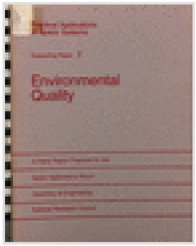

Environmental Quality (1975)

Pages
70

Size
8.5 x 11

ISBN
0309346827

Panel on Environmental Quality; Space Applications Board; Assembly of Engineering; National Research Council

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(July 1974)

PRACTICAL APPLICATIONS OF SPACE SYSTEMS

Supporting Paper 7

ENVIRONMENTAL QUALITY

The Report of the
PANEL ON ENVIRONMENTAL QUALITY
to the
SPACE APPLICATIONS BOARD
of the
ASSEMBLY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

Published by
NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.
1975

This is a report of work under Contract No. NSR 09-012-106 between the National Aeronautics and Space Administration and the National Academy of Sciences.

Available from
Space Applications Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

PREFACE

In November 1973, the National Aeronautics and Space Administration (NASA) asked the National Academy of Engineering* to conduct a summer study of future applications of space systems, with particular emphasis on practical approaches, taking into consideration socioeconomic benefits. NASA asked that the study also consider how these applications would influence or be influenced by the Space Shuttle System, the principal space transportation system of the 1980's. In December 1973, the Academy agreed to perform the study and assigned the task to the Space Applications Board (SAB).

In the summers of 1967 and 1968, the National Academy of Sciences had convened a group of eminent scientists and engineers to determine what research and development was necessary to permit the exploitation of useful applications of earth-oriented satellites. The SAB concluded that since the NAS study, operational weather and communications satellites and the successful first year of use of the experimental Earth Resources Technology Satellite had demonstrated conclusively a technological capability that could form a foundation for expanding the useful applications of space-derived information and services, and that it was now necessary to obtain, from a broad cross-section of potential users, new ideas and needs that might guide the development of future space systems for practical applications.

After discussions with NASA and other interested federal agencies, it was agreed that a major aim of the "summer study" should be to involve, and to attempt to understand the needs of, resource managers and other decision-makers who had as yet only considered space systems as experimental rather than as useful elements of major day-to-day operational information and service systems. Under the general direction of the SAB, then, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth-orbiting satellites. This work was done in July 1974 at Snowmass, Colorado.

For the study, nine user-oriented panels were formed, comprised of present or potential public and private users, including businessmen, state and local government officials, resource managers, and other decision-makers. A number

*Effective July 1, 1974, the National Academy of Sciences and the National Academy of Engineering reorganized the National Research Council into eight assemblies and commissions. All National Academy of Engineering program units, including the SAB, became the Assembly of Engineering.

of scientists and technologists also participated, functioning essentially as expert consultants. The assignment made to the panels included reviewing progress in space applications since the NAS study of 1968* and defining user needs potentially capable of being met by space-system applications. User specialists, drawn from federal, state, and local governments and from business and industry, were impaneled in the following fields:

Panel 1: Weather and Climate
Panel 2: Uses of Communications
Panel 3: Land Use Planning
Panel 4: Agriculture, Forest, and Range
Panel 5: Inland Water Resources
Panel 6: Extractable Resources
Panel 7: Environmental Quality
Panel 8: Marine and Maritime Uses
Panel 9: Materials Processing in Space

In addition, to study the socioeconomic benefits, the influence of technology, and the interface with space transportation systems, the following panels (termed interactive panels) were convened:

Panel 10: Institutional Arrangements
Panel 11: Costs and Benefits
Panel 12: Space Transportation
Panel 13: Information Services and Information Processing
Panel 14: Technology

As a basis for their deliberations, the latter groups used needs expressed by the user panels. A substantial amount of interaction with the user panels was designed into the study plan and was found to be both desirable and necessary.

The major part of the study was accomplished by the panels. The function of the SAB was to review the work of the panels, to evaluate their findings, and to derive from their work an integrated set of major conclusions and recommendations. The Board's findings, which include certain significant recommendations from the panel reports, as well as more general ones arrived at by considering the work of the study as a whole, are contained in a report prepared by the Board.**

It should be emphasized that the study was not designed to make detailed assessments of all of the factors which should be considered in establishing priorities. In some cases, for example, options other than space systems for accomplishing the same objectives may need to be assessed; requirements for

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*National Research Council. *Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee*. National Academy of Sciences, Washington, D.C., 1969.

**Space Applications Board, National Research Council. *Practical Applications of Space Systems*. National Academy of Sciences, Washington, D.C., 1975.

institutional or organizational support may need to be appraised; multiple uses of systems may need to be evaluated to achieve the most efficient and economic returns. In some cases, analyses of costs and benefits will be needed. In this connection, specific cost-benefit studies were not conducted as a part of the two-week study. Recommendations for certain such analyses, however, appear in the Board's report, together with recommendations designed to provide an improved basis upon which to make cost-benefit assessments.

In sum, the study was designed to provide an opportunity for knowledgeable and experienced users, expert in their fields, to express their needs for information or services which might (or might not) be met by space systems, and to relate the present and potential capabilities of space systems to their needs. The study did not attempt to examine in detail the scientific, technical, or economic bases for the needs expressed by the users.

The SAB was impressed by the quality of the panels' work and has asked that their reports be made available as supporting documents for the Board's report. While the Board is in general accord with the panel reports, it does not necessarily endorse them in every detail.

The conclusions and recommendations of this panel report should be considered within the context of the report prepared by the Space Applications Board. The views presented in the panel report represent the general consensus of the panel. Some individual members of the panel may not agree with every conclusion or recommendation contained in the report.

PANEL ON ENVIRONMENTAL QUALITY

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ACKNOWLEDGMENT

The Panel wishes to express its sincere appreciation to the following persons who made themselves available for consultation and who contributed significantly to the work of the Panel by providing background information and briefings as needed:

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CONTENTS

INTRODUCTION

The earth is now recognized as one large spacecraft whose self-contained environment must be maintained by wise management of its food, fiber, water, air, mineral, and other natural resource systems. To do so requires real-time knowledge of man's interaction with many of these resources. The dramatic impact of the Arab oil embargo in October 1973, for example, contributed emphatically to a growing worldwide awareness of the finiteness of the resources upon which mankind depends.

Throughout the history of human settlement, man's surroundings have strongly influenced not only his growth in numbers but also social and cultural aspects of his life. His upward struggles to overcome or control hostile aspects of his environment have been marked by his ability to harness energy for his own betterment. Until the early 1800's growth in population and growth in energy consumption were roughly comparable. The burning of wood was the principal source of energy. Wood, which was a renewable resource, was supplanted by coal, a non-renewable resource, in the late 1800's. Natural gas and oil are newcomers to the fuel scene, yet the world is now drawing so extensively upon these finite resources that they will likely be virtually exhausted by the end of the twentieth century. Coal exists in relatively abundant quantities but both its recovery and use may entail significant undesirable environmental consequences. Nuclear energy is another relatively new source but supplies of fissionable uranium are short-lived in relation to man's long-term needs. Breeder-reactor concepts promise to extend capabilities for nuclear power but pose new environmental problems.

Studies have shown a direct correlation between man's standard of living and his per-capita energy consumption. Further, the per-capita consumption rate is increasing, particularly in industrialized nations. The increasing demand for energy in industrialized nations, aspirations for higher standards of living (and hence energy demands) in developing nations, and continued growth in world population foretell even greater future stress upon: (1) dwindling supplies of finite non-renewable fuels, (2) land and sea areas from which fuels are to be recovered, (3) land, air, and water resources involved in fuel processing, and (4) man's activities associated with fuel use.

Population and its growth are critical factors in most environmental problems. Moreover, density and distribution of population are intrinsically important in determining the quality of an environment.

When the population on earth was relatively small and daily activities were simple, the effects of man's presence were hardly discernible among the many natural forces at play. If an effect is measured against the total mass of the sea, the land, and the atmosphere together with the energy involved in natural phenomena such as storms, eruptions, and earthquakes, one might reasonably wonder how man could possibly intervene to upset the natural forces, even in a minor way. There is mounting evidence, however, that today we may be doing just that, threatening not necessarily the earth itself but life on earth as we now know it.

First-order undesirable effects of man's activities show up as local and regional environmental problems. Over the past few years, there has been growing concern also about the worldwide impact of these activities. Among various conferences and symposia that have addressed the global implications of the problem, two are generally considered as milestones: (1) a summer study* held in Williamstown, Massachusetts, in which about 70 scientists participated and (2) a summer study** held in July 1971 in Stockholm, Sweden, in which about 30 scientists from 14 countries participated.

The recommendations that emerged from these two conferences provided focal points for international discussions at the United Nations (UN) Conference on the Human Environment held in Stockholm, Sweden, in 1972 and served as the basis for an international agreement that led to the global monitoring programs now underway at the UN Institute in Nairobi. As important as these actions are, at the global level it is worthy to note that the SCEP report which stimulated this global thinking also included (page 5) the following observatiions: "...the existence of a global problem does not imply the necessity for a global solution. The sources of pollution are activities of man that can often be effectively controlled or regulated where they occur...."

Background material on other problems related to environmental quality is available from a number of different sources.# Among those, for example, from which the Panel obtained valuable information are the Environmental Protection Agency (EPA) and the Council on Environmental Quality.

**Man's Impact on the Global Environment; Assessment and Recommendations for Actions.* Study of Critical Environmental Problems (SCEP). MIT Press, 1970.

***Inadvertent Climate Modification.* Study of Man's Impact on Climate (SMIC). MIT Press, 1971.

#Environmental Protection Agency, Office of Research and Development. *Proceedings of Second Conference on Environmental Quality Sensors.* U.S. Government Printing Office, Washington, D.C., 1973.

#*Environmental Quality.* Third Annual Report of Council on Environmental Quality. U.S. Government Printing Office, Washington, D.C., 1972.

#National Research Council. *Useful Applications of Earth-Oriented Satellites.* National Academy of Sciences, Washington, D.C., 1969.

#*Special Analyses, Budget of the United States Government, Fiscal Year 1975.* U.S. Government Printing Office, Washington, D.C., 1974.

Legislative and regulatory actions at both national and state levels have been mounted in recent years to limit the emission of pollutants into the environment. Federal legislation pertaining to environmental quality is summarized in Appendix A. Other bills dealing with management of hazardous wastes, control of the quality of drinking water, and control of hazardous substances are currently being considered by the Congress.

The Panel on Environmental Quality concerned itself with the potential use of space systems to assist in determining the current state of air, water, and land environments and in monitoring them for the effects of man's activities. In many respects, this Panel had overlapping interests with other panels that took part in the 1974 Summer Study of Space Applications. Areas in which these overlapping relationships exist are shown in Appendix B.

The Panel on Environmental Quality recognizes the possibility of pursuing such environmental factors as noise and aesthetics but elected to narrow its considerations to ways in which space systems might be used to determine (1) what pollutants are introduced into the major environmental media, (2) what effects of these pollutants are manifested, and (3) the effectiveness of abatement and control actions. Environmental aspects so examined are discussed in relation to (1) air quality, (2) water quality, (3) land quality as related to land use, and (4) public health.

AIR QUALITY

The existing research and development program in the use of satellites for measuring environmental quality is probably most advanced in the area of air quality. This is due to the long-term existence of an established meteorological program. Although air pollution monitoring has now evolved as a separate discipline, the interface with meteorology must remain strong.

It is the opinion of the Panel that the principal objectives in developing a program for air pollution monitoring should be:

> To evaluate the role of remote sensing in monitoring urban air quality and major point-source emissions.
>
> To determine on regional and national scales, pollutant burdens in the troposphere with particular emphasis on that part of the troposphere which is near the surface of the earth.
>
> To measure stratospheric trace constituents potentially affecting climate and health.
>
> To develop systems for assessing, on both regional and global scales, the impact of strategies for air quality control.

MONITORING IN THE TROPOSPHERE -- REGIME I

The troposphere is the lowest major layer of the atmosphere, and extends from the earth's surface to a height of about 12 kilometers. It is in this lower layer of the atmosphere that most of the important processes affecting weather occur. For purposes of discussion in this report the troposphere will be considered as divided into two "regimes." Regime I is defined as the mixing layer constituted by the air space between the earth's surface and the inversion layer. The height of Regime I is not constant since the altitude of the inversion layer varies from day to day and from day to night. Mean mixing depths over the continental U.S. vary within the range of 450 meters to 1400 meters. The importance of Regime I stems from the fact that the inversion layer acts as a cap or lid on the mixing layer. Most of the first-order effects of air-borne pollutants experienced by man, plants, and animals are highly dependent upon the dispersion and dilution capacity of Regime I. One may note that remote measurements which identify the height of the layer, the temperature gradient as a function of height above ground, and the wind speeds and directions in Regime I will add materially to meteorological modeling that may be used to predict ground-level concentrations of pollutants from point sources.

In the U.S., the Clean Air Act of 1970 requires that national standards of ambient air quality be established for protection against the chief pollutants. Primary standards are set at levels to protect human health. Secondary standards, which are more stringent, are set to protect crops, property, and aesthetics. In addition, the Act calls for reduction in pollution from some existing sources as well as for establishment of national emission standards for significant new sources, such as power plants and nonferrous smelters. It also requires the establishment of national emission standards for new and old sources of certain pollutants designated as hazardous.

Pollutants for which such national standards have been developed are shown in Table I.

		Acceptable Concentration, in $\mu g/m^3$		
Pollutant	Exposure Time	Primary Standard	Secondary Standard	Measurement Method
Total suspended particulate matter	Annual 24 hr	75 260	60 150	Gravimetric
Sulfur oxides	Annual 24 hr	80 365		Pararosaniline
Carbon monoxide	8 hr 1 hr	10×10^3 40×10^3	10×10^3 40×10^3	Nondispersive Infrared
Hydrocarbon (exclusive of methane)	3 hr	170	160	C and H counter
Photochemical oxidant	1 hr	160	160	Chemiluminescence as O_3
Nitrogen dioxide	Annual	100	100	(Not yet specified)

TABLE I U.S. STANDARDS FOR AMBIENT AIR QUALITY

Several particular points about Table I are emphasized as follows:

> Table I identifies the pollutant levels (concentrations) which monitoring systems must be capable of measuring. Ideally, detection equipment should be one order of magnitude more sensitive than these levels.
>
> Monitoring systems aimed at protecting the health and safety of people from the somatic effects of air pollutants must be capable of sensing within the mixing layer and down to ground level (Regime I).
>
> Monitoring should provide for *local* measurements that identify the magnitude of emission and the areal dispersion of pollutants from major point sources and should also provide for *regional* measurements of levels of ambient air quality (concentrations and areal dispersion) that represent the averaging effects of dilution and dispersion by the atmosphere of the total air including both natural and man-made contributions.

Much emphasis is placed upon the control of emissions from major point sources. In general, these emissions are readily identifiable, are relatively few in number and, therefore, lend themselves to effective control measures. In terms of total air pollution, however, non-point or diffuse sources, particularly vehicular traffic, residential home heating, and general industrial activities, represent far more significant contributors.

Predictions of occurrences of air stagnation and their expected durations are important elements in air quality monitoring and in the implementation of emergency control actions during air pollution episodes. Capabilities are needed for local and regional micrometeorological predictions and for on-line ground-level pollutant monitoring, particularly for total suspended particulate matter as related to atmospheric capability, visibility, sulfur dioxide, carbon monoxide, and oxidant. Reliable episode-control systems have the potential to provide guidance for scheduling or controlling the use of "dirty" fuels, to facilitate decisions to switch to limited supplies of "clean" fuels for heat and power generation, and to permit operational rescheduling for reduction of sulfur-oxide effluents from smelters.

Point and diffuse sources of potential pollution plus possible unfavorable stagnation situations lead to the need for surveillance over heavily industrialized areas and major human settlements. Objectives are:

> Measurement of concentration of pollutants to which people are exposed, as a step toward remedial action and control.
>
> Tracking of dispersal patterns of major point sources as well as diffuse wide-area polluted air masses.
>
> Better understanding of "carrying capacity" of air regions affected by man's activities.

Establishing standards of ambient air quality and strategies for abatement and control of pollutant source emissions within a stipulated compliance schedule is generally referred to as an air quality management plan. The U.S. air quality management plan calls for attaining and maintaining the primary, or health, standards throughout the nation by 1977 and the secondary, or environmental, standards within a reasonable time thereafter.

There are other air pollutants that are known to have adverse effects on public health and on various aspects of man's environment and for which control strategies will be based either on higher national standards of ambient air quality or on limitations of pollutant emissions from stipulated sources. These pollutants include aldehydes; halogens and derivatives, including chlorine, hydrogen chloride, hydrogen fluoride and fluoride compounds, and halogenated organic materials; hydrogen sulfide; polycyclic organic matter; toxic metals such as arsenic cadmium, lead, manganese, and vanadium; and organic nitrogen compounds such as peroxyacyl nitrates.

The air quality management plan calls for the development of a source emission control strategy which yields the required standard of ambient air quality. Needed emission reduction can be achieved by improved production processes, applicable emission control technologies, operational efficiencies, and other methodologies. The emission reductions required are usually established as either emission or performance standards. The U.S. has promulgated emission standards that apply to motor vehicles and cover carbon monoxide, hydrocarbons, and nitrogen oxides. Performance standards were promulgated which apply to industries of a minimum size in categories including carbon monoxide, fluorides, hydrogen sulfide, nitrogen dioxide, sulfur dioxide, sulfuric acid, and total suspended particulate matter. Industrial categories for which performance standards have been either planned or established include the following:

Asphalt and concrete batch-mixing plants
Cement manufacturing
Coal cleaning
Ferro-alloy plants
Iron and steel production
Kraft-pulp and paper mills
Municipal incinerators
Nitric acid plants
Petroleum refineries
Phosphate fertilizer plants
Primary aluminum reduction plants
Secondard brass and bronze ingot manufacturing
Secondary lead smelters
Sewage sludge incinerators
Stationary gas-turbine engines
Steam electric generators
Sulfuric acid plants

Performance standards are planned for other industrial categories which involve hazardous pollutants. The pollutants emitted from some important industrial sources and their minimum concentration upon emission are shown in Table II.

Monitoring emissions from major point sources is important for determining the extent of compliance with standards and for validating models used to relate emission limitations to expected air quality. The monitoring of major emission sources is also needed to establish the pollution burden imposed upon the air resource and to ascertain whether the required emission controls conserve air quality or contribute to its degradation. Results of monitoring major sources located in areas remote from urban complexes are expected to contribute to an improved understanding of the carrying capacity of air in motion and to provide information useful in evaluating the present national policy calling for enhancement rather than no further deterioration of the nation's air resources.

Industry	Pollutant	Concentration
Ferro-alloy plants	TSP *	46 mg/m^3
Iron and steel production	TSP	46 mg/m^3
Nitric acid plants	NO_2	200 ppm
Petroleum refineries	CO	100 ppm
	SO_2	30 ppm
Primary aluminum reduction plants	F	1 ppm
Steam electric generators	SO_2	200 ppm
	TSP	114 mg/m^3
Sulfuric acid plants	SO_2	200 ppm

* TSP Total Suspended Particulates

TABLE II MINIMUM EMISSION CONCENTRATIONS OF INDUSTRIAL POLLUTANTS

MONITORING IN THE TROPOSPHERE -- REGIME II

As used here Regime II is the upper part of the troposphere (lying above Regime I), made up of the synoptic air mass not restrained by localized inversion conditions. As indicated in the section on Regime I, national standards are based largely on consideration of potential effects of ground-level concentrations. These concentrations in turn are strongly influenced by the dispersion and dilution capabilities of the atmosphere. On the larger scene represented by the atmospheric mass of Regime II, dispersed pollutants can evolve into other chemical forms, and create undesirable situations in places far removed from the points of release. Air quality monitoring is especially useful in assessing the chemical and physical transformations of these reactive pollutants as they are transported and dispersed within the moving air mass and as resultant products are detected in areas remote from the point of initial introduction. Sensing on regional, national, and global scales the conversion of gaseous sulfur dioxide to intermediate and end sulfate particulates as well as their temporal and spatial distribution is an important task. This capability is essential to understanding air quality degradation and its impact on ecosystems and climatic change.

Monitoring the primary pollutants (reactive hydrocarbons and nitrogen oxides) and the resultant secondary pollutants (ozone and peroxyacyl nitrates) arising from photochemical oxidation is a complex and demanding task. It is, however, essential in understanding the chemical and meteorological dynamics of the ecosystem and in developing models predictive of the concentration and geographic distribution of atmospherically generated toxicants. Nonreactive methane and photoreactive hydrocarbons together with nitric oxide and nitrogen dioxide must be detected and measured as they are emitted from stationary and mobile sources. Simultaneously, aldehydes, ozone, and peroxyacyl nitrates must be sensed as they are formed at varying distances and elevations from the primary pollutant sources. The general occurrence of a photochemical-oxidant reaction (and resulting plume) over a city wherever active radiation is adequate illustrates the global nature of the problem, and emphasizes the need to ascertain the long distance transport and dynamic reactive characteristics of these urban photochemical plumes. It is also necessary to be able to distinguish between anthropogenic ozone and natural background as well as to be able to determine the nature and fate of the photochemically produced aerosol.

Pollutants present in the lower layers of the troposphere and the degree of accuracy required for measurement on a regional basis are given in Table III. Also included are potential problems that show why there is need to be concerned about each pollutant. Principal users who may be interested in data collected on local and regional bases are shown in Table IV. Basic needs within four categories are indicated for each user.

Pollutant Constituent	Accuracy	Problem
CO	10 ppb	Determination of sources, sinks, and lifetime in lower atmosphere
	10 ppb	Participates in photochemical reactions
	10 ppb	Indicative of oceanic processes
H_2CO	1 ppb	Participates in photochemical reactions
	1 ppb	Irritant at concentration near 1 ppm
Halogens	1 ppb	Toxic and damaging (especially fluorine and hydrogen fluoride)
	1 ppb	Bromine indicative of bioproductivity of oceans
NH_3	10 ppb	Combines with sulfuric acid to form $(NH_4)_2SO_4$ particulates
SO_2*	10 ppb	Damage to plants Particulate formation subsequently contributes to acid rain
H_2S*	0.1 ppb	Oxidizes to SO_2 Natural source uncertain
NO_x*	0.1 ppm	Damage to plants and toxicity at concentration (measured in ppm)
	10 ppb	Photo-oxidation of hydrocarbons and particulate formation
	10 ppb	Precursor of peroxyacyl nitrates (PAN) species
PAN*	1 to 10 ppb	Class of toxic and irritant products of photochemical processes
<HC> *	<1 ppb (necessary to distinguish species)	Particulate formation by photochemical processes Noxious and toxic products
O_3*	10 ppb	Irritant and destructive; product of photochemical processes involving <HC> and NO_x
H_g*	10^{-2} ppb	Transported in atmosphere; toxic where it accumulates in biosphere

*Accuracy estimate speculative or long term.

TABLE III REGIONAL POLLUTANTS IN TROPOSPHERE

(From *Remote Measurement of Pollution*, NASA Publication SP-285)

Principal Users	Basic Needs: Near Surface Sensing (local)	Regional Air Quality Data	Predictive Model Inputs	Major Point Source Emissions
U.N. organizations	X	X	X	X
Federal agencies				
EPA	X	X	X	X
AEC			X	
NOAA			X	
DOT		X	X	
HEW	X	X		
NSF		X	X	
State and local agencies				
Regulatory	X	X	X	X
Planning	X	X		
Resource	X	X	X	X
Regional air pollution control boards	X	X	X	X
Environmental consultants	X	X	X	X
Engineers and architects	X	X	X	X
Research and scientific investigators	X	X	X	X
Medical and nursing professions	X	X		X
Public-interest groups	X	X		X
Industrials*	X	X	X	X
News media	X	X	X	X

*Standard Industrial Classification Groupings:

(1) Transportation, communications, utilities and sanitary services
(2) Construction
(3) Manufacturing (chemical, fabricated metals, paper, petroleum, primary metals, transportation equipment)
(4) Mining

TABLE IV USERS AND NEEDS FOR LOCAL AND REGIONAL AIR QUALITY MONITORING IN TROPOSPHERE

MONITORING IN THE STRATOSPHERE

The stratosphere is the region of the atmosphere from about 12 kilometers to 50 kilometers above the surface of the earth. There are growing concerns about the potential for effecting significant changes in the worldwide climatic conditions through the introduction of both trace gases and particulates into this protective barrier of our planet. Pollutants can be injected into the stratosphere by exchange of air between the stratosphere and the troposphere. The effects of this natural phenomenon conceivably may be modified as the pollutant load at the boundary between the troposphere and the stratosphere increases or changes in character. Man has already introduced materials into the stratosphere as the result of weapons testing. Residence times of these materials in the stratosphere and fallout patterns attest that exchanges do occur between the stratosphere and the troposphere.

More recently man through aerospace vehicles has put combustion products, both trace gases and particulates, directly into the stratosphere. In addition, a number of countries have pursued development of jet aircraft that may be operating routinely in the stratosphere within a relatively few years.

A substantial amount of attention both nationally and internationally has been showered on the potential global implications of man's perturbation of the stratosphere. Several major interdisciplinary studies* have focused specifically on this issue. The case has been well documented already for developing programs aimed at investigations on a global scale. However, in the interest of placing such investigations in perspective with other environmental needs and of examining priorities, a brief summary of the situation is included herein.

Several basic properties of the stratosphere make it sensitive to the injection of trace gases and particulates of both man-made and natural origin.** The stratospheric ozone layer filters out ultraviolet radiation from the sun that is harmful to most forms of earth life. The photochemical processes that determine the ozone content are not well understood. It is easy to conceive that the introduction of new materials or the increase in quantity of chemical forms leading to new equilibrum values could significantly alter this protective ozone barrier.

Fine particles dispersed in the atmosphere affect the heat balance of the earth because they both reflect and absorb radiation from the sun and the earth. Man introduces fewer particles into the atmosphere than do natural sources. In any case, particle levels have been increasing through the years. In the troposphere, residence times of particles are of the order of six days to two weeks but, in the lower stratosphere, may be from one to three years. These long residence times, plus the photochemical processes that occur there, make the stratosphere more sensitive to injection of particles than the troposphere.

A broad spectrum of R&D programs concerned with stratospheric pollution appears to be underway or planned. A major current activity is the Climatic

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*SCEP and SMIC reports (see p. 2 above)

**SCEP report (see p. 2 above) and *Remote Measurement of Pollution*. NASA SP-285, 1971.

Impact Assessment Program (CIAP) being conducted by the Department of Transportation (DoT). This program seems to be oriented largely to the question of possible environmental effects of aircraft flying in the stratosphere. Other federal agencies such as NOAA, NSF, USAF, AEC, and NASA reportedly have increased their levels of activity on stratospheric research programs.

The Panel on Environmental Quality found it impossible, within the time constraints of this 1974 summer study, to review all the elements of what appear to be substantial national and international efforts to understand better and to establish baseline characteristics of the stratosphere. It appears, however, from the Panel's limited survey that the principal thrusts of major programs underway by NASA and DoT are mission oriented, that is, aimed at assessing the potential impact of future aerospace applications (space shuttle and supersonic jets). The supporting R&D includes studies on atmospheric modeling, fundamental physical processes, and instrument development. It appears that the global implications of expanding worldwide industrial activities and the projected growth in world population provide strong impetus for increasing our knowledge about how man's activities on earth -- quite independent of aerospace and jet aircraft development -- affect the stratosphere.

The Panel on Environmental Quality benefited from substantial staff work done at the NASA Langley Research Center on a preliminary plan (unpublished) for a stratospheric research program. Information was made available on previous work, on the present status of stratospheric research, and on unresolved problems. Although we had no opportunity to scrutinize in detail this preliminary plan, we believe that its basic organization into categories of (1) measurements, (2) modeling, and (3) fundamental physical processes addresses basic needs as we understand them.

We have shown in Table V pollutants with a potential global impact on environment, the regions in the atmosphere where the pollutants may be found, the degree of accuracy necessary to measure them, and the reasons why we are concerned about each one. Principal users and basic needs of each user within five categories are included in Table VI.

Pollutant Constituent	Region of Atmosphere	Accuracy	Problem
CO	Troposphere and stratosphere	10 ppb	Is concentration changing due to man's burning of fossil fuels? Determine destruction processes in stratosphere.
HNO_3	Stratosphere	1 ppb	Determine effect on ozone concentration. Does it influence aerosol formation?
<HC>	Stratosphere	Determined only for CH_4; other <HC> not yet detected in stratosphere.	Do they influence aerosol formation?
CH_4	Troposphere and stratosphere	0.5 ppm for troposphere 0.2 ppm for stratosphere	Participates in photochemical reactions in lower atmosphere. Influence on stratospheric H_2O and O_3 distribution.
Fluorocarbons	Total	0.001 ppb	Probably accumulating due to man's releases.
N_2O	Stratosphere	50 ppb	Determine rate of photodissociation in stratosphere.
CO_2*	Troposphere	0.5 ppm	Measure its increase, a factor in climate change.
SO_2*	Upper troposphere and stratosphere	0.5 ppb	Formation of particulates in stratosphere from SO_2 carried upward from troposphere or injected by volcanoes and supersonic aircraft.
O_3*	Stratosphere	Total content, 1%; distribution with height, 10%	What causes long-term changes in distribution? Is there correlation with solar activity?
H_2O*	Stratosphere	Total content, 20% Much less than 20% Distribution with height, 0.5 ppm	Determine effect on ozone concentration. Determine effect on radiation balance. Determine influence on particle size distribution in sulfate layer.
NO_x*	Stratosphere	10 ppb (for NO_2 and NO)	Determine effect on ozone concentration.

*Accuracy estimate speculative or long-term

TABLE V GLOBAL POLLUTANTS IN TROPOSPHERE AND STRATOSPHERE

(From *Remote Measurement of Pollution*, NASA Publication SP-285)

Principal Users	Basic Needs: Impact of Aerospace Operations	Physical Processes (Fate and Persistance)	Climatic Influence	Long-Term Trends and Effects	Man vs. Natural Loadings
Federal agencies					
DOT	X	X	X	X	
NASA	X	X	X	X	X
DOD	X	X		X	
NSF		X	X	X	X
NOAA		X	X	X	X
EPA	X	X	X	X	X
Department of State	X		X	X	
AEC		X	X	X	X
Research and scientific investigators	X	X	X	X	X
National Center for Atmospheric Research (NCAR)		X	X	X	X
U.N. organizations		X	X	X	X
Aerospace industry	X	X		X	
Environmental consultants	X	X	X	X	X

TABLE VI USERS AND NEEDS FOR AIR QUALITY MONITORING IN STRATOSPHERE AND TROPOSPHERE (GLOBAL DATA)

WATER QUALITY

Major changes in the approach to water quality management have taken place in the United States -- changes whose impact will be almost as dramatic as the space program itself. Analogous to the goal of achieving a moon landing within the 1960's, the U.S. now has a goal of total water pollution control from point sources by 1985. Although there are many who consider the goal as unnecessary from a scientific point of view and/or unwise from an economic point of view, there should be little doubt that the goal is achievable or at least approachable.

The goal was established by the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500, October 18, 1972). The Act not only sets national goals and policies but spells out specific steps for implementation and a timetable for achieving results. In addition, states have passed parallel and supplementary legislation to assist in meeting the national goals. Various federal laws related to toxic substances and ocean disposal also support the national goals.

Basically, the Act spells out in an explicit manner that our approach to water quality management is now based on the concept that we will keep pollutants or impurities out of the environment to a maximum extent. By contrast, the prior policy allowed the discharge of pollutants based on the carrying capacity of the environment. Dilution is no longer an acceptable method for waste disposal although it may be necessary in certain situations. Nondegradation is a very significant factor in water quality management.

The Act is very comprehensive. A limited number of provisions which have a direct bearing on the needs are identified here, as follows:

Dischargers required to have permits by December 31, 1974.

All municipal sewage treatment plants required to have secondary treatment by 1977.

Best practicable control technology currently available must be applied by industrial sources by 1977 and by municipal sources by 1983.

Best available technology economically achievable must be applied by industrial sources by 1983.

All waters to be suitable for recreational purposes, fish, and aquatic life by 1983.

Discharge of pollutants from point sources eliminated by 1985.

Control of toxic and hazardous materials.

Ocean discharge limitations (Marine Protection, Research, and Sanctuaries Act of 1972).

Residue disposal.

Although there may be some slippage in meeting the dates, total pollution control may not occur, the National Commission on Water Quality (which is to report to the Congress in 1975) may recommend changes in the Act, and current court cases may result in changes in the interpretation of the Act, the Act *is* being implemented by the states and by the federal government. We can expect the following to occur within the next *five* years:

Major reduction in pollution from all point sources, both industrial and municipal, including combined and storm sewers;

Significant reduction in pollution from diffuse sources such as urban and rural runoff, and activities related to agriculture, mining, oil and natural gas, and construction; and

Almost total elimination of discharge of toxic substances.

Within *two* years we may expect to have a monitoring program which will include:

Over 40,000 industrial plants (point sources);

Over 13,000 municipal sewage treatment plants (point sources); and

Over 10,000 water quality stations operated by local, state, interstate, and federal agencies (ambient).

USERS OF MONITORING AND NEEDS

Water quality monitoring is required for regulation and enforcement, planning, forecasting, and scientific inquiry. Users include all government agencies, local, state, and federal, who are responsible for these activities. The data also are useful to industries that in any way affect water quality. These include manufacturing, agriculture, fishing, commerce, mining, and recreation, for example. Concerned international groups and the public at large, particularly persons interested in ecology and conservation, also would and want to have access to the water quality information.

Specific needs include the identification and location of pollution sources (point, diffuse, and natural); the measurement of specific parameters at point sources and in the environment (streams, rivers, lakes, estuaries, coastal waters, oceans, and ground water); and the collection of data to assist in the development and verification of models by which we can convert emission levels to corresponding ambient levels.

Regulatory and enforcement requirements include the measurement and quantification of specific water quality parameters at both point sources and in the water environment. To be adequate for these functions, the instrumentation should meet the following requirements:

Spatial resolution:	0.5 m to 100 m
Temporal resolution:	1 second to 3 months
Area coverage:	0.5 km sq. to 1/3 of earth's surface
Vertical resolution:	0.5 m to 2 m
Delivery time of data:	real-time to 1 year
Concentration sensitivity:	10^{-9} g/m^3 to 0.1 g/m^3

In addition, the instruments should have all-weather, day and night capabilities and should be sensitive to changes in turbidity, color, etc. The data obtained should be directed toward the determination of pertinent quality parameters, physical, chemical, and biological.

A number of requirements and problems in water quality management for which a spatial monitoring component may be desirable or necessary include:

- Spills of toxic and hazardous materials and other accidents and episodes
- Optimal location of *in situ* sensors
- Verifying location of *in situ* sensors
- Strategic location of facilities for spill cleanup
- Sediment sources
- Red and toxic tides
- Biosensor application in wildlife and in fish and aquatic life
- Fish kills
- Pollution from boats, vessels, and marine structures

Data from a satellite-based sensor may be essential to the solution of certain other environmental quality problems. Some of these are listed in Appendix C.

MONITORING COASTAL ENVIRONMENT AND OPEN OCEANS

Two areas in which there are high priority needs for water quality measurement and monitoring are (1) pollution sources near coasts and (2) the oceans (the ultimate sink for many of the pollutants). Changes in open ocean quality will be small even if direct discharges from coastal sources, runoff from lands adjoining oceans, and pollutants discharged through rivers are considered. Any changes in ocean quality or the effects of those changes will first appear and will be concentrated in estuaries and near-coastal zones. Therefore, particular emphasis must be placed on monitoring these parts of the coastal environment.

An understanding of coastal water dynamics is needed in solving the problems of liquid waste disposal and power plant siting. Rapid initial mixing and dilution are well understood but it is difficult in practice to detect what happens to the subsequent plume, often at depths of 20 meters to 40 meters. The plume may persist for several kilometers and the width may vary from a few to hundreds of meters. Sensing probes are needed for accurately detecting such plumes. The information will be particularly valuable not only if the plumes can be detected but also if the nonpoint source inputs from air and land to the oceans can be synoptically obtained.

Ocean current patterns are of great importance to liquid waste dispersion, diffusion, precipitation of remaining solids, etc. Definitive information about water movements will greatly aid in monitoring existing discharges, in setting ocean discharge standards, and in design of future works. Today very little is really known about the sources of sea water in any given coastal area, how long it stays in an area, and how quickly it diffuses when polluted with foreign materials.

Although the Earth Resources Technology Satellite (ERTS-1) was not specifically designed for water quality nor marsh investigations, it may be seen from Table VII that some degree of success was achieved even in these applications. The encouraging results achieved so far with ERTS-1 and other space systems lead us to conclude that additional effort toward further development of space systems to monitor the coastal environment can help significantly in satisfying the requirements outlined herein.

Temperature

The temperature of materials introduced into open ocean water may have some ecological impact but is considered unimportant by most authorities.

Degradable Organic Material

Degradable organic material may be either dissolved or suspended. The oxygen consuming characteristics are not considered to be significant in open ocean or coastal waters but can be significant in estuaries. Particulate matter can result in reduced water transparency; however, low transparency is generally typical of coastal waters. The organic material may stimulate phytoplankton growth and enhance the biomass of the area.

Concentrations of material from waste disposal plants are of the order of 100g/m^3 or less. Rapid initial dilution may reduce this value to between 0.01 g/m^3 and 1 g/m^3. Thus, the detection range must be from 0.01 g/m^3 to 100 g/m^3.

Floatable Material

Minor but important components of waste water discharges are buoyant and appear on the ocean surface as thin films. Materials included are oil, waxes, tars, fats, greases, and particulate debris. The slick or oily surface is visibly

Parameters Discriminated and Correlated	Application to Coastal Environment Monitoring
Suspended Sediment Concentration	
Concentration maps prepared by matching multispectral scanner (MSS) band-5 image radiance with suspended sediment concentration and with other water properties sampled from boats and helicopters	To verify and extend sediment transport models and monitor water quality
Current Circulation Patterns	
Good agreement with predicted current circulation as function of tide and wind	To monitor and verify predictive models of oil slicks and other pollutants
Water Mass Boundaries	
Foam lines along convergent boundaries with toxic substances	To modify hydrodynamic models of estuaries wherein toxic substances are concentrated at boundaries
Waste Disposal Plumes	
Sludge and acid plumes observed in MSS bands 4 and 5	To study dispersion of wastes dumped along continental shelf (sludge and acid dumps coordinated with ERTS-1 overpasses)
Wetlands Vegetation	
Maps of wetlands showing five vegetative species and three other properties prepared	To develop marsh relative-value model and plan wetlands development
Land Use and Environmental Impact	
About 12 coastal land use categories mapped with use of ERTS digital tapes with accuracy of 85% or better.	To monitor land use, its impact on marsh environment and coastal erosion

TABLE VII TYPICAL RESULTS
OBTAINED WITH ERTS-1 IN WATER QUALITY INVESTIGATIONS

displeasing and when concentrated in convergence zones contributes to littering of the ocean and subsequently of the shore.

Fatty and waxy substances are not foreign to the sea surface and are produced in large quantities as a part of the sea's natural ecology. Natural sea slicks are not uncommon.

Present methods of distinguishing between natural and man-induced floatable materials are difficult and subject to error. A *real need* exists to develop space system capability to measure and identify various types of ocean slicks. If developed, this capability should be extended to distinguish between man-induced petroleum spills and petroleum contributed to the world's oceans by natural seeps. This should be feasible because petroleum from different sources varies in characteristics, such as sulfur content, metals, etc., as do refined products from crude oils. Monitoring the movement of such slicks is required for verifying protective models and for real-time surveillance and cleanup operations.

Nonbiodegradable Organic Materials

A principal class of relatively nonbiodegradable organic materials is the chlorinated hydrocarbon series such as DDT and polychlorolbiphenol (PCB). These materials are retained if consumed in the food chain and their concentration is accumulative.

Present regulations in California limit chlorinated hydrocarbons in wastewater effluents to 0.002 g/m^3. Initial dilution reduces the concentration by a factor of at least 100. Detection of this material at a depth of 20 meters to 40 meters is considered difficult.

Trace Elements and Compounds

Metals that are considered important trace elements are arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. Cyanides and phenols are also important. These elements and compounds, if present in sufficient concentration, either inhibit or destroy marine life and, consequently, rather severe restrictions are imposed on their discharge. Regulations at present in California specify from 0.1 g/m^3 to 0.005 g/m^3 for these materials. If wastewater effluents have an initial dilution of 100 to 1, the subsequent concentrations range from 0.001 g/m^3 to 0.00005 g/m^3, the latter value representing background sea water concentration. It thus appears unlikely that any remote sensing equipment can be developed for these materials.

Water Turbidity

Water turbidity limits the depth over which photosynthetic activity takes place in coastal waters and also serves as an indicator of water quality. It limits the ability of remote sensors to penetrate water in order to provide the needed third dimension. Penetration depths in most coastal waters range only from about 1 meter to 5 meters and even that range is at only visible wavelenths.

Recently, ERTS-1 has been successfully employed to monitor suspended sediment concentrations and current circulation patterns in the upper few meters of the water column. It is desirable that these techniques be further refined, since suspended sediment and its movement significantly affect marine life.

Chlorophyll and Algae

Concentrations of chlorophyll and algae in various forms can indicate the productivity or pollution of coastal waters. Both properties have been successfully mapped from aircraft and satellite altitudes. It is important that sensors be developed to monitor concentrations of not only chlorophyll-a, but also of other chlorophylls and pigments. Tunable laser systems for detecting chlorophyll have been used at low altitude. These systems should be improved in order to be usable from higher altitudes than at present.

WETLANDS MANAGEMENT

Commitments to environmentally sound coastal land management that have been generated in federal and state governments over the past few years have produced a demand for accurate and complete data on which to base policy decisions. Coastal wetlands, in particular, have been the subject of much controversy and litigation. The lack of survey-type information over broad areas of the wetlands is evident. Wetlands of the type found along the east coast and elsewhere in the U.S. are well suited to monitoring by remote sensing techniques, particularly by multispectal analysis. The uniform flatness of marsh topography eliminates variations in reflectance due to sloping surfaces and shadows. The most common species of marsh plants are few in number so photo-interpretation is simplified. Environmental changes, whether natural or man-made, generally take place over large horizontal distances in a marsh. Therefore, zones of relatively uniform vegetation or land use are usually large enough to be discernible, even in satellite imagery. In particular the morphologies of the major species are different enough that the plants have distinct reflectance characteristics. Thus, multispectral imagery can be readily used to make detailed wetlands maps showing vegetation growth patterns which are related to local environmental factors. As a result, automated techniques have been successfully employed to prepare from ERTS-1 digital tapes precision map overlays which show more than 12 categories of coastal land use and vegetation and have accuracies higher than 85 percent for all categories mapped. The most urgent improvement required is an increase in resolution from about 100 meters to between 20 meters and 50 meters. The ERTS-1 coverage cycle of 18 days, even with losses due to cloud cover, is more than adequate, since most land use managers are satisfied with annual updates of their land use maps.

LAND QUALITY RELATED TO USE

Land use planning and management are determining factors in the quality of man's environment. The kind, extent, and location of agricultural, commercial, domestic, industrial, recreational, and transportation development affect air and water quality as well as the productivity or deterioration of the land. Farm and urban water runoff may cause damaging land erosion and chemical as well as sediment loading of streams and contamination of domestic water supplies. Domestic and industrial water outfalls typically cause river pollution while leaching of municipal refuse disposal sites may pollute aquifers. Air pollution resulting from dispersed residential space heating is generally more troublesome than that from an efficient central heating station. Concentration of industrial sources of air pollution upwind of a community usually causes greater air quality deterioration than dispersion or location downwind. In most metropolitan areas the overwhelming source of air pollution is the exhaust of automobiles, buses, and trucks traveling on freeways, arterials, and downtown roadways. The transportation system, vehicle mode, distribution and density of commercial centers, location and allocation of planting space for roadways, and provision of parks and recreation areas influence the severity of transportation-created air pollution. Amelioration of pollution and thus an improvement in environmental quality can be achieved by consideration of weather and climate and by utilization of the dynamics of the carrying capacity of air, water, and land.

Land may be used for the disposal of wastes in the following ways:

- Application of waste waters
- Application of organic residues
- Disposal of residues, such as toxic and hazardous materials, tailings, culm, etc., and solid wastes

Some of these uses may be beneficial but others have a potential for causing environmental problems associated with the disposal of solid wastes. These problems may be related to (1) topography, as in changes in land surface and in land quality at surface (humus); (2) leachates, as in varying composition and in presence of salts and dissolved organic material; generally require sensing at varying depths in land; (3) gas generation, as when appreciable quantities of methane and carbon dioxide produced in some disposal sites pollute underground water and gases escape through temporary or permanent ground cover; sensing of escaping CH_4 and CO_2 at ground level by remote sensors can help delineate problems with old sites.

PUBLIC HEALTH

Habitats on land and in coastal waters are strongly influenced by climatic conditions and by air, water, and land quality. These habitats and their ecosystems usually display associations which become useful environmental signatures. Chlorophyll-a descriptors have demonstrated the ease with which plant communities can be identified and have led to the mapping of their discrete vegetative components. Information on specific soil, water, and light requirements of certain plant species allows detailed descriptions of habitats and, in turn, opportunities to identify animal communities associated with them; e.g., use of chlorophyll detection for remote sensing of plant communities in the vicinity of New Orleans has provided a fast and ready means of identifying the breeding grounds of mosquitoes and thereby has enabled an economically efficient chemical control of that obnoxious insect.

The soil, temperature, and moisture conditions required for the development of certain insects in particular habitats may provide a means of early detection and application of appropriate biological or chemical control; e.g., the hatching of the cattle screwworm under certain habitat and environmental conditions may be detected, by remote sensing, in advance of population buildup and control may be effected by release of sterile males in specific geographical areas. The fire ant, a scourge of the southeastern U.S., exhibits epizootics* and frequently requires extensive chemical control by aircraft applications of pesticides that are only nominally hazardous. Considering the life cycle of the fire ant and the environmental parameters of its habitat may reveal a remote sensing capability for detection and early control through localized applications of pesticides. Thus, the public health hazard incurred through inadequate and inappropriate contemporary control procedures may be reduced.

Disease epidemics of economic crops may be controlled through timely sensing of foliage color changes together with measurement of air temperature, relative humidity, and possibly the duration of surface water films. The feasibility of this type of control should be evaluated for its potential in identifying affected areas and in scheduling of the use of chemicals against foliage fungus blights, such as downy mildew of tobacco, late blight of potatoes, and powdery mildew of grapes. Remote sensing of chlorophyll may also be a useful tool in assessing the

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*A disease that affects many animals of one kind at the same time.

occurrence, distribution, and economic value of damage to forest crops that are exposed to toxic dosages of fluorides, ozone, or sulfur dioxide.

The application of habitat and environmental sensing should be considered for purposes of controlling vectors* responsible for critical disease in man. The success of the mosquito control program in Louisiana suggests that timely location of breeding grounds for vectors known to transmit pathogens to human beings may provide opportunities to treat chemically the breeding grounds and thus forestall epidemics. A seriously debilitating disease in regions of Africa is an insidious and devastating blindness caused by an organism which is transmitted to man by a black fly. The insect's breeding areas and life cycle are associated with identifiable aquatic habitats and particular environment conditions. The sensing and reporting of events leading to a buildup of black fly populations will enable a concerted, targeted, and preventive chemical control action. The application of space technologies to the control of this age-old disease with its appalling toll will indeed be a signal achievement in public health and demonstrate a truly humanitarian aspect of the space program.

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*Life-forms (usually insects) capable of carrying disease-causing bacteria or viruses.

MEASUREMENT TECHNIQUES

UTILITY OF EXISTING SPACECRAFT

Although measurements of environmental quality from space have not been planned as primary goals of satellites launched to date, useful data have nevertheless been obtained in a number of instances. These data have included air, water, and land quality information. There is no doubt that, particularly in the case of air and water pollution, a remote sensing system designed to evaluate environmental quality will yield far more useful data.

The data collection system (DCS) on ERTS-1 has been very successful. It has shown that low-cost ($2,000 to $3,000) surface platforms can transmit data to a spacecraft for subsequent transmission to a ground station. The large number of data stations, in addition to the relatively low bandwidth of this type of data, make this kind of system very attractive for environmental quality monitoring.

MONITORING SYSTEM CONCEPT

Remote sensing from spacecraft and the DCS approach will probably be most effective when used in conjunction with lower altitude sensing using aircraft and balloons and with *in situ* sampling within the total system. Figure I is a simplified block diagram showing the flow of data in an environmental monitoring system. In this case, some *in situ* sensors send data directly to the user while others transmit them to a spacecraft DCS. Two ground terminals are shown in Figure I. One receives a high-bandwidth remotely sensed data from the spacecraft for subsequent processing by an agency data center. The other is under the direct control of the user and receives DCS data and low-bandwidth remotely sensed data. Agency aircraft are used to collect data with both remote and airborne *in situ* sensors and to transmit them to the center (in some cases via a DCS) for processing and later distribution to the user.

It is clear that a spacecraft data collection system which monitors environmental platforms is a key element of the total system. In all likelihood, however, remote sensing can be used to effect a substantial reduction in the number of platforms required. This would be accomplished by (1) using remotely sensed data to help select optimum platform sites, (2) using remote measurements to interpolate between platform measurements, (3) comparing remote data with *in situ* data from platforms so that a relationship can be established and the platform eventually removed.

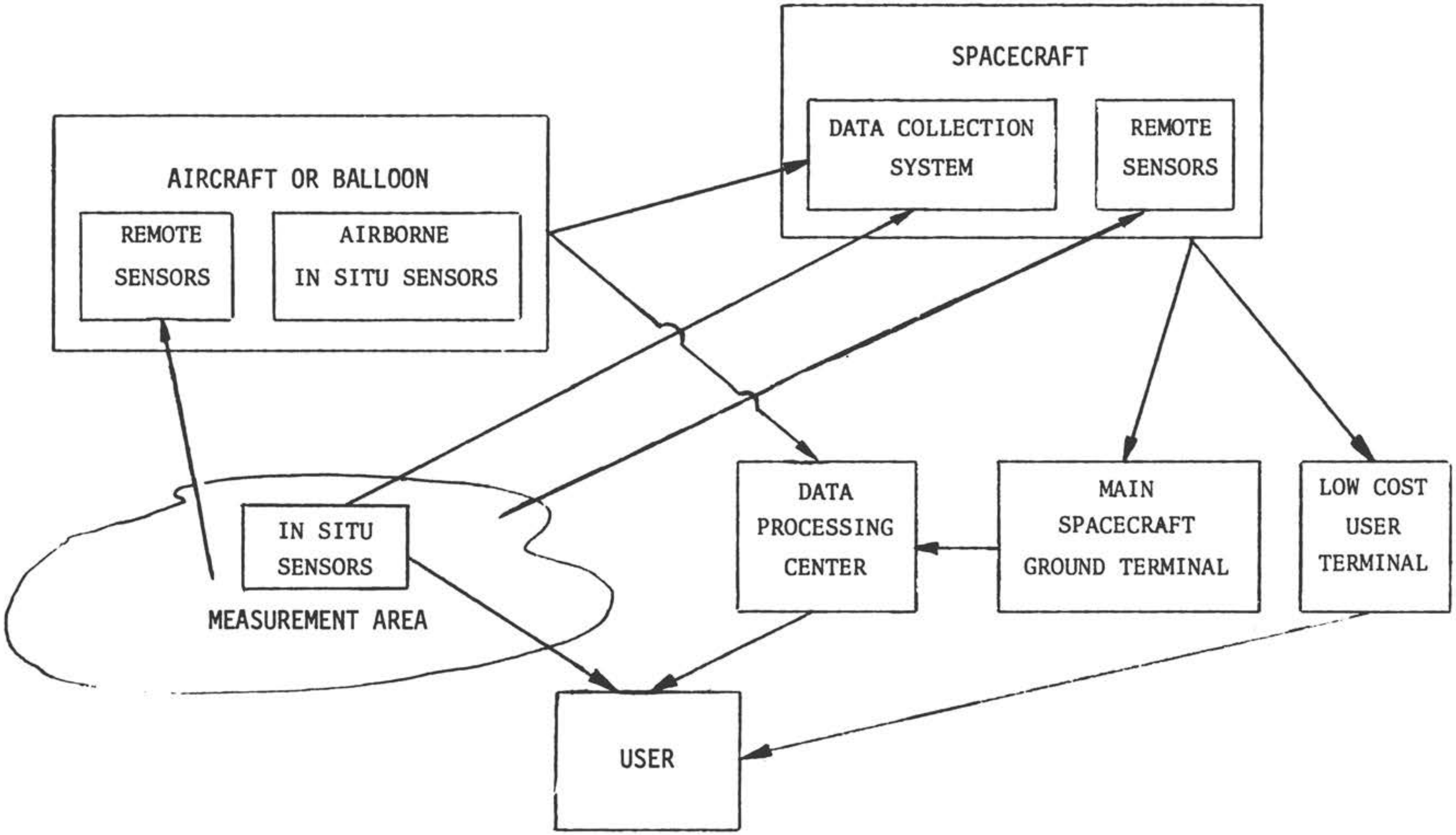

FIGURE I DATA FLOW IN ENVIRONMENTAL MONITORING SYSTEM

TRENDS IN REMOTE SENSOR DEVELOPMENT

Certain trends in the development of remote sensors for pollution measurement appear to offer particular promise in terms of user needs described in the preceding sections. These trends should be encouraged. They are the basis for the following recommendations:

Techniques for vertical sounding of gaseous air pollutants, particularly below the stratosphere, should be investigated.

Investigations of lidar for aerosol measurement should continue.*

The longer "dwell time" available for instruments to make a measurement when in geosynchronous orbit should be fully utilized to improve sensitivity (many environmental quality applications require geosynchronous orbits for coverage purposes, in any case).

Radar and passive microwave measurements should be vigorously pursued wherever applicable because of their all-weather capability.

Sensors operating in the region of water transparency between 0.4 μm and 0.7 μm (multiband lidar, high-resolution spectrometers) should be developed for remote measurement of subsurface phenomena.

None of these recommendations should be taken to construe that the Panel believes that an exclusively spaceborne system will be the optimum solution to the environmental monitoring problem. As stated before, a system involving a satellite data collection system, remote sensing from both aircraft and spacecraft, and *in situ* measurements as required will probably prove most effective. Thus, the user needs described in this report should be carefully reviewed in terms of each method of measurement, both in current and future time frames.

Sensing of Air Pollution from Space

The first quantitative measurements of air pollution will be made from space by the NIMBUS-G satellite in 1978. Table VIII shows approximate minimum concentrations of pollutants to be detected as well as the horizontal resolutions to be obtain by each NIMBUS-G instrument. It should be noted that the two instruments giving vertical resolutions of 1 kilometer are limb scanners and, as such, will only rarely be able to make measurements below the stratosphere because of cloud cover. The Gas Filter IR Radiometer, which views the entire vertical column, sees to the surface but is unable to resolve vertically.

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*Light detecting and ranging; analagous to radio detecting and ranging (radar) but using the coherent light output of lasers.

Because of lack of vertical resolution, effective minimum measurable concentrations are higher than the values shown in Table VIII. For example, if a pollutant fills the field of view of the instrument but is homogeneously distributed below an inversion layer at 3 kilometers altitude, the effective minimum measurable concentration is higher than the value shown in Table VIII by a factor of about 3. Similarly, because the horizontal resolution is 115 kilometers features of limited expanse, such as plumes, must have minimum concentrations greater than the values of Table VIII by a factor of

$$\frac{(115)^2}{LW}$$

where L and W are the horizontal dimensions of the feature in kilometers. Thus, the planned instruments on NIMBUS-G will be of very limited utility for measurements below the stratosphere. For example, a sulfur dioxide plume 3 kilometers wide, 3 kilometers thick, and 25 kilometers long must have an average concentration of 1.6 ppm to be detectable. Also, the frequency of measurement will be less than that desired for tracking low-altitude pollutants.

If only stratospheric pollution is considered, these problems almost disappear. The pollutants are much more dispersed and in most cases should completely fill the field of view of the instrument. In addition, frequency of coverage should be quite adequate to cover the rates of change anticipated in the stratosphere.

In order to make measurements at lower altitudes and with greater frequency, techniques for use in a geosynchronous satellite should be investigated. Resolution may be improved, while sensitivity is maintained or improved, by taking advantage of the longer time available to make an individual measurement. Studies of both gas-filter-correlation and interferometer techniques, operating in such a low-frequency measurement mode, may yield new ideas of low-altitude pollutant measurement from geosynchronous orbit and perhaps result in both improved vertical resolution and sensitivity.

The great distances involved in measurements from geosynchronous orbit make the use of laser methods appear rather unpromising. However, the availability of very high electric power in orbit may make possible the use of Raman spectroscopy and of lidar for aerosol profiling and resonance measurements.

As currently planned instrumentation develops, the ability to measure additional species may be expected so that H_2S and NO will likely be eventually included with the gases of Table VIII. Aerosol measurements from space, as currently planned for NIMBUS-G with the use of limb-scanning and occultation techniques, will be limited to stratospheric and mesospheric regions. Newer multispectral methods show promise of yielding both size distribution and complex refractive index of the aerosol.

The only currently conceived methods of investigating lower-altitude aerosols from space involve laser backscattering or measurement of target polarization from a range of viewing angles. Both methods are in process of development. The laser probably offers the best potential and, with multiple-wavelength capability, may yield information on the nature of aerosols as well as on both horizontal and vertical distribution.

Year	Pollutant	Concentration (in ppb)	Instrument	Horizontal Resolution (in km)	Vertical Resolution (in km)
1978	CO	10	Gas Filter IR Radiometer (NIMBUS-G)	115	None
	CH_4	140			
	SO_2	3			
	NH_3	2			
1978	O_3	± 10% of total	Limb Radiance IR Radiometer (NIMBUS-G)	≃ 500	1
	NO_2	1			
	HNO_3	1			
	H_2O	?			
1978	Aerosols	± 15% of total	Solar Extinction Photometer (NIMBUS-G)	≃ 500	1
1980	Aerosols	± 10% of total and size distribution	Advanced Solar Extinction Photometer (Earth Observatory Satellite)	≃ 500	1

TABLE VIII PROBABLE CAPABILITIES FOR AIR POLLUTION MEASUREMENT FROM SPACE

Sensing of Water Pollution from Space

Currently planned measurements of water pollution from space are very limited and are shown in Table IX. With the exception of the coastal zone ocean-color sensor on NIMBUS-G, other measurements are by-products of experiments not related to pollution. However, other remote sensing techniques available are in process of development which can be applied to water pollution measurement and should be pursued include

Passive microwave measurement of salinity and temperature; detection of oil slicks

Lidar; vertical profiling of suspended solids

Laser-excited fluorescence and Raman scattering; identification of oil spills and plankton species

Reflection spectroscopy; evaluation of thickness of oil spills; identification and concentration of plankton species.

Development of new methods of water pollution measurement from space should concentrate on the following three areas:

Development of instrumentation which can be used from geosynchronous orbit; this will allow the frequent coverage necessary in monitoring operations and also will enable more sensitive measurement by allowing long instrument time constants.

Development of instrumentation and techniques to enable the vertical profiling of water bodies as discussed in the next section.

Development of all-weather measurement capability, which is also of importance in monitoring operations.

Vertical Profiling of Subsurface Pollutants

In order for electromagnetic radiation to penetrate the surface of water by more than a fraction of a wavelength, radiation wavelengths between 0.4 μm and 0.7 μm must be considered. At shorter wavelengths, molecular scattering acts as an effective attenuator and, at longer wavelengths, the absorption coefficient becomes very large. Within this constrained spectral region, several other important characteristics obtain: a large source of energy, the sun, emits its peak output; a window of almost complete atmospheric transparency covers the region; and wavelengths are short enough that electromagnetic instruments operating in this region can be physically small.

It thus seems that an effort should be made to determine if this region (at wavelengths between 0.4 μm and 0.7 μm) can be used to measure the characteristics of subsurface pollutants. To this end, two tasks should be undertaken: (1) an investigation of the wavelengths of molecular rotational and vibrational bands of all chemical pollutants of interest to determine which, if any, fall within

Year	Pollutant	Instrument	Horizontal Resolution (in km)	Measurement Requirements
1977	Thermal	5-band multi-spectral scanner (ERTS-C)	0.24	18-day repeat coverage; $\pm$ 0.7° C accuracy
1978	Oil	Coastal zone color scanner (NIMBUS-G)	0.8	Location only
	Eutrophication		0.8	Chlorophyll-a $\pm$ 0.1 mg/m^3
	Red tide		0.8	Approximate concentration
1980	Sediment plumes	Thematic mapper (Earth Observatory Satellite)	0.03	9-day repeat coverage
	Thermal		0.12	9-day repeat coverage; $\pm$ 0.5° C accuracy

TABLE IX PROBABLE CAPABILITES FOR WATER POLLUTION MEASUREMENT FROM SPACE this region (it is realized that most may be expected to be at longer wavelengths), and (2) preparation of a mathematical model of a pulsed-laser backscatter experiment which would be used to determine how the concentration of particulates varies with depth and also, by utilizing two or more bands, to determine the concentration of certain dissolved pollutants.

Although it is emphasized that the chances of success of this investigation are modest, the usefulness of a viable scheme to remotely measure and map subsurface pollutants makes the effort of considerable importance.

USER ACCEPTANCE

The space applications program, as currently planned, is not moving ahead rapidly enough to have a major impact on the needs of existing programs for monitoring environmental quality, whether for enforcement, control, or economic benefit. At the same time, major new approaches that are technologically innovative and economically beneficial are not finding ready acceptance where they challenge established practices. The application of space technology for monitoring environmental quality is typical. A large number of sensors and instruments have been developed for specific purposes in different federal agencies. Each has demonstrated a unique measurement capability although within limitations. Generally, these instruments or systems now need to be calibrated and refined for adaptation to monitoring environmental quality. Their precision and accuracy can be modified to provide the specificity needed for measuring pollutants in the environment. The synoptic view afforded by remote sensing techniques can provide the overall perspective needed. Eventually, the capability should lead to better understanding of spatial and temporal parameters existing in our environment. Urgent and decisive action is required, however, if we are to achieve the technological innovations necessary to develop the potential that exists for monitoring environmental pollution, directly or indirectly, from space, aircraft, and ground systems. Education and training are needed among users in the public and private sectors. Also needed are effective communications between these users and various governmental agencies, local, state, and federal.

COSTS AND BENEFITS

The Panel did not attempt to estimate costs of remote sensing and data collection using spacecraft. To provide some measure against which to consider costs of R&D and of space systems, however, the Panel considered it useful to show the level of current or anticipated expenditures for environmental data collection and monitoring.

Expenditures for pollution control monitoring are currently estimated to be between $150 million and $200 million annually with an anticipated severalfold cost increase if the current state-of-the-art continues to be used. It is estimated that the federal (EPA) expenditure is $33 million, that of state and local governments is $65 million, and that of industries is $50 million to $100 million. Additionally, the federal budget includes annual expenditures in excess of $1 billion to increase understanding of the environment, which is necessary to protect and enhance its quality as well as to control pollution and curtail degradation. The annual construction costs for pollution control and abatement facilities are estimated at $15 billion to $25 billion over the next five years.

The manpower, energy, and other natural resources required to carry out these needs are enormous and in some instances may limit achievement of objectives. The benefits from more cost-effective solutions at even the 1 to 10 percent level, however, are so dramatic in terms of dollars alone that the justification for additional *well-planned* research, development, and demonstrations is readily apparent. Additional benefits that are more difficult to quantify include:

Rapid detection and response to environmental hazards

Public health improvement

Reduced manpower requirements

Reduced energy and resource requirements

Better understanding of carrying capacity of air and water.

TECHNOLOGY TRANSFER, TECHNOLOGY APPLICATIONS, AND SPIN-OFF

Although the subject is outside the scope of this study, the Panel on Environmental Quality suggests that the National Aeronautics and Space Administration can probably make a very significant contribution to national programs and efforts in environmental quality management through effective technology transfer, technology applications, and spin-off.

During the next 10 years, many billions of dollars will be spent in carrying out pollution control efforts, most of the funds being spent to install treatment facilities or new processes which reduce pollution. Needed are new and improved techniques that consider cost-effectiveness, reliability, energy utilization, resource and manpower requirements, technology, and systems in relation to:

Treatment processes

Materials of construction

Methods of construction

Methods of design

Operation of facilities

Data and information systems

Monitoring and surveillance

Resource recovery and reuse

NASA has demonstrated capabilities in management of large systems and in the handling of large amounts of data. These capabilities can be applied to environmental quality management and should be offered to these agencies, organizations, and individuals responsible for developing or carrying out programs to monitor and control pollution.

SUMMARY

Recent passage of major legislation at federal and state levels and initiation of action programs at federal, state, and local governmental levels and by industries are moving us at an accelerated rate to a cleaner environment. An implementation schedule has been established wherein most of our goals will be met within 10 years. It has been projected that in excess of $100 billion will be spent during the next decade for pollution control.

The Panel on Environmental Quality has reviewed the needs of major users of environmental quality data, reviewed recent progress in environmental quality programs, and identified specific areas where current and evolving space technology can contribute to achieving national environmental goals. The National Aeronautics and Space Administration (NASA), recognizing the need for environmental quality monitoring, has been carrying out cooperative programs to apply space technology to meet user needs. In reviewing the NASA program, as well as related programs, the Panel has concluded that substantial progress has been made in developing sensors and systems for air quality monitoring in the stratosphere. In contrast, the development of sensors and systems for water quality monitoring is lagging. The Panel has identified future needs and made recommendations for further systems development. In addition, the Panel has identified an immediate need to use state-of-the-art technology to place in operation improved and expanded programs for monitoring air and water quality to meet enforcement and regulatory requirements set up by the federal government and by the states.

The need and opportunity for the application of more cost-effective solutions to the problems of pollution control and public health are greatest today and in the near future, although there will always be a need for improved solutions. Accordingly, for the effort to have a significant impact on pollution control programs, the timetable for using space technology in environmental quality monitoring must be greatly accelerated.

CONCLUSIONS AND RECOMMENDATIONS

MONITORING SYSTEMS

The Panel on Environmental Quality offers the following conclusions concerning monitoring systems:

The feasibility of collecting useful data on air, water, and land quality from remote sensors in orbiting satellites has been demonstrated.

The feasibility and value of sending environmental quality data from *in situ* monitors to data receiving stations via satellite relay have been demonstrated.

Monitoring and surveillance are necessary to satisfy regulatory and enforcement requirements for environmental quality, to establish baselines, and to obtain data on trends. Monitoring requirements include:

A. Location and identification of pollution sources and measurements of emissions (for point, diffuse, and area sources) of both man-made and natural origins; specifically,

(1) Remote sensing of spills of toxic and hazardous materials and other accidents and episodes, for which satellites have a quick and repetitive response capability.

(2) All-weather, day and night capabilities which are needed for many environmental quality monitoring systems.

(3) Vertical resolution from ground up, which is needed for air quality monitoring.

(4) Data on subsurface water quality at various depths, which are needed for water quality monitoring.

B. Measurement of ambient air and water quality, including chemical changes in pollutants with time.

C. Development and verification of models to convert emission levels to acceptable ambient levels.

D. Operational continuity in local, regional, and national programs.

E. Research bearing on future capability.

There is an immediate requirement to place in operation an improved and expanded program for monitoring air and water quality to meet enforcement and compliance regulations. The space applications program, as currently planned, is not moving ahead rapidly enough to have a major impact on this monitoring and control program. Systems that appear to be most feasible for the near future are ones which employ both remote and *in situ* sensors and collect data samples through combinations of surface stations, aircraft, and satellites.

Users of environmental quality data require a wide range of quality parameters -- physical, chemical, and biological -- which can be determined by using instrumentation of adequate spatial resolution, temporal resolution, area coverage, vertical resolution, concentration, sensitivity, and delivery time of data.

The scope of user needs has not been adequately reflected in current NASA programs for environmental quality measurements.

Some potential user agencies are not currently taking advantage of existing remote sensing techniques to the extent possible.

Massive amounts of environmental quality data are being collected and stored by many federal agencies without systematic reduction and interaction for potential users.

Widespread use of collected and stored data is discouraged due to difficulties in obtaining data in a usable form.

Based on these conclusions, the Panel makes the following recommendations:

That immediate steps be taken to make full use of the techniques and systems developed by NASA which are currently available for environmental quality measurement and monitoring, including use of both in situ and remote sensing capabilities.

That those elements of the space applications program which show promise in meeting enforcement and regulatory requirements for environmental quality be accelerated.

That better institutional arrangements be developed to provide a broader input from users into program planning.

That a more active interagency program be developed to assure utilization of the new cost-effective technology now available.

That a system be developed to assure to the extent practicable, regardless of which agency or organization has responsibility for collection or storage, all environmental quality data collected are compatible and are available in forms suitable for use by all who need them.

AIR QUALITY

The Panel offers the following conclusions concerning air quality:

More progress has been made in the program for monitoring air quality by remote sensing than in other environmental quality programs, due in a large measure to the existence of an established meteorological program and chemical and physical methods for detection and measurement of air pollutants. The relationship between air quality monitoring and meteorological programs has been strong and productive.

A well-developed R&D effort has been mounted for better understanding of natural processes in the stratosphere as they affect global climate and of potential effects on existing equilibrium of the increasing amounts of trace gases and particulates introduced into the stratosphere by man.

The research program on stratospheric environmental effects has received the most attention to date. This stems from several factors:

A. The fact that several major studies on potential global effects of environmental pollution have had a dramatic impact in attracting the attention of both scientists and politicians.

B. Recognition that space-based systems offer an unique capability for addressing stratospheric problems.

C. Awareness that a program is needed to assess the potential environmental impact of injecting man-made materials into the stratosphere.

The most immediate air quality problems involve sensing and controlling the pollutants in the layer of the troposphere nearest the earth.

The following recommendations are based on these conclusions:

A vigorous program should be mounted for monitoring the troposphere to assess, on both regional and global scales, the impact of air pollution and of air quality control. Specific needs include the development of capabilities for all-weather, day and night measurements and sensors to measure the vertical distribution of pollutants from the ground up.

Plans for monitoring the environmental quality of the stratosphere should be pursued on a global scale. The first need is to make baseline measurements of stratospheric species, both gases and aerosols, with emphasis on the species involved in ozone chemistry. Follow-up measurements should be directed at determining the impact of man-made pollutants on significant stratospheric natural processes.

WATER QUALITY

The Panel offers the following conclusions concerning water quality:

There is an extensive need for improved techniques in water quality measurement.

Inadequate progress has been made in the development of *in situ* and remote sensors for water quality measurements.

The following recommendations are based on these conclusions:

That the current cooperative efforts between the Environmental Protection Agency (EPA) and NASA to meet requirements for water quality measurement be expanded and accelerated.

That a major effort be carried out to develop new and improved remote and in situ sensors to measure specific environmental parameters of water quality. Among the requirements for remote sensors are:

A. All-weather, day and night capabilities.

B. Measurements of subsurface water quality at various depths.

C. Spatial resolution to levels of 0.5 meters.

PUBLIC HEALTH

The Panel conludes that a need exists to determine the feasibility of using remote sensors to identify and report habitat and environmental features associated with the development of organisms and vectors responsible for diseases in man, animals, and plants. Timely sensing and reporting will enable public health and agricultural officials to mount appropriate control actions.

The Panel therefore recommends that *a research and development program be undertaken to identify vegetative types associated with habitats supporting vectors of human disease and pests that are of economic importance. Sensors should be evaluated for capabilities in detecting environmental parameters that contribute to epizootics and human-disease episodes.*

USE OF SPACE SHUTTLE

It is concluded that remote sensing instruments which may eventually provide and transmit reliable and accurate data will likely benefit from actual testing in outer space.

The Panel, while recognizing the needs for new and improved systems and technology and making recommendations for major new efforts to achieve cost-effective solutions, has not defined precise ways of meeting those needs. It is apparent that combinations of satellite data collection systems, remote sensing from both aircraft and spacecraft, and *in situ* measurements will be required to satisfy the diverse needs.

The Panel therefore recommends:

That the space shuttle be considered for use as a platform for testing sensors antecedent to their application in remote environmental quality monitoring systems.

That the space shuttle be considered for use in placing cost-effective remote environmental sensors in orbit.

That the potential of the use of the space shuttle be explored for studies of atmospheric reactions of ozone and the oxides of nitrogen and oxidation of projected stratospheric materials resulting from inadvertent and intentional release of pollutants.

That in developing systems and sensors to meet user needs, tests of feasibility, usefulness, efficiency compared to alternatives, possible amenability to application, and orderly development should be applied.

APPENDIX A

FEDERAL LEGISLATION PERTAINING TO ENVIRONMENTAL QUALITY

Federal Water Pollution Control Act, Amendments of 1972 Public Law 92-500, 33 USC 1251

Clean Air Act, as Amended by Public Law 91-604, 42 USC 1857b

Federal Environmental Pesticides Control Act of 1972, Public Law 92-516, 7 USC 136

Resource Recovery Act of 1970, Public Law 91-512, 42 USC 3251

Noise Control Act of 1972, Public Law 92-574, 42 USC 4901

Reorganization Plan #3 of 1970 (creating EPA), 42 USC 4321

Marine Protection, Research, and Sanctuaries Act of 1972, Public Law 92-532, 33 USC 1401

National Environmental Policy Act of 1969, 42 USC 4332(2)(C), 4344(5)(1970)

Public Health Service Act, Public Law 78-410, Sec. 361, 42 USC 264

APPENDIX B

RELATIONSHIPS WITH OTHER PANELS

The Panel on Environmental Quality and other panels of the 1974 summer study share problems and potential solutions in the following areas:

1. Weather and Climate

   Transport of pollutants, fate and persistence, prediction of air pollution incidents, control strategies, low-flow predictions

2. Land Use Planning

   Source of pollutants, sites for disposal of pollutants, wetlands definition and protection, environmental zoning, environmental futures, siting of power plants and other pollutant sources, identification of habitats harboring vectors of human diseases

3. Agriculture, Forest, and Range

   Source of pollutants, user requirements for water and air quality, utilization of waste water and organic residues, use of changes in plants as indicators of pollutants and pests

4. Inland Water Resources

   Water quantity-quality relationships, natural and cultural sources of pollution, mechanisms for pollutant transport, air quality effects on precipitation, prediction of water quantity, salt water intrusion, irrigation return flows, phreatophyte* control, flow augmentation

5. Extractable Resources

   Source of pollutants, user requirements for water and air quality

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*A deep-rooted plant which draws its water supply from the water table.

6. Marine and Maritime Uses

   Source of pollutants, user requirements for fish and aquatic life, ocean disposal of residues, power plant sitings

7. Uses of Communications

   Data and information transmission, control of treatment facilities

8. Information Services and Information Processing

   Need for *effective* systems to meet user needs

9. Institutional Arrangements

   Need for *effective* cooperation among government agencies, need for *effective* communication between users and government agencies

10. Space Transportation

    Provide transportation for remote sensing platforms to measure environmental quality, provide facility for sensor research and development

APPENDIX C

ENVIRONMENTAL QUALITY PROBLEMS WHICH CAN BE MONITORED BY SPACE SYSTEM COMPONENTS

Monitoring systems located in space may contribute to the solution of a number of environmental quality problems. These problems are related to the following:

1. Storm and combined sewer overflow
2. Algal blooms
3. Land application of waste waters and aerosols
4. Land application of organic residues
5. Land disposal of tailings and residues that may be toxic and hazardous or nondegradable
6. Mining, including mine drainage, fires in closed or abandoned mines, tailings, and culm
7. Sites of dumping into oceans
8. Wetlands
9. Flood plain
10. Siting of power and industrial plants; land use in such sitings
11. Subsurface water quality
12. Environmental impact statements
13. Salt water intrusions
14. Intermittent control technology
15. Critical flows in estuaries

16. Agricultural runoff from feedlots, irrigation return flows, and dust

17. Total burden in both water and air systems

18. Locations of natural sources of oils, nutrients, dissolved solids, brines, sediments, and gases

19. Carrying capacity of air and water

20. Precipitation and runoff relationships

21. Indicator biological systems