generated by the primary centers are responsible for forecasts and warnings within an assigned area. NOAA has 46 area and guidance centers called Weather Service Forecast Offices in the U.S. and one in Puerto Rico.

Specialized centers meet the unique requirements of a specific user group. NOAA has specialized centers to serve aviation, agriculture, air pollution control and fire-weather activities. NOAA's National Climatic Center which is the central archival, processing and service center for weather records in the U.S. is also designated as a specialized center.

To be effective, warnings and forecasts must be presented to the general public and special user groups in a timely fashion. A wide range of communications media are used for this purpose. The NOAA Weather Wire Service is a series of statewide and area circuits used to distribute consumer-oriented weather warnings, forecasts and data to the mass media for relay to the public and various specialized users. Voice communications systems also have a major role in the dissemination of environmental information. NOAA operates a continuous radio weather broadcast service consisting of 65 VHF/FM facilities. The broadcast provides continuous weather forecasts and warnings directly from the weather office to the general public, mariners, safety officials, news media, utility companies and schools. Automatic telephones and cable television are also employed for this purpose. Special facsimile circuits are used to disseminate environmental information in graphic form to users at sea or in remote locations.

To meet the national requirement for the proper management of living ocean resources, NOAA, through its National Marine Fisheries Service (NMFS), has initiated the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) Program. The overall objectives of MARMAP are to develop techniques for obtaining accurate measures of the abundance and geographic distribution of living marine resources available to the United States, to assess the productive capacity of these resources on a sustained yield basis and develop models for predicting future yields, and to monitor seasonal and annual fluctuations in the distribution

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and abundance of various life stages of pelagic and demersal fishery resources and relate them to environmental factors and utilization by man. The MARMAP initiative involves three kinds of resource surveys--ichthyoplankton, groundfish, and pelagic fish--and a continuing analysis of the effects of harvesting on exploited populations. Information is obtained on catch effort, mortality, fecundity, growth, migration, etc., to monitor the conditions of utilized stocks. These surveys are performed aboard ships of the NOAA fleet, together with those of the Coast Guard, cooperating States, laboratories, and private organizations. Supplemental data will be obtained from buoys, satellites, and ships of opportunity.

In 1973 an initial MARMAP survey for ichthyoplankton was conducted in the waters from Cape Cod to the Caribbean. In addition to the expected plankton and larval fishes, significant amounts of plastic and tar contaminants were collected in nets towed at the surface. Concentrations of plastics were found in the waters of the Mid-Atlantic Bight from Long Island to Cape Hatteras. The tar balls occurred most frequently in offshore waters; greatest concentrations were in the western boundary of the Sargasso Sea about 200 miles east of the Bahamas. The results of these initial efforts demonstrate the need for large-scale environmental monitoring to detect potentially harmful conditions and to provide assessments of environmental trends in the oceans.

Radiation emissions from the sun produce disturbances in the ionosphere and space which can interfere with telecommunications and endanger space flight operations. To cope with the problem NOAA has a program for providing reliable, accurate, timely, and comprehensive monitoring and forecast services for the upper atmosphere and space to meet the needs of civilian and military users. An additional goal of this program is to develop methodologies for modifying or preventing the disruptive effects of magnetic storms. The basic observations for these services are made by a cooperative world-wide network of nine solar optical and radio observatories. Additional data are collected by surface-based ionosondes, magnetometers and riometers at high latitudes and by satellites. These data are processed into forecasts and warnings of solar events that induce magnetic storms, dangerous radiation levels and other effects in the ionosphere.

International environmental programs fall primarily under the auspices of the U.N. specialized agencies although such important non-governmental bodies as the International Council of Scientific Unions (ICSU) have been instrumental in initiating major international efforts. The U.N. agencies involved include the World Meteorological Organization (WMO), the World Health Organization (WHO), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the Food and Agriculture Organization (FAO), and the International Atomic Energy Agency (IAEA).

The World Weather Program (WWP) of the WMO is an illustrative example of the type of international cooperation and coordination that is possible to effect a truly global environmental monitoring system. The goals of the WWP are to increase the accuracy and extend the time range of atmospheric predictions, to assess the consequences to global environmental quality of man's activities, to determine the feasibility of large-scale weather modification and to establish new dimensions of international cooperation. The WWP is composed of two essential elements--the World Weather Watch (WWW) and the Global Atmospheric Research Program (GARP). These two elements are mutually supportive. The WWW, which is the operational arm of the WWP, provides synoptic data and information to GARP which in turn develops new techniques and methodologies for predicting atmospheric events. Both elements are supported by a continuing effort in system and technology development.

In addition to the Global Observing System (GOS) of the WWW which consists of selected stations within the national networks of participating countries, a well defined system has been developed for processing global data and telecommunicating both data and prepared products. The Global Data Processing System of the WWW includes World Meteorological Centers (Washington, Moscow, and Melbourne) and Regional Meteorological Centers which provide basic services to the National Meteorological Centers. These centers are linked together by the Global Telecommunications System which provides for the real-time transmission of data and information and the quick dissemination of products. The WWW is essential not only to the preparation of weather forecasts but also to the timely warning of potentially disastrous atmospheric conditions.

A major advance in the GOS will be the implementation of the geostationary environmental operational satellite (GOES) system in the 1975-76 time period. Plans call for five GOES--two from the U.S., and one each from the USSR, Japan, and the European Satellite Research Organization. The five-GOES system will provide not only nearly total continuous global coverage, but will have communication capabilities for relaying other environmental data from earth-based sensors such as ocean data buoys or hydrology stations to warning or processing centers.

Complementary to the WWW is GARP which involves major international activities in analyzing global observations, in numerical modeling and simulation, and in intensive field experimentation. Ongoing and planned efforts within GARP include the GARP Atlantic Tropical Experiment (GATE), the Polar Experiment (POLEX), the Monsoon Experiment (MONEX), the Air Mass Transformation Experiment (AMTEX) and the First GARP Global Experiment (FGGE).

GATE, which is scheduled for implementation in summer of 1974, will involve the indepth analysis of tropical weather systems to improve capabilities for forecasting atmospheric phenomena, particularly hurricanes, for extended periods. FGGE, which is tentatively planned for the 1977-78 period, has as its objectives the modeling of atmospheric motion for extended range forecasting, general circulation studies, and climatic predictions; the assessment of the ultimate predictability of weather systems; the development of methods for assimilating observations from an array of platforms in various time and space scales; and the design of optimum observing systems for weather prediction.

An important part of the WWP is the network of global atmospheric baseline stations and regional air pollution monitoring stations. The U.S. has established two baseline monitoring stations--at Mauna Loa, Hawaii, and Point Barrow, Alaska--and plans two additional stations in Antarctica and American Samoa. It was observations taken over an extended period at Mauna Loa that documented the trend of increasing background carbon dioxide concentrations that could effect global climatic conditions. Other nations have indicated their intent to establish atmospheric baseline stations as part of the global network. The basic monitoring program at these stations include carbon dioxide, turbidity, and precipitation chemistry.

Regional air pollution stations monitor turbidity and precipitation chemistry. Approximately 45 countries have either established or plan to establish regional air pollution stations for a total network of more than 70 stations. The U.S. has established 10 stations which are operated by NOAA for the Environmental Protection Agency.

In addition to atmospheric monitoring, other international activities are either underway or in the planning stages. The International Tsunami Warning System is comprised of tide and seismograph stations and services some 16 nations and territories in the Pacific basin. NOAA operates the International Tsunami Warning Center in Honolulu, Hawaii, which provides for the centralized analysis and issuance of warnings to participating nations.

An important aspect of environmental assessment is the development of natural disaster risk maps to assist in local and regional planning activities. The World-Wide Standardized Seismic Network provides observations from some 120 stations in 60 nations that contribute to the development of seismic risk maps, an essential first step in hazards reduction and preparedness planning.

The focal point of international ocean monitoring programs is the Intergovernmental Oceanographic Commission (IOC) of UNESCO. The IOC, in cooperation with the WMO, recently implemented the Integrated Global Observing Station System (IGOSS) program with a pilot project to collect, telecommunicate, and process bathythermograph data from ships of participating countries for purposes of analyzing the thermal structure of the upper layer (300 meters) of the ocean. Program plans are being finalized for a follow-on pilot project to monitor pollution over large ocean areas. Oil substances are included initially and other contaminants are to be included when feasible technologically. When fully implemented, IGOSS will provide systematic observations of a broad range of physical, chemical, and selected biological parameters for the preparation of assessments, warnings, and predictions of significant oceanic phenomena.

A major new environmental thrust in the international arena was the U.N. Conference on the Human Environment held in Stockholm in June 1972. The results of the Stockholm Conference, which were subsequently approved by the U.N. General Assembly, include an Action Plan with 109 recommendations for environmental action; a new U.N. body--the U.N. Environment Program (UNEP) headed by an Executive Director; a Governing Council of 58 nations to set policy; a U.N. interagency coordination board composed of the various U.N. specialized agencies; and a voluntary U.N. Environment Fund of $100 million.

The Action Plan contains three main functional areas: EARTHWATCH, Environmental Management, and Supporting Measures. Furthermore, within EARTHWATCH four kinds of environmental activities are recognized: Monitoring, Evaluation and Review, Research, and Information Exchange.

EARTHWATCH provides the needed framework for undertaking global environmental action, particularly in the area of monitoring. It provides for the international collaboration among nations, for the sharing of facilities and observational platforms, and for the assistance to developing countries to allow their full participation in global efforts. EARTHWATCH is built upon existing national and international capabilities and serves to integrate these capabilities using the Environment Fund to fill gaps where necessary and resulting in a comprehensive multidisciplinary global assessment effort.

The first step in implementing the Action Plan was taken at the first meeting of the Governing Council (GC) in June 1973. The GC identified a series of priority areas for early action, endorsed a pilot project to demonstrate the viability of an international Information Referral Service, and called for early implementation of the monitoring portion of EARTHWATCH focusing on pollutants that may affect climate and human health. In response to this last directive, the UNEP Secretariat convened an Intergovernmental Working Group on Monitoring (IWGM) in February 1974 to prepare a monitoring plan for approval at the second meeting of the GC held in March 1974.

During preparations for the IWGM, it became clear that in order to implement a comprehensive monitoring program, two separate streams of action must be recognized to take into account the state-of-the-art in science, technology, and program development. First stream actions are those for which facilities and technology are available, the approach to the problem has been fairly well defined, and adequate scientific knowledge is available. Second stream actions involve program development, additional research, and new technologies prior to implementation of an expanded program. These two streams of action must be considered parallel and should proceed simultaneously.

In developing the U.S. position for the IWGM and the GC, a series of objectives were established to which the global monitoring program should be responsive. These objectives included the establishment of capabilities for the surveillance of human health, natural disasters, and food contamination, and the assessment of man's impact on climate, ocean pollution, ecosystem stability and modification, and the impact of land-use practices. To meet these objectives, the U.S. has proposed a series of priority actions that pull together existing capabilities into a coordinated, integrated structure and allow sharing of resources and the development of a multidisciplinary data base for more comprehensive global environmental assessments. These actions include a global network of EARTHWATCH Reference Sites, cooperative impact monitoring efforts, selected indicator monitoring programs, and a coordinated international system of pollutant analysis facilities and data and information management centers.

The momentum created at Stockholm has brought us to the point where a coordinated international thrust to monitor the global environment is possible. Furthermore, there is a new spirit of cooperation within the community of nations to collectively address the critical problems of global significance. We are at the threshold of a major new initiative that can unite many diverse efforts and implement important new ones to attack environmental pressures and threats that concern all people. The battle to preserve and enhance our world environment will not be won by global monitoring alone. It will, however, be lost without it.

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OPTIMIZATION OF WATER QUALITY MONITORING PROGRAMMES

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The optimization of water quality monotoring programmes is an important question and a difficult one. The primary difficulty rests with the problem of defining "optimum". In one instance it might be a network of monitoring stations which maximizes the information on water quality for a given budget, and on the otherside it might be one which minimizes the cost of data collection for a required accuracy of information. In any event, one cannot begin to design an optimal monitoring program unless a clear objective has been specified.

And thus the first step in the design of a monitoring program is the establishment of a clear and unamibiguous objective in quantitative terms. For instance, a treatment plant monitoring program may be desired which determines the BOD of the effluent to ± 5 mg/l, or, a regional river basin survey should be conducted such that the total pollution load is determined to within 10 per cent. These are clear and quantitative statements of an objective, and it makes sense to label a monitoring program, which will achieve these objectives at minimum costs, as optimal in an economic sence. By contrast, statements such as "we need the most in water quality monitoring for the least cost" are well intended, but operationally useless and mathematically impossible.

If one attempts to classify different water quality monitoring programmes, a separation into national, regional and local programmes appears to be feasible. At the highest, or national level, information is necessary for broad planning purposes, such as to determine an overall level of water pollution, to determine the total investment necessary for pollution abatement, to determine national policies and to project the problems into the future. At the second level, the regional level, all of the above information is necessary, plus the particular information needs for this region. The third, local level, consists usually of checking the operation of waste treatment plants to ensure compliance with regulations and statutes. And thus due to the different requirements and objectives, a monitoring program which may be optimal at one level, is usually far from optimal at some other level. Unless a clear objective has been set, there is no guarantee that all critical bits and bytes of information are collected, and that the gathering of useless data is minimized. Whether the monitoring system should be automatic or not, depends on the parameters to be monitored and the economics thereof.

Monitoring a Single Point

Monitoring the water quality at a single point may be required for a variety of objectives. These include: a) to determine the suitability of the water as source of water supply, for swimming, or boating and recreation; b) the day-to-day monitoring of the effluent of a treatment plant, an outfall, or water intake, to determine compliance with regulations; c) to detect accidents and spills.

Monitoring a single point can be optimized. The sampling frequency is based on the variability of the data. To get an estimate of the variability a first, almost continuous recording of the data is necessary. Based on this information, the necessary frequency of samples can be determined for various confidence levels and a decision can be made on grab samples versus continuous recording. Conventional statistical methods can be employed to resolve the questions of an optimal strategy and of statistical significance. With automatic data collection the problem is one of resolution; that is can data be digitized at a time interval larger than the recording interval without losing essential information. If this is the case, then data collection programmes can be designed accordingly with a saving in the cost of collection, storage and analysis.

Monitoring a Region (Riverbasin)

The monitoring of a region is usually done for several reasons: a) to establish the pattern of the pollution loads, b) to determine compliance with existing water quality standards, c) to estimate the parameters of a mathematical model of the system useful for predicting water quality for other flows and loads. In contrast to the monitoring of a single point over a long period, these studies are concentrated over shorter times but are more intensive. Problems which arise here are the number and location of sampling stations and a sampling frequence. There are no general rules for such a study, except that the data collected should be analyzed immediately, used in the mathematical model, and the outputs or predicted values from the model should be compared to the data collected. This in turn will dictate new data collection, and thus there exists a closed loop between data collection and model building. Since these models usually serve as the basis for optimizing investment programs for pollution abatement, the sensitivity of the parameters should be tested. The number of monitoring stations and the length of their record should be based on the values of the information they provide. Under budgetary constraints those stations should be deleted, which contribute the least information.

There are two studies in the literature, which address themselves to the problem of the optimum gauging station location. Their models could be applied to a limited degree in water quality monitoring programmes.

The basic concept is that the flows in streams are correlated as a result of meteorologic phenomena that to an extent affect all streams in a region. In water quality monitoring this would only hold true if a number of monitoring stations are located below a major industrial area, and no additional pollution loads occur between these stations.

Correlation implies that information about some property of a sequence of parameter values may be transferred from one station to another. This implies that the monitoring at some stations may be discontinued, since the parameter values may be inferred from the properties of adjacent stations. The notion of information content is the basis of the scheme. Information content is defined as the inverse of the variance. Maximizing information content is equivalent to minimizing the variances. The approach is therefore to seek to identify those stations that are to be discontinued, such that the sum of the variances of the estimates at all stations are at a minimum, subject to a budgetary constraint.

Maximum Spacing of Monitors

Ideally speaking monitors should be spaced very closely if it is desired to follow the variation in the water quality along a river. However, budgetary constraints usually prohibit an unlimited number of monitors. The basic question there-

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