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Comprehensive environmental information, management and planning system for the San Antonio River Basin: an exploratory study

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A COMPREHENSIVE ENVIRONMENTAL INFORMATION, MANAGEMENT AND PLANNING SYSTEM FOR THE SAN ANTONIO RIVER BASIN: AN EXPLORATORY STUDY

By

ERNEST JOHN GERLACH, B.A.

ABSTRACT OF THESIS

Presented to the Faculty of the Graduate School of
Trinity University in Partial Fulfillment
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For the Degree of

Master of Science in Urban Studies

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ABSTRACT OF THESIS

This study will examine the concept and the feasibility of establishing a comprehensive physical environmental information, management, and planning system for the San Antonio River basin utilizing an extensive sensor system.

A sensor system--for the purpose of this paper--may be defined as a network of automatic devices designed to monitor certain environmental and man-made processes occurring within a specific geographical area.

The basic premise underlying this system is that certain kinds of data are essential for planning and subsequently managing extensive natural and man-made environments. In order to develop comprehensive regional plans, formulate environmental policies, and understand the complex and often dynamic interrelationships that characterize natural and artificial environments the planner and the policy-maker requires information of an extremely high quality in the shortest time possible. The system outlined in this paper is one approach designed to achieve this end.

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Introduction

Any system--whether it be a natural system such as a carefully balanced ecological/biological relationship, or a devised system designed by man--is characterized by two major properties, namely its behavior, and its internal structure. The behavioral properties of any system relate to its input-output functions. These functions are essentially stimuli-response reactions to the external environment. The stimuli impinging on a system represent an input, and the response of that system represents a reaction to the external stimuli. For example, in a natural system the climatic conditions occurring in a specific geographical area are the result of a number of interrelated environmental factors or stimuli such as solar radiation, prevailing wind patterns, rainfall, and cloud cover. These stimuli are modified by the intensity or degree of cloud cover, land form, forest cover, the presence of large bodies of water, land utilization-agricultural, recreational or urban, and the location of the area with respect to its latitude and longitudinal coordinates. These environmental elements are all interrelated in the sense that each contributes to the resulting phenomenon or response which in this example is the climate of a particular environment.

In defining a system--whether it is a natural system or a devised one--the idea of subsystems and their subsequent

linkages is an important conceptual tool. All systems are constructed by an additive process that links together single elements or components into a larger, more complex system. This means that systems can be changed by rearranging their internal components or sub-elements. For example, in a devised system, such as a transportation network, the addition of new pathways will change the intensity of flow through the original network. In a natural system, such as a river system, the addition of dams will have an effect on the ecological conditions of that river's system.

This process of creating larger systems is brought about by a "synthesis" of subsystems. The inverse process of reducing a given system into a series of subsystems is called "projection". The ability of systems to adapt and to link up components in order to create increasingly complex structures or hierarchies is an important conceptual tool in designing comprehensive environmental information, management, and planning systems. However, in designing such a system one must also take note that each system is defined by its own particular universe, and its own relationships with the external environment. These constraints limit, to some extent, the amount of interaction that any devised, man-made system can have with the natural environment. In addition, the transfer of information from one type of devised system

to another, or from the natural environment to a devised system represents only an approximation of the particular phenomenon or value being measured.

It is necessary to distinguish more precisely between the natural environment and the artificial or quasi-artificial environments created by man. A natural environment is essentially a "complex of climatic, edaphic and biotic factors that act upon an organism or an ecological community and ultimately determines its form and survival.[1]" An environmental system consists of a set of interrelated processes acting within a complex ecological relationship. This relationship is in a constant state of change, and each set of processes occurring within this relationship has some kind of repercussion upon some or all of its member variables.

The natural environment operates through the "laws of nature." It includes the whole biosphere as well as the atmosphere, and all of the interlocking ecological/biotic systems within the biosphere. Artificial, or man-made environments are those environments created by man for the purpose of sustaining and protecting himself from the natural world. These environments are also the result of man's socio-cultural responses to that world. The scale of these man-made environments range anywhere from the micro-systems created by man to protect himself from the rigors of the immediate environment

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[1] Webster's Seventh New Collegiate Dictionary (1969)

to the vast urban complexes which sustain a high order of social, economic, political, psycho-cultural, and institutional interaction.

The artificial environment unlike the natural environment is essentially a devised system. However, like the natural environment, it is characterized by its behavior and its internal structure. Both of these characteristics can, to some extent, be monitored and subsequently measured. For example, the intensity of crime in a certain neighborhood, income levels, housing quality in an urban area, transportation flows between metropolitan areas, and regional population densities are all phenomena that are common to man-made environments which can be monitored and measured over time. These phenomena are also interrelated within themselves as well as with the larger, more encompassing biosphere. Thus, the feedback or cybernetic relationships active within the artificial environment, and between the aritifical and the natural environment becomes extremely important in terms of its effect on both environments.

Although both kinds of environment and their related systems are basically different they cannot be totally isolated from one another except in very special situations. Both the biosphere and the man-made environment(s) impinge directly and indirectly on the life processes of the human body and upon the functioning of human societies. Conversely, human societies have a direct impact on the biosphere. Thus, both environments

may be said to be "under the influence of natural conditions and of human action and each of its component parts is influenced by its relations to the other parts of the complex."[2]

The San Antonio River basin will be the primary natural environmental system for the proposed information, management, planning system henceforward referred to as the IMP/S. The reasons for using this basin are twofold: First, it is a reasonably well defined geographical region; and, second, it offers a fairly well known ecological/biotic framework for the IMP/S. However, it should be emphasized that the IMP/S concept, as envisioned here, can be adapted to fit any defined geographical area or environment.

The IMP/S is designed specifically to monitor conditions in both the natural and artificial environments and then transfer these data to either an appropriate decision-making point within the system; or, stored for future use in a data bank. Thus, the question of how to gather, process, analyze and disseminate data concerning a broad range of environmental conditions to a diverse group of users is an important one. However, just as important is the question of determining the kinds of data that are needed, and how that data will ultimately be used.

Dr. Donald W. Pritchard, Director of the Chesapeake Bay Institute noted in a recent symposium dealing with water and air resource management, that "most environmental data have

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[2]Philip Wagner, The Human Use of the Earth (Glencoe, Illinois: The Free Press, 1969), pp. 153-154.

been collected under programs without adequate consideration of how the results will be used."[3] He then suggested a course of action:

> First, we must recognize that from a practical standpoint it is impossible to develop a single overall observational program involving even a limited number of environmental parameters and a restricted natural environment, that will provide data suitable for use in answering all, or even a considerable fraction, of the questions that need to be answered regarding the subject environment.[4]

It should be understood that the methods and timing of data collection suitable for the treatment of one question about the environment will seldom be satisfactory for dealing with other questions unless the data is organized into some kind of data relationship or file structure which would relate to the needs of a wide range of specialists. In order to expedite the flow of information from one point to another the user of the IMP/S must know in advance not only the kinds of information he will need, but also how this information will be used. What is implied here is some kind of system that would not only monitor and subsequently measure certain conditions in both kinds of environment, but also automatically assess and index this data in such a way that the user could readily interpret what is occurring within a defined spatial structure.

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[3]Donald W. Pritchard, "Interpretation and Conclusions," Proceedings of the IBM Scientific Computing Symposium on Water and Air Resource Management (IBM Data Processing Division, White Plains, New York, 1968), p. 241.

[4]Ibid.

In deciding on the specific information to be included in this system, two basic rules will be applied: the rule of parsimony, and the rule of specificity. The former states that only critical information should be included in the system to avoid information overload. The latter rule specifies that "for each piece of information included in the system, the dimensions or units in which it should be measured must be specifically identified to avoid ambiguity."[5] However, in applying the rule of "parsimony" one must make a careful distinction between the information requirements of the decision-maker, and the data needs of the analyst. Since both will be served by the same system, this distinction becomes important. The decision-maker generally requires very broad information inputs to arrive at decisions or formulate policy; while the analyst is more concerned with specific data inputs so that he can measure, test, and study discrete variables.

In order to carry out this environmental monitoring and information transfer function, the IMP/S will consist of six interdependent systems: a sensor network, a telemetry system, an operations or surveillance center, an environmental information and planning system, a comprehensive simulation system, and an interactive computer system.

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[5]Werner Z. Hirsh and Sidney Sonenblum, Selecting Regional Information for Government Planning and Decision Making (Institute for Urban Studies, Washington University, St. Louis, Holt, Rinehart and Wilson, 1970), p. 11.

The sensor network is used to monitor and measure environmental processes occurring within a defined geographical area or environmental grid. This grid is designed to serve as a framework for encompassing a geographical area with a multi-dimensional array of sensors. The grid also provides the basic environmental observation, monitoring, and measurement structure for the IMP/S.

The telemetry system is used to transmit data to and from the sensor network. The nucleus of the entire system is the surveillance center. This center houses the environmental information and planning system, simulation system, and interactive computer system. It also coordinates the operation of the telemetry network.

As the data is received at the surveillance center it is processed, indexed, compiled, and then transferred into the IMP/S. The IMP/S, in turn, is designed to store, retrieve on demand, and automatically disseminate pertinent data to individual specialists. In addition, specific data items are directed into specialized information subsystems. The simulation system--which is integrated into the IMP/S--is used to depict social, economic, and environmental conditions. In general, the system is designed to offer the analyst, planner, or environmental protection administrator a way to generate scientifically based estimates of current and future states of the natural and man-made environments. The interactive computer system allows the analyst to work directly with his

data. Using this mode the analyst would be able to interject new variables into a series of dynamic model structures. In effect, a "dialogue" is created between the analyst and the computer.

In summary, the basic premise underlying this system is that information is an essential factor in planning complex natural and man-made environments. This need requires the development and implementation of a very sophisticated man/computer/sensor interface with the external environment, and other program/agency networks that can facilitate the transmission of pertinent data from point A to point B. As a result, a system utilizing a complex array of sensors, computers, data banks, and interactive displays will be needed to handle the vast information inputs acquired by this network. By channeling this input through the system and programming it into meaningful information formats designed to describe a wide range of phenomena occurring within a specific geographical area, the user could expect to receive in the shortest time possible a realistic assessment of the area or phenomenon being monitored and measured.

STATEMENT OF THE PROBLEM

The purpose of this study is to: (1) Define the data requirements needed to evaluate, monitor, manage and plan for a specific geographical area; (2) develop a computer based system for collecting, storing, processing, and transmitting data from both natural and man-made environments; (3) study the current technology and application of sensing devices designed to monitor and measure specific environmental processes; (4) examine the possibilities for integrating a composite sensor network with a combined environmental information, management and planning system; (5) design a general environmental information, management and planning concept that would be applicable to a wide range of regions; (6) investigate the potential of using environmental simulations for monitoring certain natural and man-induced processes; and (7) develop an environmental planning and management methodology.

CHAPTER I

SYSTEM CONCEPT

This chapter will be concerned with outlining the basic configuration for an operational IMP/S to be used in monitoring and planning for the San Antonio River basin. The river basin region is shown in Figure 1.1. A very general landuse map for the region is shown in Figure 1.2.

The San Antonio River basin is bounded on the north and east by the Guadalupe River basin and on the south and west by the Nueces River and San Antonio-Nueces Coastal basins, and includes within its boundaries parts of Kerr, Bandera, Bexar, Kendall, Comal, Guadalupe, Wilson, Karnes, Goliad, DeWitt and Victoria counties. The basin heads on the Edwards Plateau in the Great Plains geographical province, and leaves this province near San Antonio to continue to the Gulf of Mexico through the Coastal Plain province.

The population of the San Antonio River basin in 1970 was approximately 990,000. The Texas Water Development Board has estimated that by the year 2020 the population in the basin will increase to about 1,884,500. Of this projected total, about 1,740,000 people are expected to be concentrated in urban areas having populations greater than 5,000. The San Antonio metropolitan area--which includes the cities of San Antonio, Alamo Heights, Terrell Hills and Castle Hills--

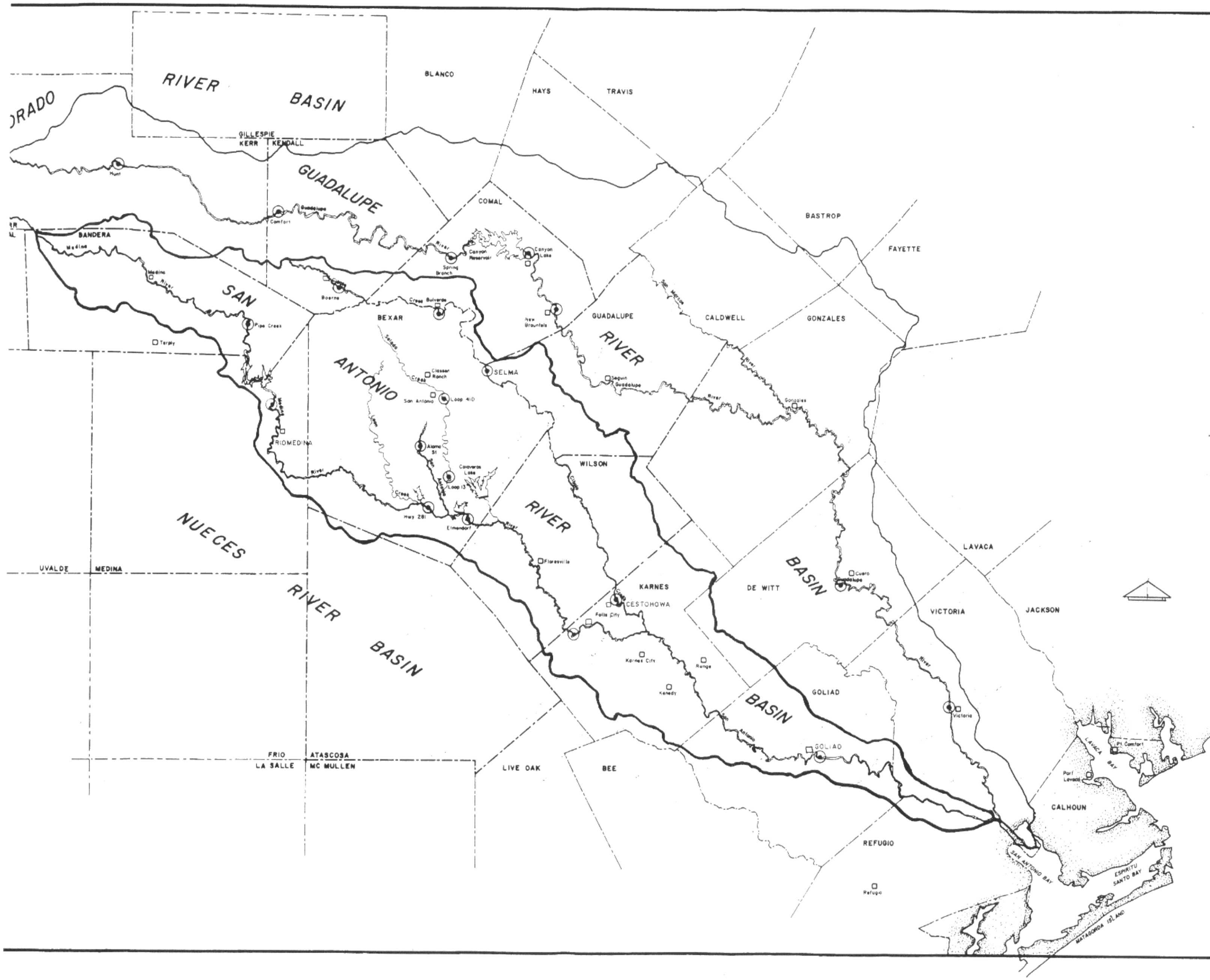


FIGURE 1.1

SAN ANTONIO RIVER BASIN

[redacted]

is the dominant urban center in the basin having a total population of about 670,000 people in 1970. This population figure makes up about 68 per cent of the total population in the region. The 1970 populations of these and other municipalities in the basin, and their projected population growths for the years 1990 and 2020 is shown in Table I below.

Table I. Population projections for selected municipalities, San Antonio River Basin.

City	1970[6]	1990[7]	2020[8]
Alamo Heights	6,933	9,000	10,900
Castle Hills	5,311	6,700	11,000
Floresville	3,707	4,000	5,000
Goliad	1,709	3,600	6,500
San Antonio	654,153	1,154,100	1,693,600
Terrell Hills	5,225	7,000	8,700

Figure 1.2 indicates that most of the San Antonio River basin is devoted to agriculture. The major urban center in the region is San Antonio. San Antonio is also the primary commercial and industrial center for the region. The upper basin which includes parts of Kerr, Bandera, Kendall and Comal counties has developed a rather extensive recreational

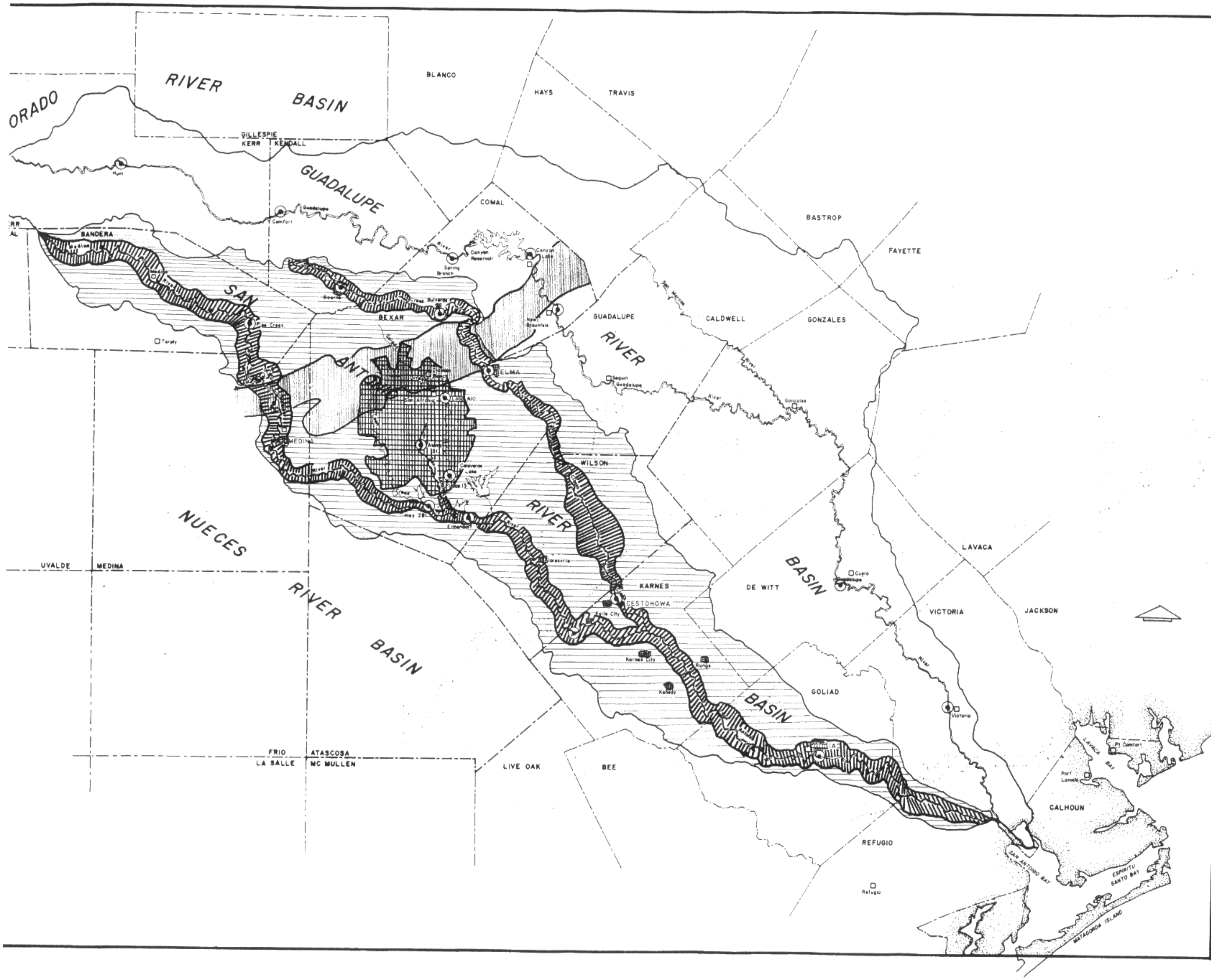
[6] U.S., Department of Commerce, Bureau of the Census, United States Census of Population: 1970, General Population Characteristics, Texas.

[7] Texas Water Development Board, Reconnaissance of The Chemical Quality of Surface Waters of the San Antonio River Basin, Texas (Texas Water Development Board, Austin, Texas April, 1969).

[8] Ibid.

FIGURE 1.2

GENERAL LAND-USE MAP
SAN ANTONIO RIVER BASIN



River Basins

Edwards Aquifer

Urban Areas

and retirement industry that is expected to grow steadily in the future. The lower basin, to the east and south of San Antonio, is oriented mainly towards agriculture and related industries.

There are four major reservoirs in the San Antonio River basin. The Medina Reservoir is by far the largest. This 254,000 acre-foot reservoir is located on the Medina River and is approximately 15 miles northwest of San Antonio. Its primary function is to provide a water supply for irrigation of lands in Bexar, Medina, and Atascosa counties.

Olmos Dam, owned by the City of San Antonio is used for flood control purposes and provides flood protection for a large part of the city. Approximately five miles southeast of San Antonio, the City Public Service Board has constructed the Victor Braunig Dam and lake. This 26,000 acre-foot reservoir is used mainly for cooling water for a steam electric power plant. Calaveras Lake, also located in the southeastern part of Bexar County, is used mainly as a cooling reservoir for a power station. In addition to their primary functions as cooling reservoirs for power plants, these lakes are being developed into major recreational areas.

The cities of San Antonio, Alamo Heights and Terrell Hills obtain their water from the Edwards aquifer as do several smaller communities in the upper basin. A number of small communities in the lower basin are using ground water from the Carrizo-Wilcox and Gulf Coast aquifers for their water supply.

In 1960, according to Texas Water Board statistics approximately 99,700 acre-feet of ground water was used for municipal purposes, and about 600 acre-feet was used for water flood operations in petroleum production. In 1964, about 46,300 acre-feet of ground water was used for irrigation in the region.

Figure 1.3 shows some of the sources of major pollutants in the San Antonio area and surrounding regions. The primary sources of water pollution in this region are sewer plants and septic tanks. In addition, oil fields, pesticides used in agriculture, cattle feeding stations, surface runoff, and a number of processing plants in the San Antonio metropolitan area add to the water pollution in the region.

The major air pollution sources in the San Antonio area were determined by a survey conducted by the San Antonio Metropolitan Health District in 1968 of all establishments and properties which might possibly have been an air pollution source. Figure 1.4 shows the major stationary sources of pollution as determined by this survey. Not shown are area sources such as residences and commercial establishments which burn fuel for heating, air fields, and various commercial activities which contribute to solvent losses such as dry cleaning shops and gasoline stations.

According to the 1968 Metropolitan Health District survey report, transportation modes accounted for about 76 per cent of all the air pollution in the city of San Antonio and

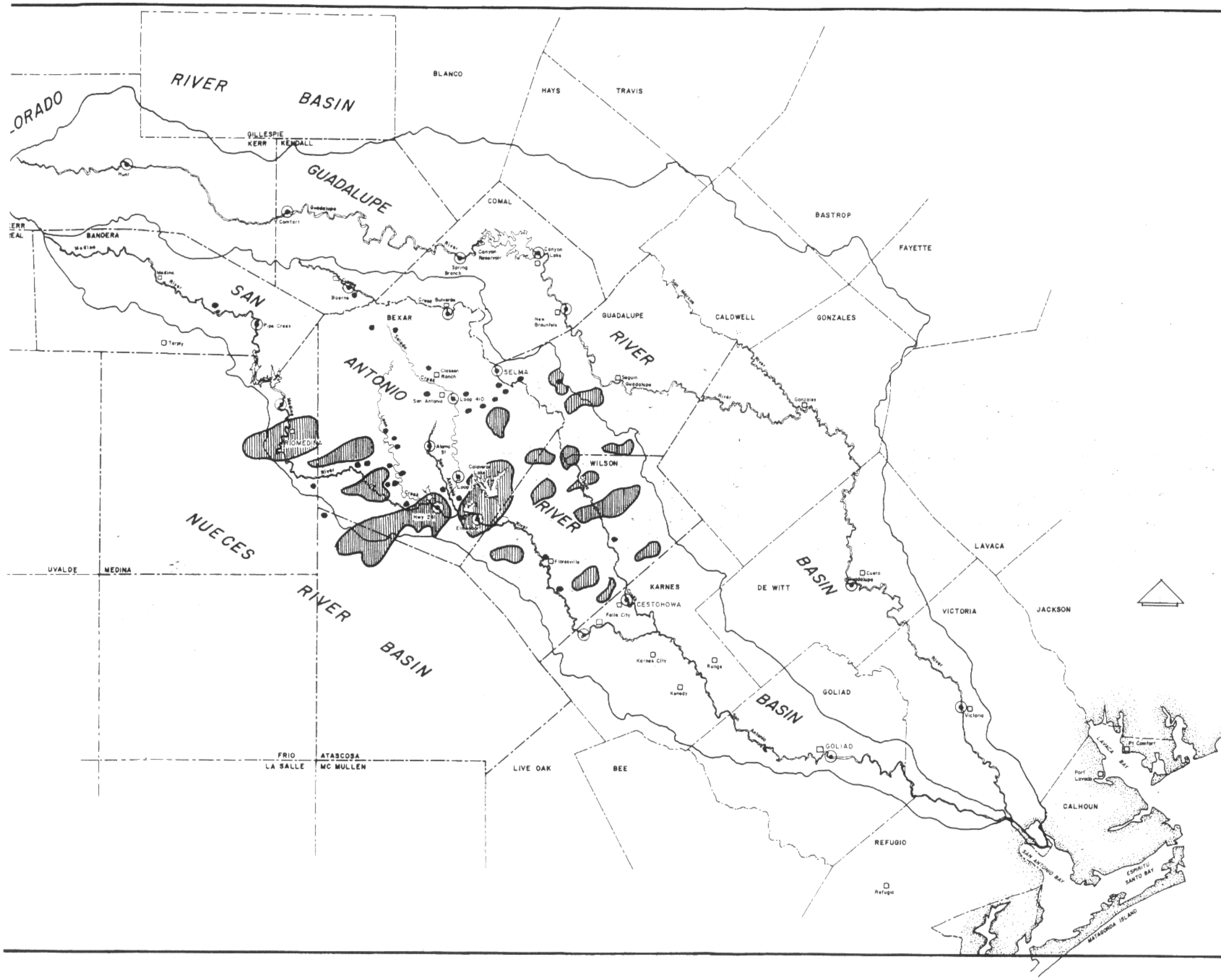


FIGURE 1.3

MAJOR GROUND POLLUTION SOURCES

SAN ANTONIO METROPOLITAN AREA

● Sewage Treatment Plants

Oil Fields

1968 SIGNIFICANT STATIONARY SOURCES OF CONTAMINANTS

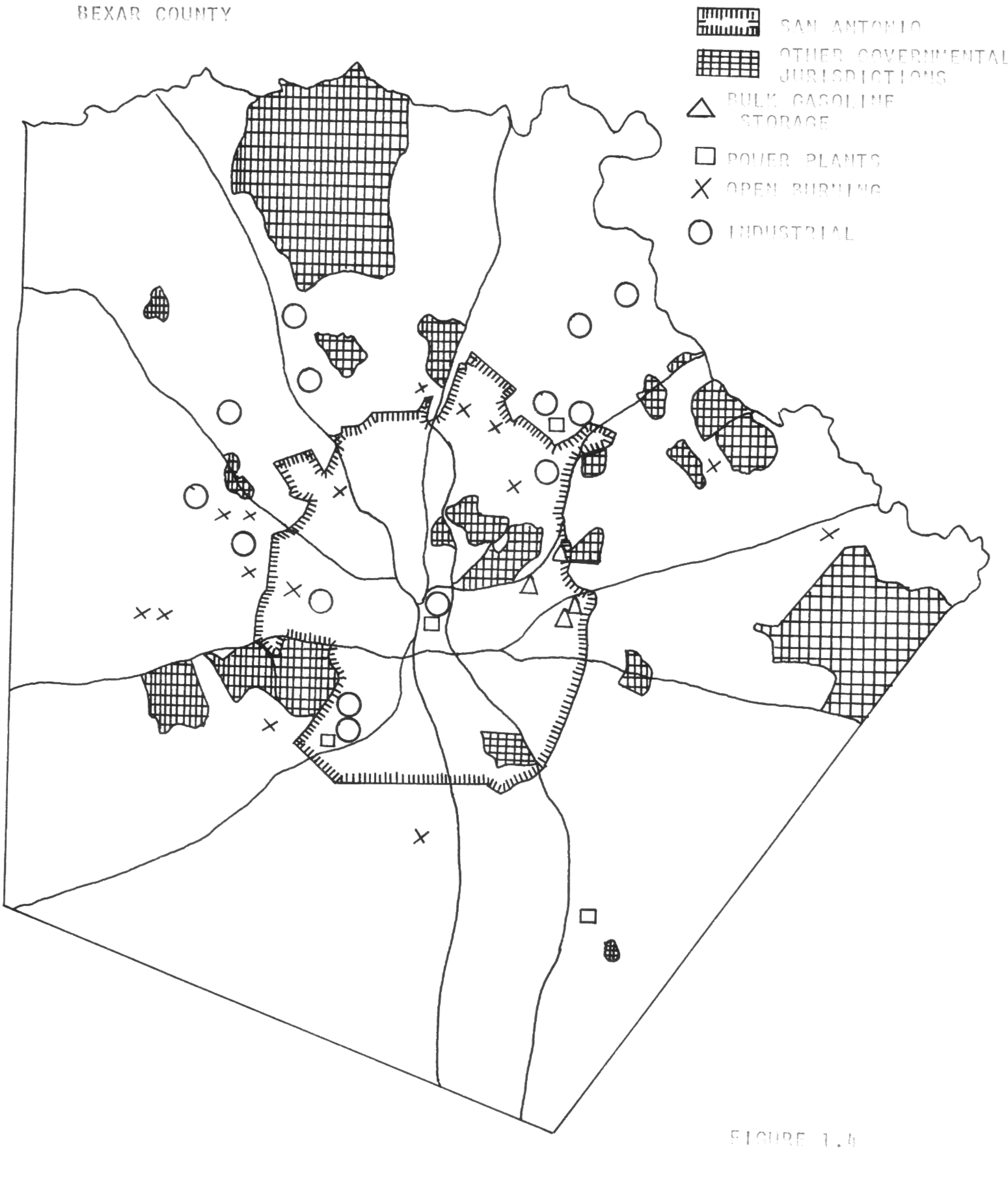


FIGURE 1.4

Bexar County. Automobiles alone accounted for 90 per cent of all the emissions from the transportation sources with trucks, buses, trains and aircraft making up the other ten per cent. The report went on to point out that:

> The industrial category was the next largest contributor of emissions and included process losses as well as contaminants from fuel combustion in furnaces and boilers, and solvent losses from storage of petroleum products. The major emission from industrial processes were from the manufacture of cement and lime, asphalt batching, rock crushing and concrete production. Other emissions were from metal foundry operations, feed and grain processing, petroleum refining, roofing manufacturing, and burning of salvage materials, especially junk car bodies.
>
> All of the other categories accounted for only 3% of the emissions, including emissions from the generation of electric power, heating of residence and commercial establishments, open burning of solid wastes and losses of solvents from the transfer and storage of gasoline at bulk terminals and service stations and dry cleaning operations.[9]

Figure 1.5 shows the present air and water monitoring system for the San Antonio River basin. Rainfall measurement stations are located at Medina, Boerne, Bulverde in Comal County, Classen Ranch directly north of San Antonio, Loop 410 near the San Antonio International Airport, Floresville in Wilson County, Falls City on the San Antonio River, Cestehowa in Karnes County, Karnes City, Kenedy, Runge, and Goliad. Gauging stations are located at Pipe Creek in Medina County, Boerne in Kendall County, Selma in Guadalupe County, Rio Medina in Medina County, Loop 410 in northeastern San Antonio, Alamo Street in San Antonio, southeastern San Antonio, Southern

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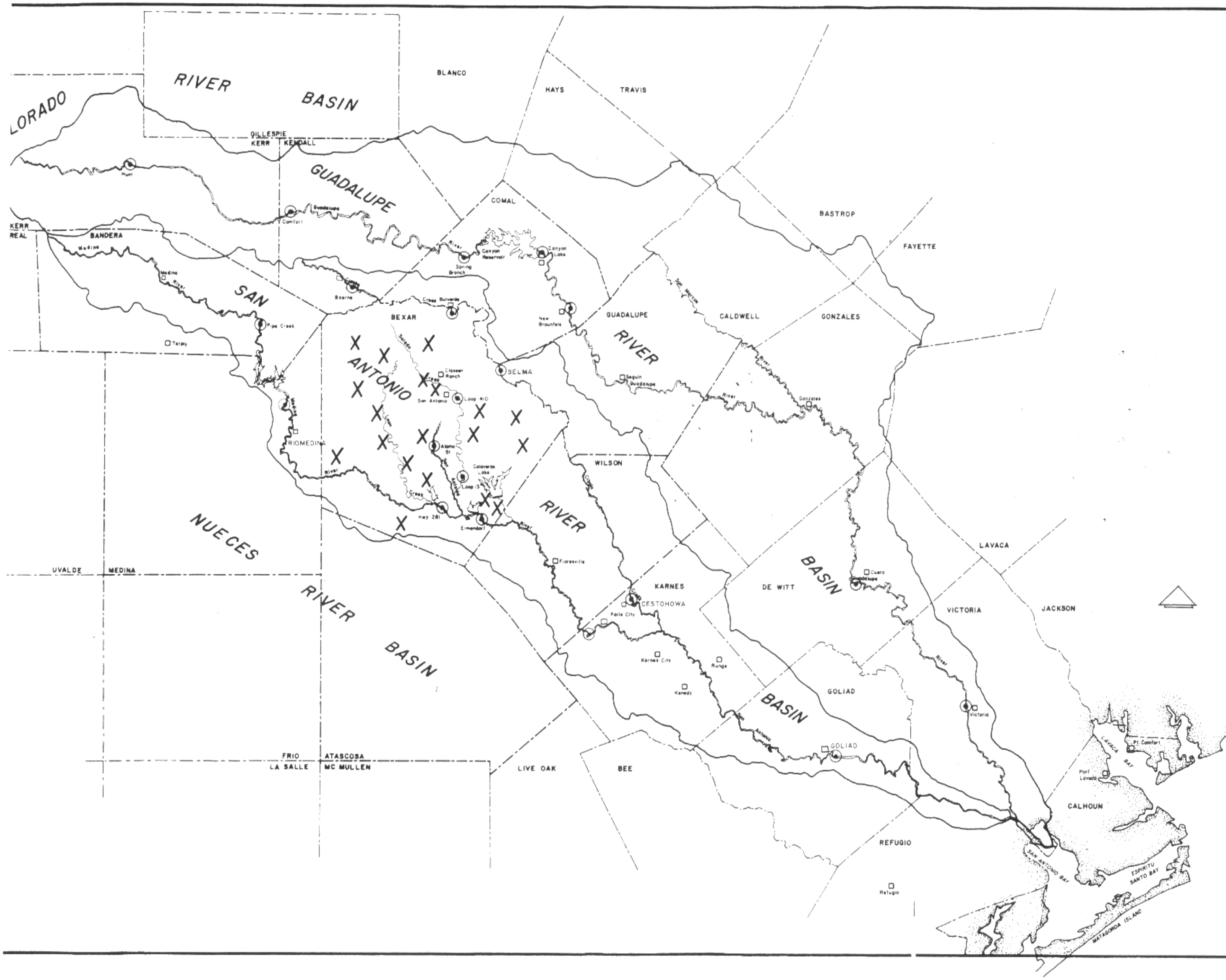
[9]San Antonio Metropolitan Health District, Texas, Annual Report: Air Pollution Project (1968), p. 6.

FIGURE 1.5

EXISTING AIR AND WATER
MONITORING SYSTEM
SAN ANTONIO RIVER BASIN



X Air Sampling Stations

⊙ USGS Gauging Stations

□ Rainfall Stations

Bexar County near the intersection of Highway 281 and the Medina River, Elmendorf, San Antonio River near the Wilson/Karnes County line, Cestehowa in Karnes County, and in the city of Goliad.

The existing air sampling network for San Antonio and Bexar County is also shown in Figure 1.5. Table II below gives the general location of each sampling unit in the network. Each unit is designed to measure the following: the amount of suspended particulates in the air, the amount of organic soluble particulates in a given volume of air, the amount of settled particulates, and the sulfation rate of sulfur dioxide in a given volume of air.

In designing a comprehensive sensor network for the San Antonio River basin, the sensor deployment plan should take into consideration not only the phenomenon to be monitored, but also its area of occurrence, the location of other sensor devices with respect to the phenomenon, the rate of phenomenon occurrence, and its magnitude and area coverage. The accessibility to and maintenance of sensor devices must also be considered in formulating a sensor deployment plan.

In general, the operational system will be designed to maintain varying degrees of surveillance over the entire region. It will consist of three major data collection/sensor systems: a satellite data collection system which will use a modified NASA, Earth Resources Technology satellite system; an aircraft surveillance system; and a composite surface/

Table II. Fixed Air Sampling Stations--
San Antonio Metropolitan Area

Site No.	Location	Geographic Area
1	Helotes Park	Bexar County
2	Fredericksburg Road	Bexar County
3	Northwood Estates	Bexar County
4	Culebra Road	City of San Antonio
5	Oak Hills	City of San Antonio
6	Cadillac Drive	Bexar County
7	Northern City Service Center	City of San Antonio
8	Newport	City of San Antonio
9	Converse	Bexar County
10	Highway 90 West	Bexar County
11	Lackland	Bexar County
12	Lady of the Lake	City of San Antonio
13	Edison Drive	City of San Antonio
14	Midcity--Corporation Court	City of San Antonio
15	Seale Road	City of San Antonio
16	S. Zarzamora	City of San Antonio
17	Rhoda Avenue	City of San Antonio
18	South East City Service Center	City of San Antonio
19	Beck Road	Bexar County
20	Somerset	Bexar County
21	Braunig Lake	Bexar County

Source: Air Pollution Project-1968 Metropolitan Health District

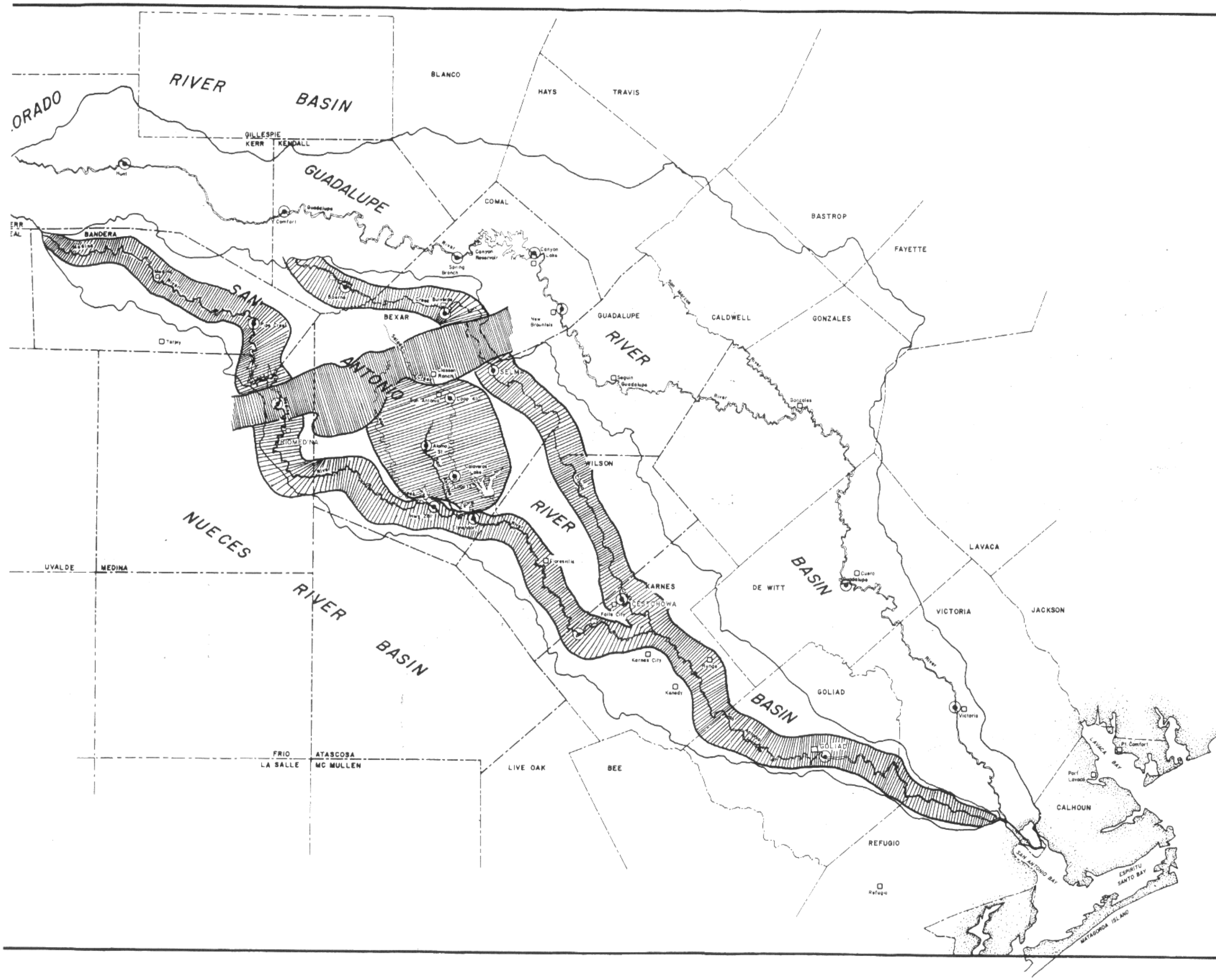
subsurface monitoring system. Each of these systems will encompass its own sensor component, telemetry/communications subsystem, computer linkup for processing environmental data, and an automatic display component. The total sensor configuration is outlined in Chapters II and III. The telemetry/communications network which provides the framework for integrating these data collection systems into the operational system is discussed in Chapter IV.

The overall environmental structure for the proposed IMP/S is outlined in Figure 1.6. For practical reasons the region will be divided into three types of surveillance zones: primary, secondary and critical. An area will be defined as a primary surveillance zone if it meets two or more of the following criteria: (1) the area must be important to the overall economic well-being of the region, (2) there must be a high degree of urbanization occurring or existing in the area, (3) certain environmental conditions or features that are important for human survival and well-being must be located in the area, (4) the area must be important to the overall ecological and biological environment of the region. In addition, areas having high degrees of air and/or water pollution, watersheds, airsheds, major transportation corridors, aquifers, forests, reservoirs, lakes and flood plains will be included in this classification. Those areas not defined as primary will be automatically classified as secondary. Critical

FIGURE 1.6

SURVEILLANCE SECTORS

SAN ANTONIO RIVER BASIN



Secondary Zone

Primary Zone

surveillance zones will encompass high priority areas where intensive monitoring is essential over an extended time span.

Environmental elements included in the primary and critical zones will receive maximum coverage; whereas, those elements located in the secondary zones will receive varying degrees of coverage. Maximum coverage will involve the use of all data collection systems, while minimum coverage will usually require only one, or at the most, two data collection systems. For example, for those areas classified as secondary the satellite system will be the major data collection system used. However, if additional monitoring or surveillance is required the aircraft system could be used. The primary zones, on the other hand, will have rather extensive surface and subsurface sensor infrastructures in order to maintain constant surveillance over the area. In addition, periodic airborne and satellite surveillance will be maintained to supplement and complement the surface/subsurface system. Critical zones, unlike primary zones, will be smaller, and sensor deployment will be more concentrated in order to intensify surveillance.

In the San Antonio River basin there will be five primary surveillance zones. These zones are as follows: (1) the San Antonio metropolitan area, (2) the Edwards aquifer subregion, (3) the San Antonio River from its head in San Antonio to San Antonio Bay in the Gulf of Mexico, (4) the Medina River from the northwestern corner of Bandera County to its

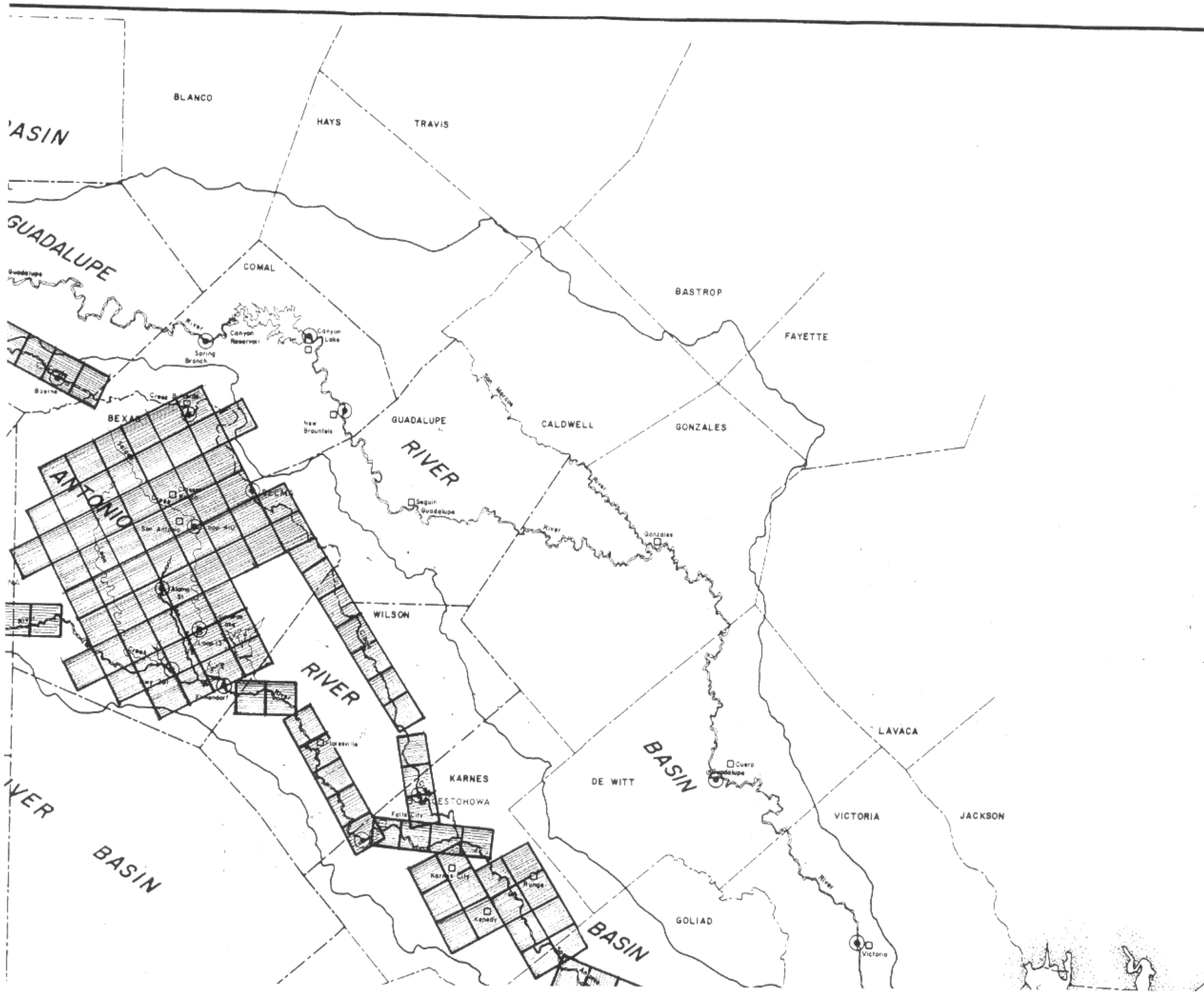
interception with the San Antonio River in southern Bexar County; and, (5) the Cibolo Creek region from Boerne to its interception with the San Antonio River in southern Bexar County. The rest of the region will be assigned a secondary status. No critical zones will be initially established since the primary zones designated above should be sufficient for the foreseeable future. However, the survey classifications noted above can be expected to change as needs and priorities change. Thus, the environmental structure outlined in Figure 1.6 is a flexible one. Future demands might cause this structure to expand into other areas in the basin. Conversely, some areas now defined as primary zones could become secondary or critical in the future.

Each primary surveillance zone is divided into a system of environmental grids. Figure 1.7 outlines a preliminary grid location plan for the San Antonio River basin. The grid concept (see Chapter IV) is a means for structuring the environmental monitoring system. It is also used as a framework for deploying sensors within a particular geographical area. In addition the grid is used as a geographical reference system for coding important environmental elements in the region.

Figure 1.8 describes a preliminary sensor deployment plan for the San Antonio River basin. The kinds of sensors used, their dispersal within the grid, and their data linkage with the Central Processing Unit (CPU) will be based on the kinds of phenomema to be monitored, the detection capabilities

FIGURE 1.7

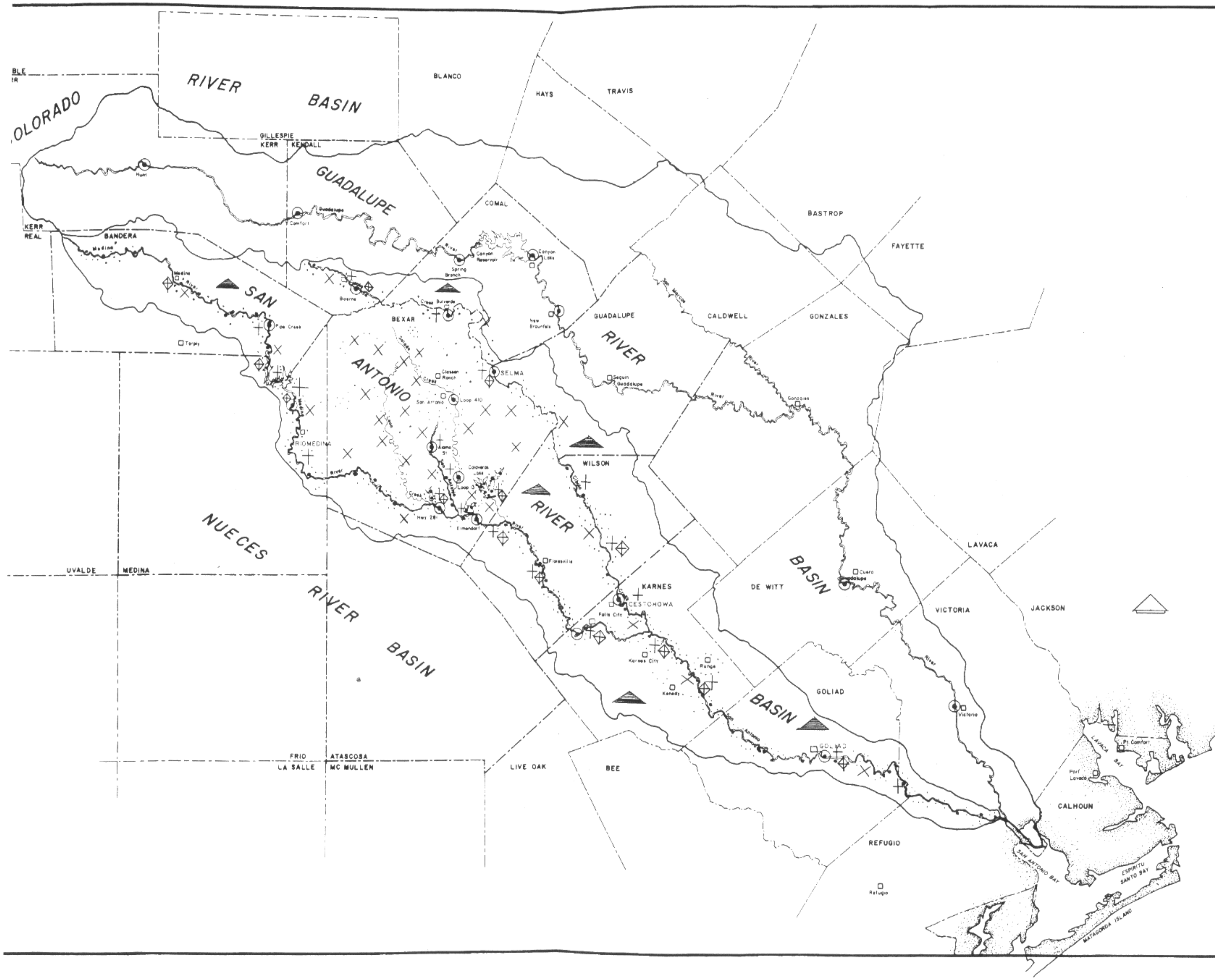
ENVIRONMENTAL GRID FRAMEWORK



 Standard Grid 4x4 miles

FIGURE 1.8

SENSOR DEPLOYMENT PLAN
SAN ANTONIO RIVER BASIN



- · Specialized Sensors
- • Underwater Sensor
- ▲ Remote Meteorlogical Sta.
- X Air Monitoring Sensor Unit
- ⊙ River Gauge
- + Water Analyzer Unit
- ◈ Water Monitoring Unit
- □ Rainfall Station

of each sensor unit, the specific data acquisition and transmission rate of each sensor device, its coverage capability, and the amount of detail required by the planning and management components of the IMP/S. In addition, easy accessibility, the availability of reliable power sources, and low maintenance needs are important factors governing the deployment of certain types of surface and subsurface sensor units. Table III on page 109 describes some of the major operational characteristics for each sensor device that will be used in the network.

The preliminary network outlined in Figure 1.8 indicates both the kinds of sensor devices that will be used and their general location. However, it should be noted, that only the surface and subsurface systems are described in this chapter. The aircraft surveillance system will be used to monitor each of the primary zones on a periodical basis. The satellite system is designed to monitor the entire San Antonio River basin on a predefined schedule.

The surface system described in Figure 1.8 will include at least six remote meteorological stations which will be designed to transmit automatically certain kinds of meteorological data to the CPU. Their main function is to provide a comprehensive climatic picture of the region. The air monitoring network will be expanded to cover the entire basin. The exact location of these monitoring stations will depend on the precise evaluation of known air pollution sources and prevailing wind vectors in the region. The water monitoring

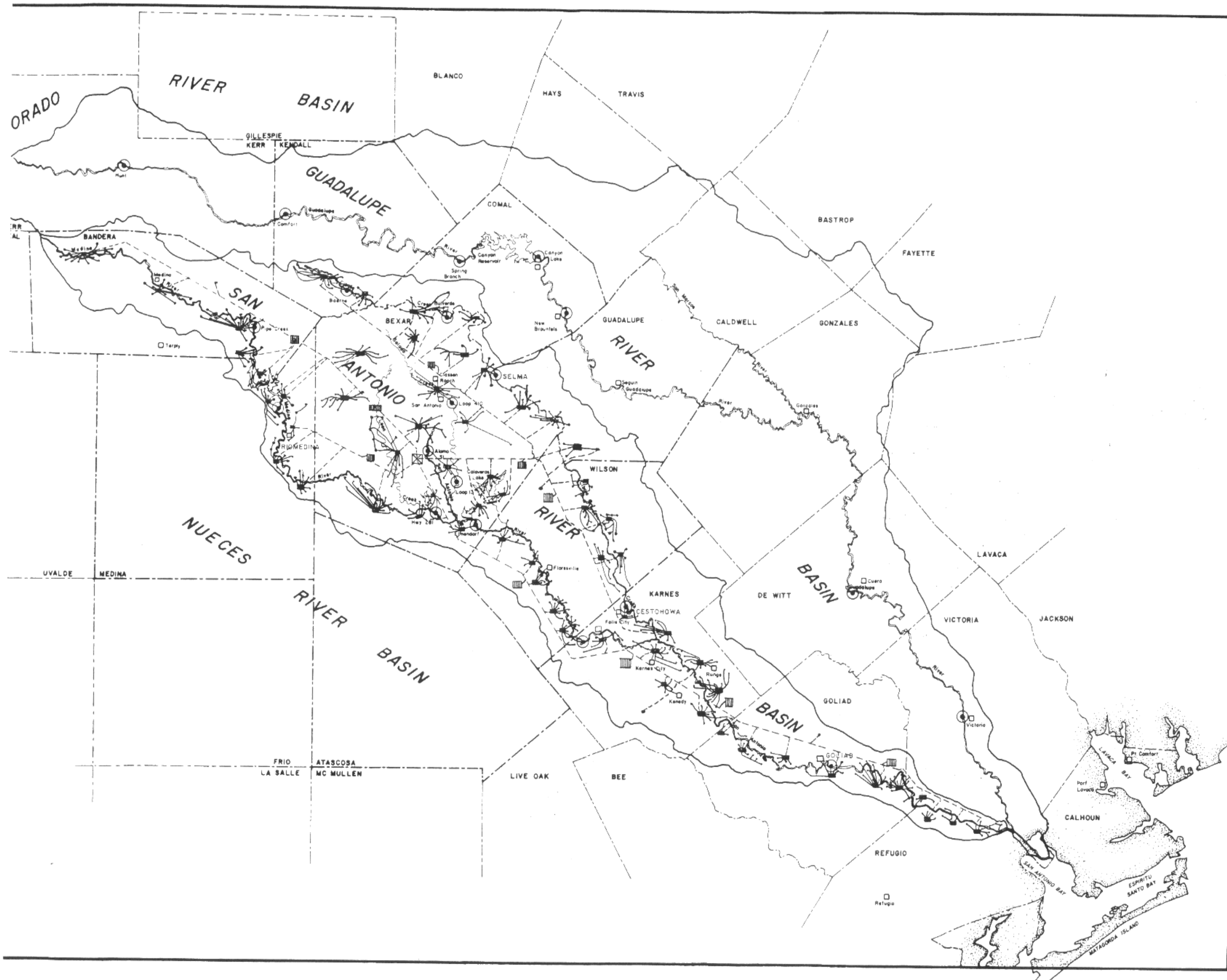
and analysis system will be dispersed along the Medina and San Antonio Rivers, in the Cibolo Creek region, and on the Medina, Calaveras and Braunig lakes. Water monitoring units will also be located on certain tributaries in the region such as Salado Creek, Leon Creek and a number of larger feeder streams. Underwater sensors will be strategically located in the major rivers and lakes in the region. Again the exact location of these sensor units will depend on the requirements of the environmental management and planning component of the IMP/S.

Specialized surface and subsurface sensors will also be deployed throughout each of the primary sectors. These sensors will be designed to measure specific phenomenon such as local particulate levels, carbon dioxide levels, local climatic conditions, soil conditions,wildlife movement patterns, noise levels, underground water quality, traffic flows, etc. The exact location of these specialized sensors will depend largely onthe needs of special user groups associated with the IMP/S.

Figure 1.9 describes the basic telemetry system. As noted above, every grid will have its own sensor configuration. Each grid will contain both remote and interactive sensor devices capable of measuring surface, subsurface and atmospheric phenomena. Each device, in turn, will be linked to a data concentrator through a telephone cable connection, or by a microwave system. The concentrator, as explained in Chapter IV, serves as a buffering device which integrates data from a

FIGURE 1.9

TELEMETRY NETWORK



- Sensor Device
- Data Concentrator
- Node Receiver Unit
- Surveillance Center/CPU Facility
- Sensor to Concentrator Link
- Telephone/Telemetry Link

number of individual sensors into composite messages. These messages are then re-transmitted via a telephone line to a node station. The node station stores all data transmissions originating from the concentrators, and prepares them for retransmission to the CPU. The CPU facility controls the operation of the entire sensor-telementry network.

The transmission-communications hierarchy for the network is as follows: The basic transmission link will originate at the sensor level, and then passes through a concentrator, node and then to the CPU facility. The CPU, in turn, will be able to communicate directly with either of these components. Only the remote meteorological stations, air sampling stations, and water monitoring/analyzer sensor units will be directly linked to the CPU through a telephone-telemetry system. This means that these sensors will need to have intermediate buffering devices. The rationale for this direct transmission link is that these particular sensor devices are concerned with very critical environmental vectors which must be constantly monitored in order to effectively evaluate regional phenomena and environmental status on a real-time basis.

A simplified concept of an operational IMP/S is described in Figure 1.10. The system will operate as follows: Data is constantly picked up from environmental sensors dispersed throughout a geographical area. All of the data collected by both surface and subsurface sensors are then transmitted via data concentrators to a node station. The node

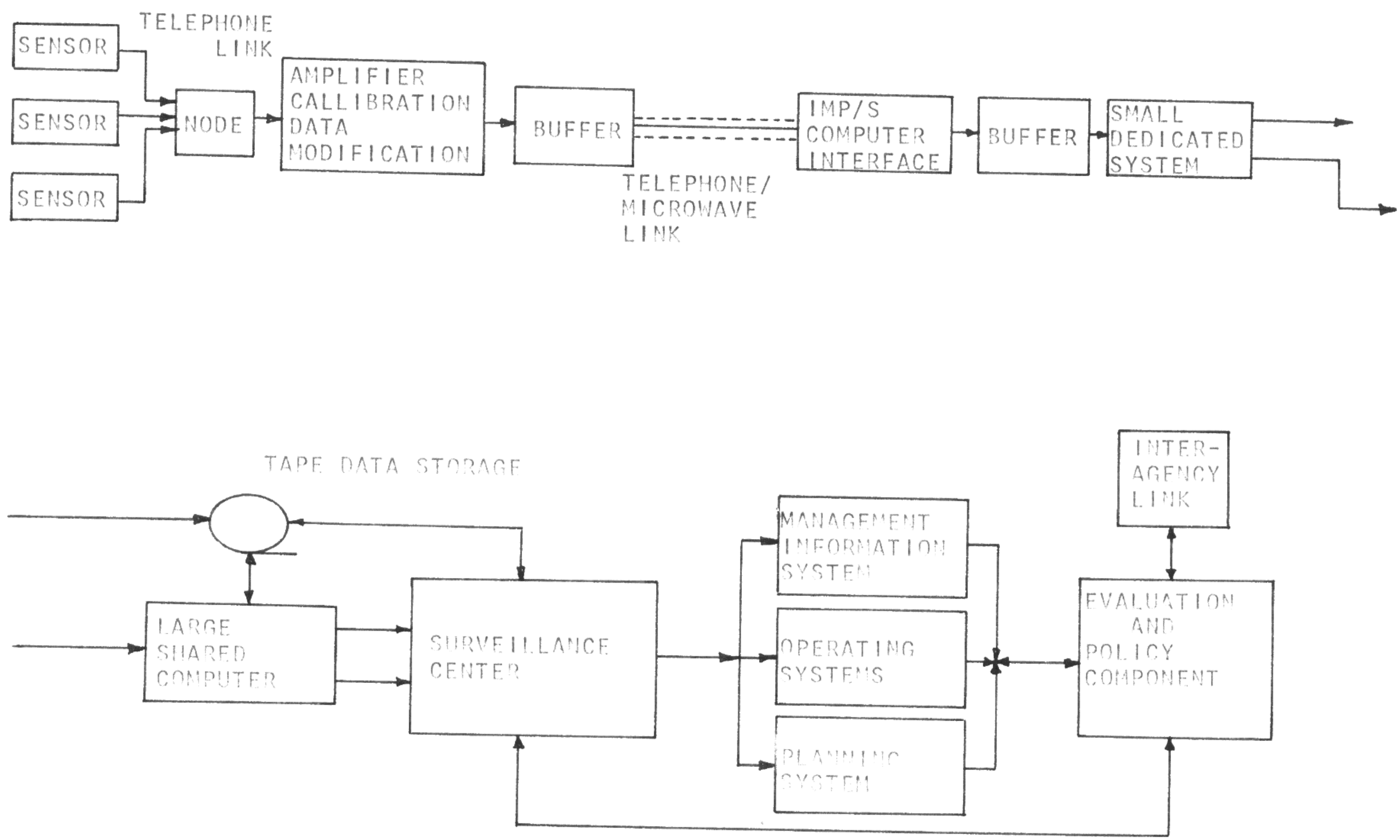


FIGURE 1.10

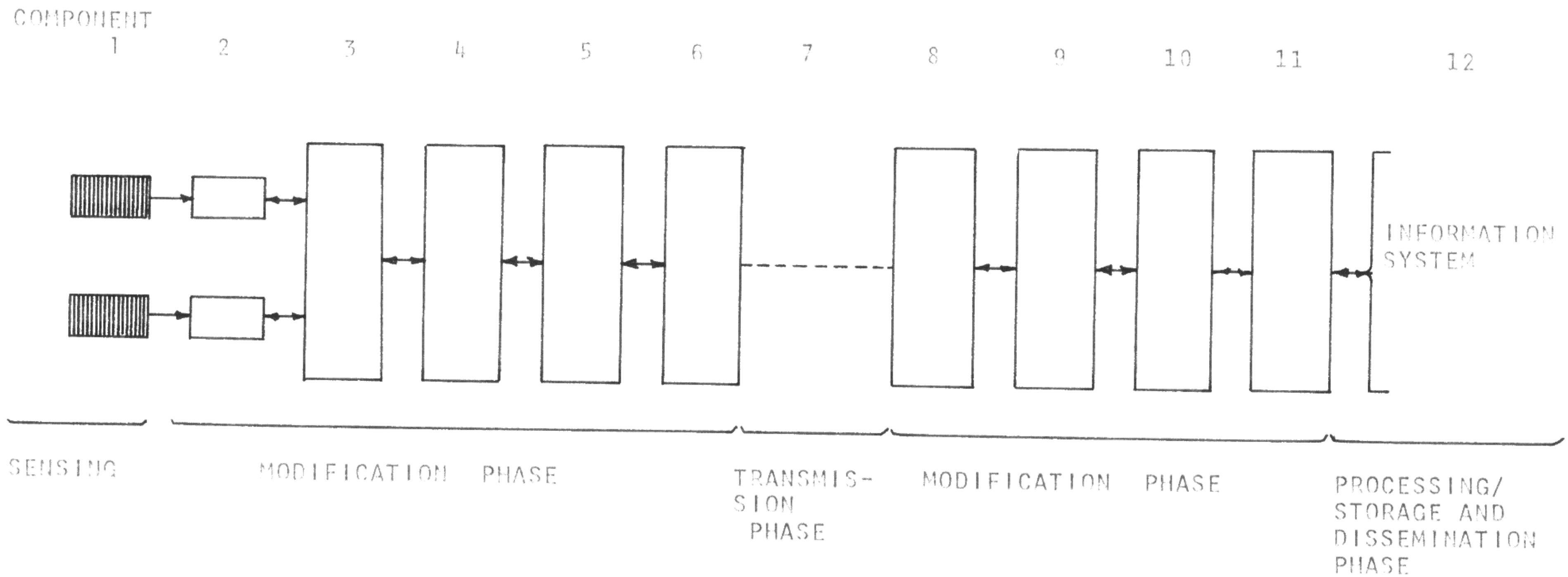
IMP/S CONFIGURATION

station filters out all incoming analog data, and prepares it for re-transmission via telephone linkup to a central processing unit located at the Surveillance Center. The Surveillance Center consists of three major systems: a computer interface, data bank and an environmental information, management and planning system.

Figure 1.11 describes some of the basic components of the data communications system of the IMP/S. The system itself is a relatively closed one having very little interaction with the external environment. The sensors are, in effect, the eyes and ears of the IMP/S. Thus, the system receives a pre-selected stimulus, measures it, prepares it for transmission, transmits the signal, and ultimately directs the measured value into a computerized information system.

For the sake of clarity one can perceive each component as a separate element. In the process of defining each of these components or subsystems we will first indicate their primary role and then proceed to describe very briefly their major function:

Component	Primary Role	Function
1. Transducer	Sensing	Converts physical quantities into a form of energy
2. Signal Conditioning	Modification	Processes and modifies the output signal from the transducer in order to make it suitable for further modification.



1. Transducer
2. Signal Conditioner
3. Multiplexer
4. A-D Converter
5. Modulator
6. Buffer
7. Telephone Line
8. Receiver
9. Demodulator
10. A-D Converter
11. Demultipler
12. Information System

FIGURE 1.11

SUB-SYSTEM COMPONENTS

3. Multiplexer	Modification	Forms a composite transmission signal or a single transmission circuit.
4. A-DConverter	Modification	Digitizes the amplitude of an analog signal.
5. Modulator	Modification	Data is converted into a single frequency for transmission.
6. Buffer	Storage	Data is stored for transmission.
7. Telephone Line	Transmission	Conveys the signal at a specific frequency.
8. Receiver	Modification	Amplifies the incoming signals to make them suitable for additional modification.
9. Demodulator	Modification	The inverse of modulation, the combined signal is separated into a number of frequencies.
10.A-D Converter	Modification	Converts signal data back into digital or analog data.
11.Demultiplexor	Modification	Filters each signal to reproduce the original data.
12.Information System	Processing	Data is processed and channeled to appropriate decision points.

Figure 1.12 also outlines the data modification subsystem. All data received by the sensor is processed and modified. The data signal is first calibrated and its amplitude, frequency or phase is modulated. A sequential multiplexer is used to transmit several signals or messages simultaneously on the same circuit or channel. A digital/analog converter quantifies the amplitude of an analog signal thereby transforming it into a digital signal. The signal is

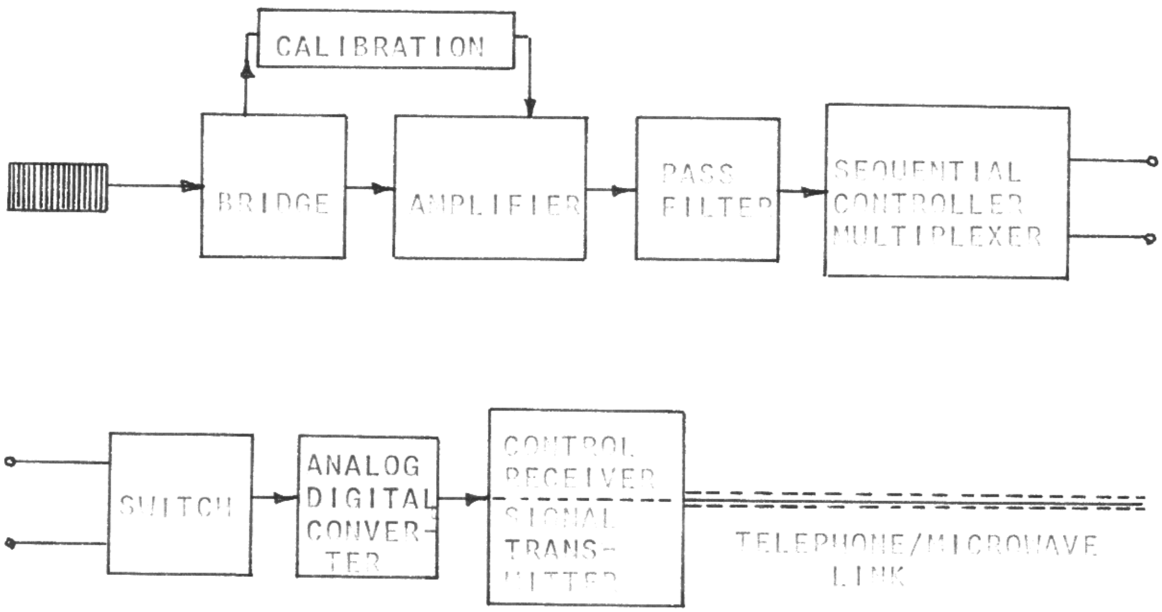


FIGURE 1.12

AMPLIFIER, CALLIBRATION AND DATA MODIFICATION SUBSYSTEM

then transmitted through a telephone circuit.

The computer interface outlined in Figure 1.13 serves as a boundary between the computer and the external environment. All data coming into the computer system or going out to the sensor network are prepared here. In-coming data are demodulated, decoded, and processed to make them compatible to the computer system. Out-going signals or messages are coded and modulated for transmission to each of the data collection systems in the sensor network.

Figure 1.14 describes the initial processing of data. The computer first scans all incoming data and channels it into appropriate components. The data is then checked further, filtered and then transferred as output to the Surveillance Center. The Surveillance Center is the core of the whole system. Its primary function is to monitor the entire basin, plan for and manage its natural and man-made environments, maintain a viable ecological system for the basin; and, take prompt action in case some kind of environmental crisis takes place. The Center, which is described in Figure 1.15, encompasses three major subsystems--a management information subsystem, an information-decision subsystem, and an operating or planning subsystem. Chapters VI and VIII describe the management/information, and information-decision subsystems respectively. Chapter IX outlines the planning subsystem.

The Surveillance Center is built around a data bank and programming system which coordinates all of the other functions

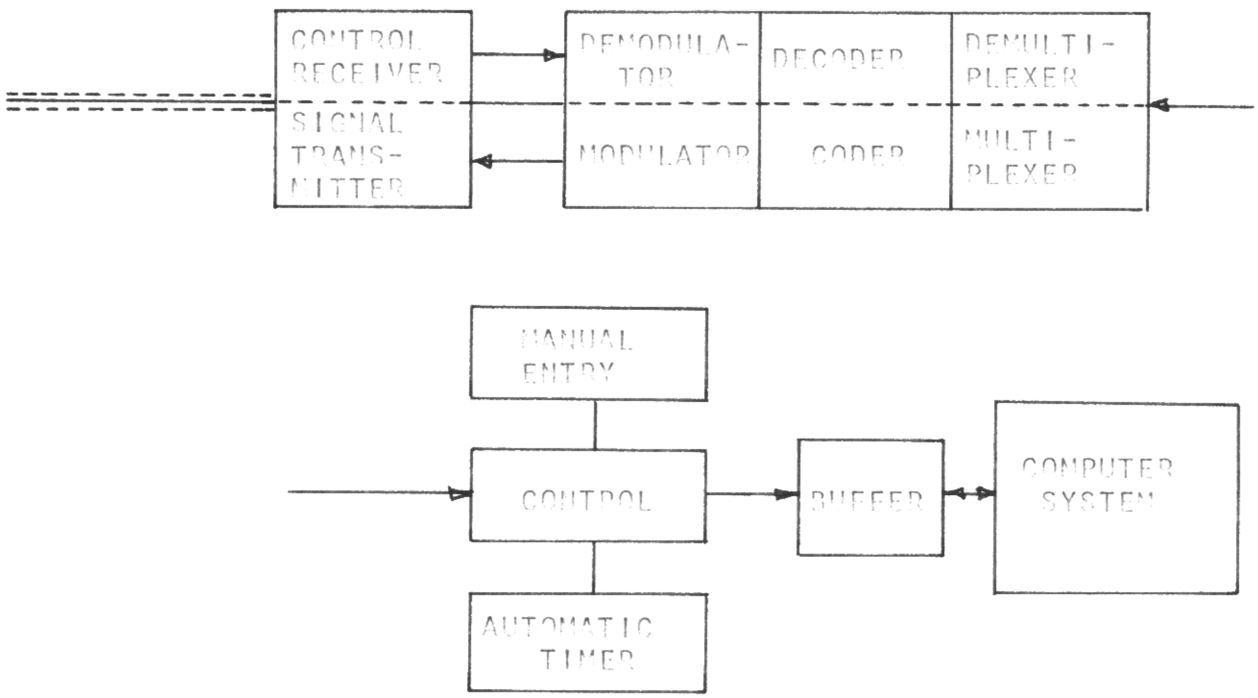
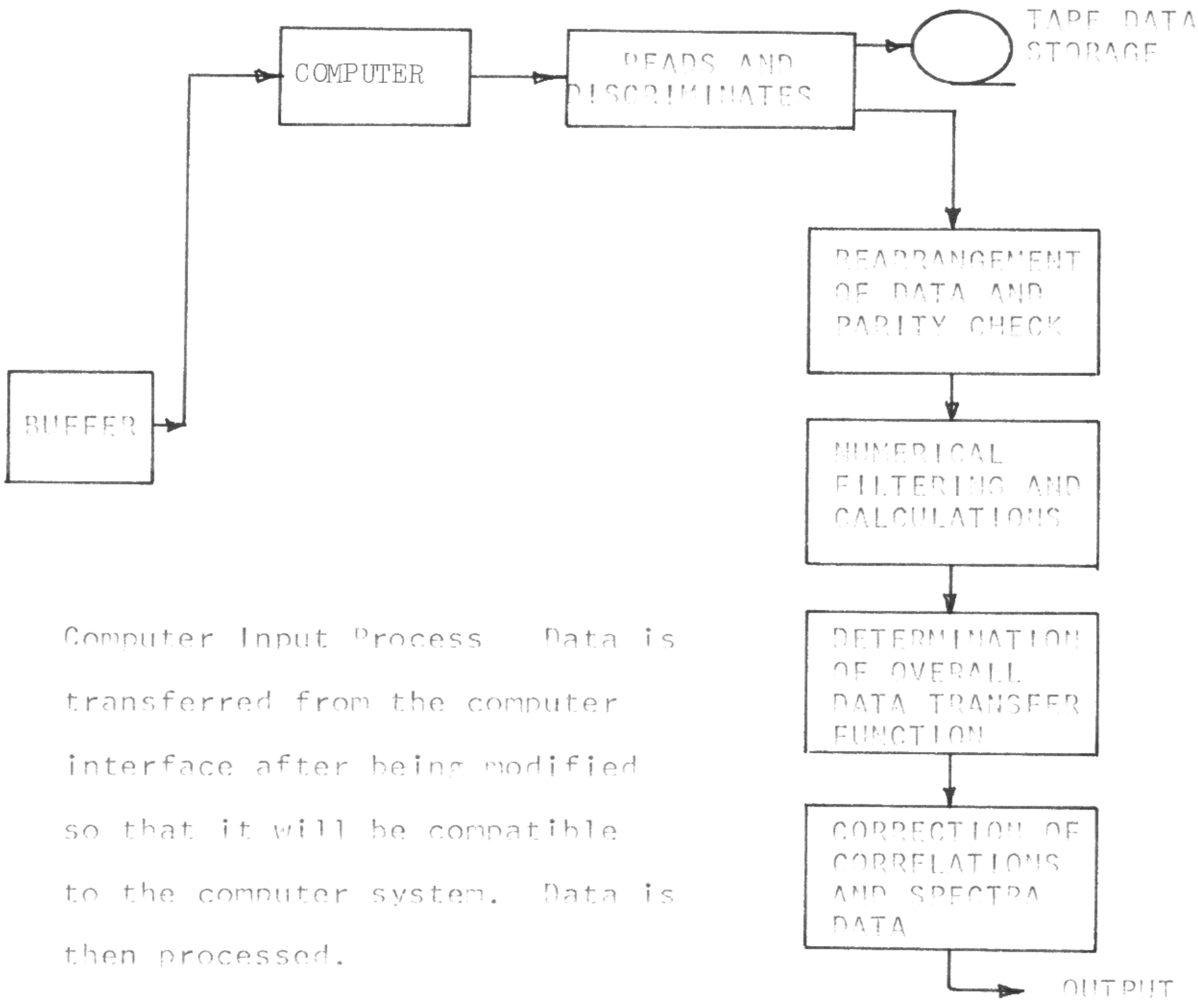


FIGURE 1.13

COMPUTER INTERFACE



Computer Input Process Data is transferred from the computer interface after being modified so that it will be compatible to the computer system. Data is then processed.

FIGURE 1.14

INITIAL PROCESSING OF DATA

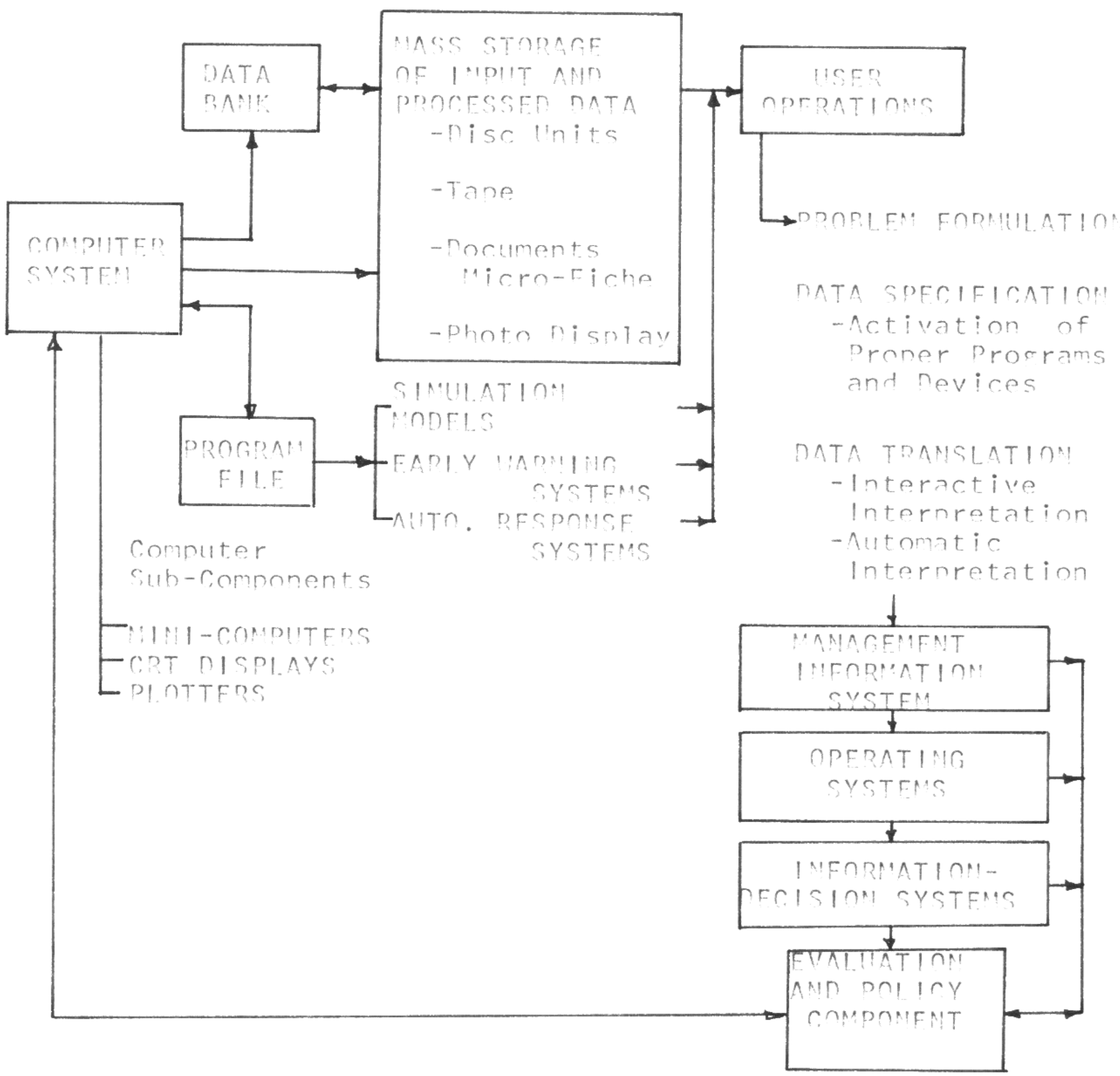


FIGURE 1.15

SURVEILLANCE CENTER
AND SUB-SYSTEMS

in the Center. Within the Center a variety of functions will be performed on the data collected by the sensor network in order to provide specialists with the data they want in the desired formats. These functions include:

1. Initial Processing
2. Quick Reaction Analysis
3. Storage and Retrieval of Data Files
4. Data Bank Generation
5. Processing of User Requests
6. Data Reproduction and Distribution
7. Research and Planning

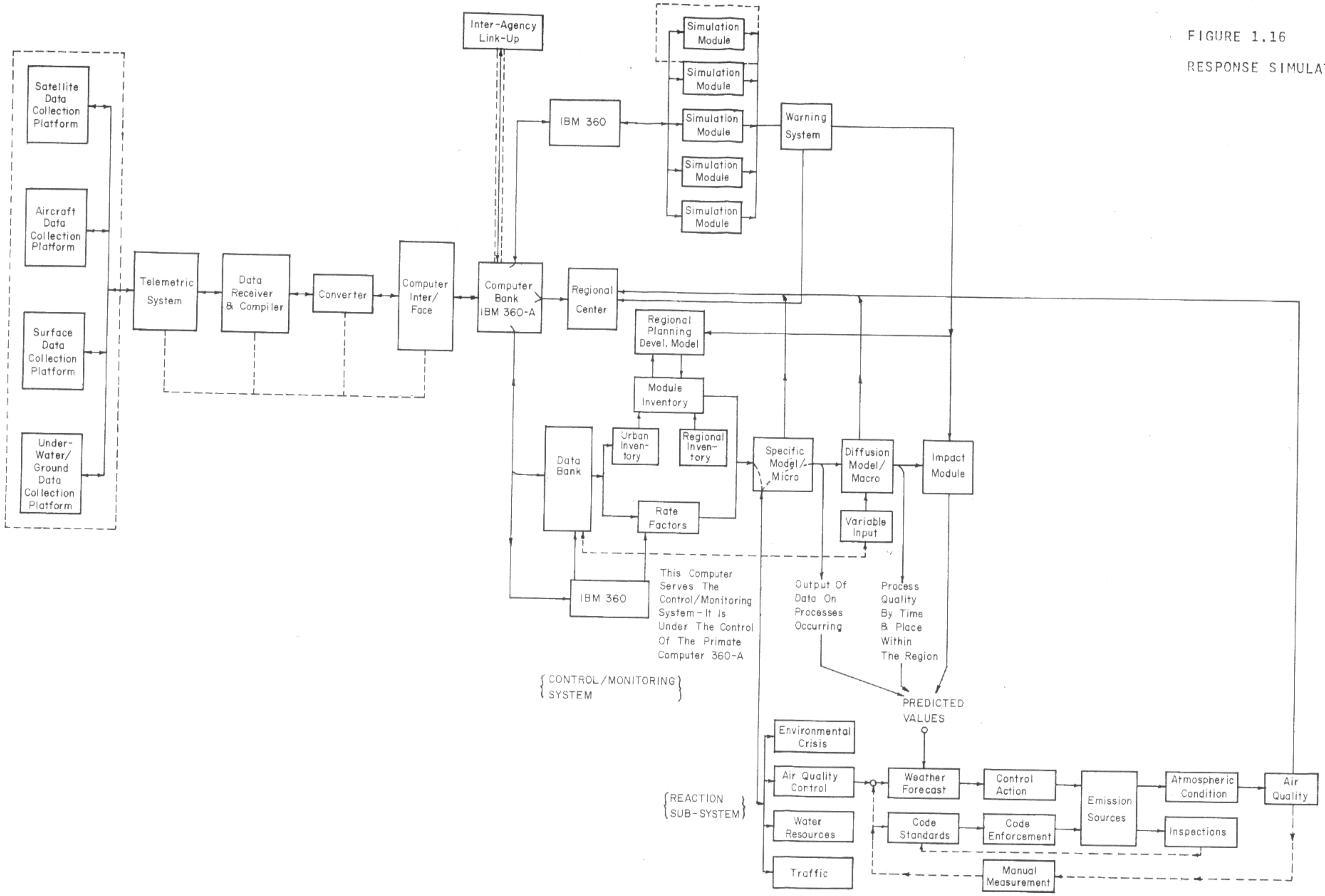
The data collection system provides three kinds of data to the Surveillance Center. These are the wide band video (imagery) data taken by aircraft and satellite cameras, the digital data collected by satellite, surface and subsurface sensors, and multi-spectral photographs taken by aircraft and satellite systems. Initial processing involves the correlation of these data and the preparation of them in forms so that they can be further used. This processing will be done in the computer facility.

One early analysis function will be to channel certain data elements into an Early Warning System (EWS) to determine whether critical conditions are developing in the basin environment. In addition, through prior specification some of the imagery data can be examined immediately in order to determine if they contain time-sensitive information requiring

immediate action. This Quick Reaction Analysis function is designed to pin-point known environmental conditions occurring in the region so that immediate action can be implemented. The Response Simulation system (RS) is a software system designed to use this data and analyze it in order to formulate effective policies or courses of action to alleviate or modify a certain condition. Figure 1.15 describes the relationship between the RS system and the rest of the IMP/S. In this example, air quality data is channeled into an Air Quality Control Model. This data is then correlated with real time meteorological data. In addition, predicted meteorological values are interjected into the model. As this data is processed, other variables are merged into the model such as pollution emission sources, atmospheric conditions in the region, and air quality vectors over a specific area. Code standards and code enforcement data are then merged with the ongoing simulation. The results of this simulation are then listed and forwarded to the appropriate decision-making levels. This listing could be either a simple presentation of alternatives that could be used to rectify a certain condition concerning air quality over a particular area; or, it could provide general policy parameters which could be used by the decision-maker or administrator in developing new controls and standards to maintain optimum air quality conditions. Although Figure 1.16 lists only four basic RS models--environmental

FIGURE 1.16

RESPONSE SIMULATION SYSTEM



crisis, air quality control, water resources, and traffic control--many more can be added to the system.

A major function of the Surveillance Center will be the storage and retrieval of data files from which reproductions are made for distribution in response to user requests. The files themselves will be listings of received data, positive and negative transparencies of both rectified and unrectified versions of aircraft and satellite photographs, and color negatives. In addition, tabulated digital printouts, maps, and special simulated printouts will be made available.

Retrieval of these files will be by computer. This retrieval process will be based on a special index file which lists all data as they are being stored in the computer data bank. Requests can be received automatically (as a result of a prior specification for certain data items) or at random times. Non-automatic requests will be accepted for specific data items or reports. It is also anticipated that some requests may be received in other forms, requiring research on the part of the Center personnel or a designated group.

The generation of data files will be a regular function of the Surveillance Center. There will be four master files in the system--Environmental Files, Grid Files, Derived Data Files, and Model Generated Data Files. Each file classification is based on the type of information included, the intensity and extent of coverage (the geographical, political, economic, or social unit encompassed), its origin and its intended use.

These files, in turn, are further subdivided into sub-files. These sub-files will include data on general phenomenon class vectors and basic data categories or subvectors. The overall IMP/S information system is described in Chapter VI.

The Surveillance Center will also operate and maintain a Satellite Systems Data Bank. This data bank will be designed to store and process information related to that collected by the satellite sensor system. It will also contain references to results of analysis of satellite data, and data indexes relating to material on the same subject but generated from a different base. The exact content of such a data base for the Center is uncertain at this point, but when one considers the potential impact of such satellite systems as the Earth Resources Satellite (ERS), the Earth Resources Observation Satellite (EROS), and the Earth Resources Technology Satellite (ERTS), the need for a specialized data base is clear. It should be emphasized that this Satellite Systems Data Bank will handle only satellite sensor data. Consequently, there will be two major data banks in the system--the larger, more general IMP/S data bank, and the smaller, more specialized Satellite Systems Data Bank. However, both data banks will be linked together in order to facilitate the analysis of environmental data, and for display purposes.

The reproduction and distribution of sensor data will be one of the major functions of the Surveillance Center. Although very few requests would be expected for magnetic tapes

of video data, reproductions of these could be made available by prior request. Most requests for sensor data will probably be for tabulated information, two and three-color composites, and black-and-white photographs in both transparency and print forms.

The distribution of sensor data will be mainly facilitated through an inter-agency linkup arrangement. Remote terminals will be used by other user groups to enable them to secure their data on a demand basis. The user could also manipulate certain data elements by interactive techniques. The user would formulate the problem in a user language and specify the needed data. The proper programs would then be activated in the IMP/S software system and the computer would sort, edit and update all relevant data items. A complete data package is then developed and displayed on the terminal display screen. This package could then be copied directly form the terminal display and used immediately. The interagency link-up will also provide remote mapping and plotting systems allowing the user to secure special maps, graphs, schematics, and three-dimensional statistical diagrams from the IMP/S on a real time basis.

The Surveillance Center will have to increase its functions and capabilities regularly if it is to service its users properly and enhance its own operational efficiency. To permit this, a research group should be an integral part of the Center. This group will have the following responsibilities:

1. Define new data needs.
2. Update, modify, verify and replace current simulation models and develop new models.
3. Improve Center data handling functions.
4. Investigate various processing techniques to aid in the analysis of data.
5. Recommend new facilities for the system.
6. Train personnel.
7. Determine new applications and requirements for each of the data collection systems.

In general, this group will assure the proper growth and utilization of the IMP/S.

The major decision-making, planning and management component in the IMP/S will be the Evaluation and Policy Section (EPS). This component will encompass all of the major decision and policy formulation levels in the system. It will also have the primary responsibility for all long-range environmental management and planning functions. In addition, the EPS will serve as the major link between the IMP/S and the Regional Authority. Figure 1.17 describes the overall organizational structure of the EPS, and its relationship to the IMP/S and the Regional Authority.

The EPS will have three inter-locking components: an administrative section, an evaluation section, and an environmental management and planning section. The administrative section will be mainly concerned with operating and managing

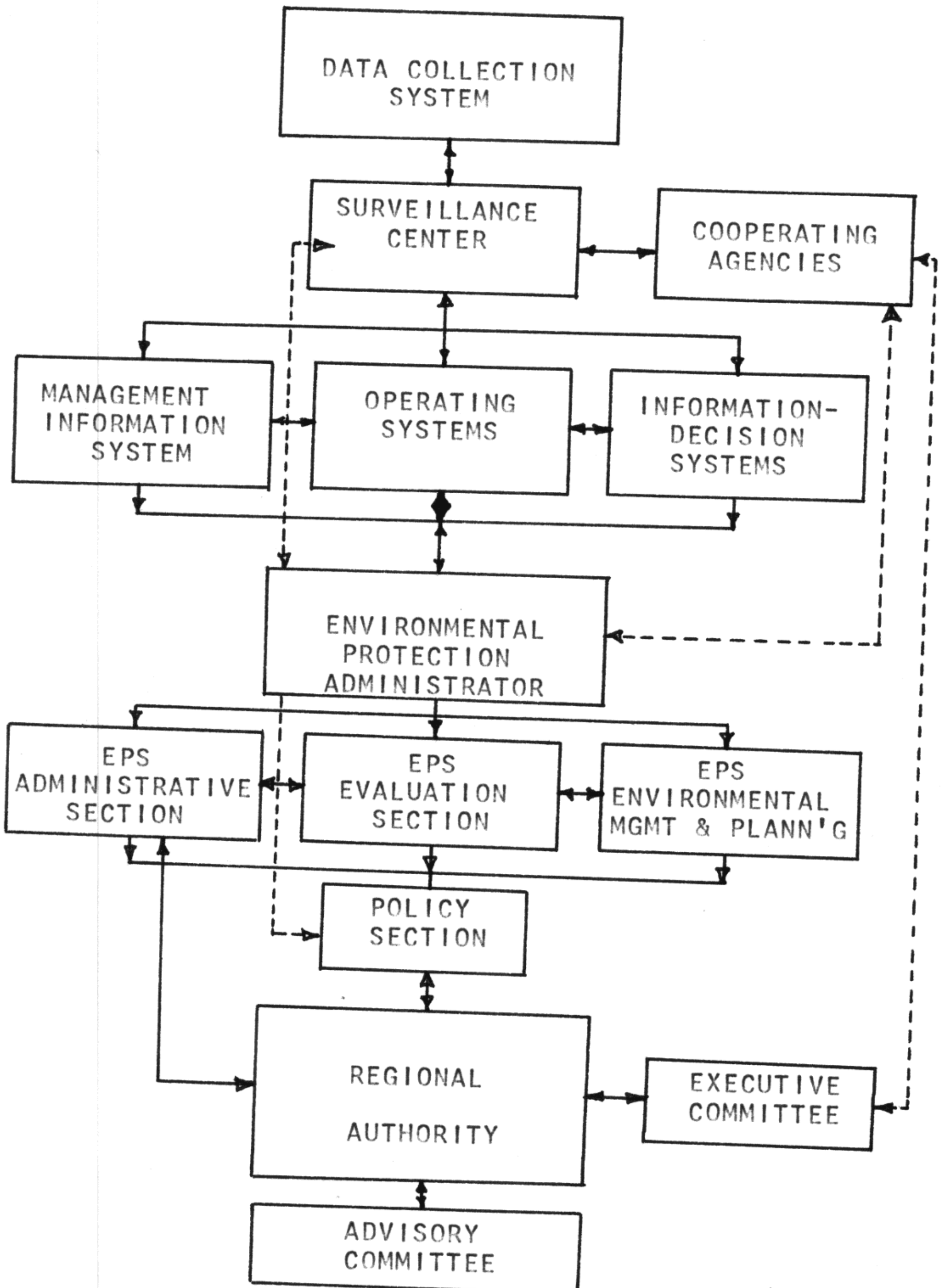


FIGURE 1.17

ORGANIZATION DIAGRAM OF THE IMP/S-EPS..

both the EPS and all other components of the IMP/S as well as providing assistance to the Regional Authority. The evaluation section will analyze all refined data coming from the IMP/S. This section will also include the major decision-making levels in the system. It will have the responsibility for responding to all crisis situations. The Environmental Protection Administrator will have direct control over this evaluation section. The environmental management and planning section will be responsible for environmental design, management, and long-range comprehensive planning for the San Antonio River basin. Its primary functions will include land use management and planning, economic development, regional planning, transportation planning, water quality and facilities planning, and infrastructure planning for the entire basin.

The Policy Formulation section serves as the primary mechanism for linking and integrating the administrative, evaluation, management and planning components together. The major objective of this section will be to develop policies and long-range strategies for the development of the San Antonio River basin. It will have direct input from the evaluation and environmental management and planning sections. It will also have a direct relationship with the Environmental Protection Administrator and the Regional Authority.

The Regional Authority itself will consist of an Executive Committee, a Regional Council and a number of Advisory

Committees (see Figure 1.17). It will include representatives from all of the political jurisdictions in the basin as well as those currently in the Alamo Area Council of Governments (AACOG). In addition, relevant state and federal agencies, regional agencies such as AACOG and SARA, and special interest groups would be included. The Advisory Committees will provide technical assistance to both the EPS and the Council on matters concerning regional planning, regional economic development, water resources, pollution, environmental management and conservation, and environmental management technology. As explained in Chapter IX, the Authority will be the governing body in relation to regional development and environmental control in the basin. It will be chartered by the State and receive funds from both state and federal sources. Local jurisdictions will also contribute some financial aid to the Authority. The amount of funds derived from these local sources will be based on a per capita formula.

The implementation of the IMP/S will occur in three phases (see Figure 1.18). These phases will be called: Initial Development, Interim Development, and Continuing Operations and Growth. During the Initial phase, the Regional Authority is formed and the final decisions are made for the implementation of the system. Hardware and facilities are procured and prepared for operation; the software systems, programs, interfaces, file structure are designed. Some personnel--primarily computer programmers, facility planners,

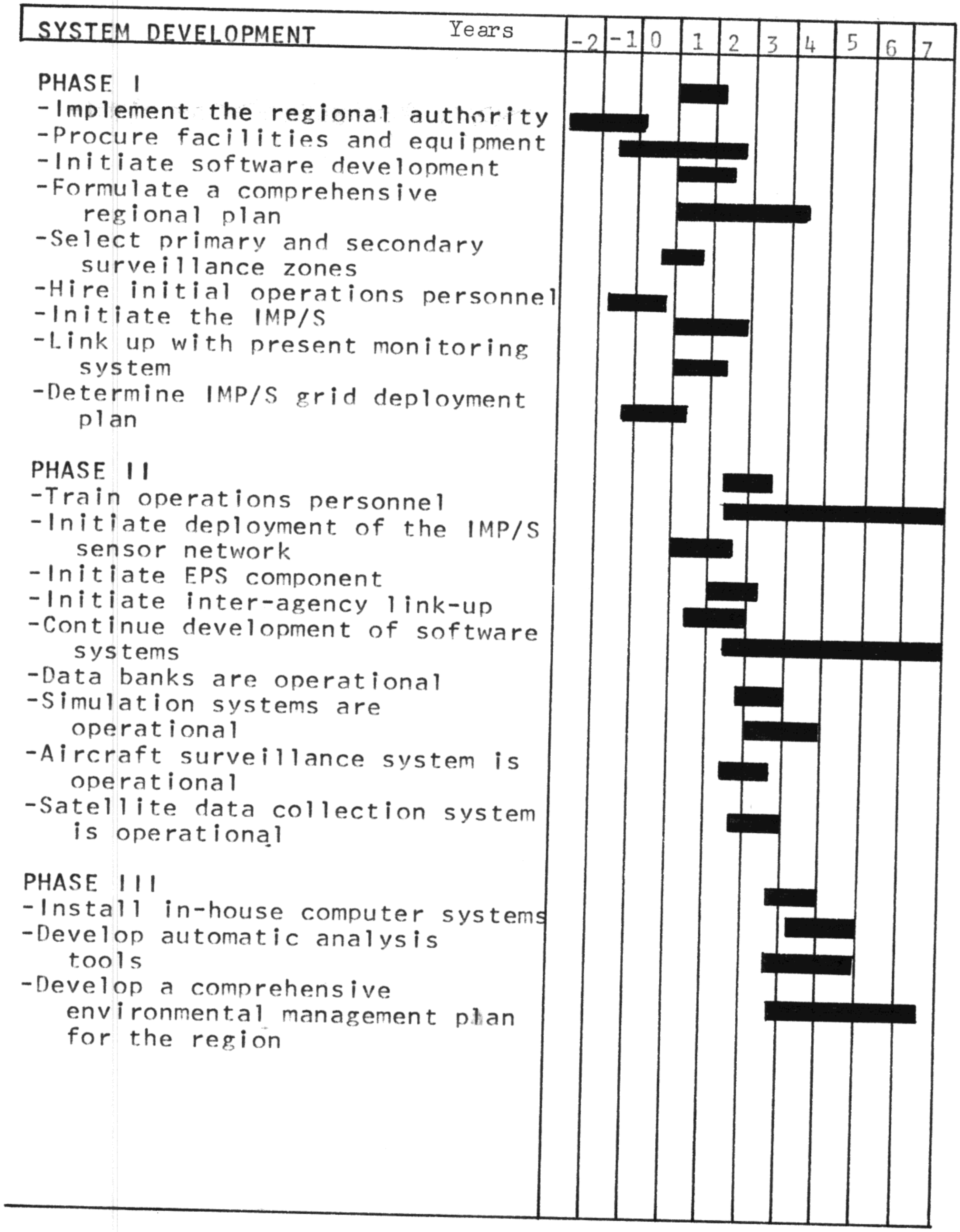


FIGURE 1.18

SYSTEM IMPLEMENTATION PLAN

systems analysts, management specialists and research personnel--are hired. However, many of the operations personnel for data handling and processing will not receive their training until the Interim phase. In addition, the present monitoring system is linked to the Surveillance Center and all monitoring functions are assumed by the IMP/S.

The second or Interim phase will be concerned with the deployment of the sensor system, and implementing the EPS and inter-agency linkup. During this phase the more sophisticated software for each of the simulation systems is developed and put into operation. The data banks are established, and the computer interface is put into operation. This phase can also be thought of as a shakedown period for the Surveillance Center in order to determine how well it meets the actual initial systemic needs, and where procedures or design changes are needed. The Continuing Operations and Growth phase extends indefinitely, and can be expected to undergo continual change. It is anticipated that during this phase the efforts of the research group associated with the Center should begin to bear fruit with increased software capabilities, improved retrieval, data handling and automatic processing equipment to aid interpretation and data analysis activities.

Each of the data collection systems will be deployed within a specific time frame and integrated with the IMP/S. The first system to be deployed will be the surface date collection system. This will involve the selection of high

priority surveillance zones within the larger surveillance sectors. Then the placement of environmental grids with their specialized sensors will begin. During the interim phase both the aircraft surveillance system, and the satellite data collection system will be integrated with the IMP/S. In addition, the entire grid structure will have been deployed, and all surface and subsurface sensor systems will be functioning. At this point the IMP/S will be operational.

In conclusion, the concepts discussed in this chapter represent the major integrating elements for the proposed environmental information, management and planning system. The purpose of this chapter was to briefly outline these elements and link them together into some kind of conceptual framework. Succeeding chapters will expand on this initial concept by examining in more detail its particular systems.

CHAPTER II

SENSING ENVIRONMENTAL CONDITIONS

The word "sensor" denotes a device which is designed to respond to specific physical phenomenon and subsequently translate certain attributes of the phenomenon into electrical signals or images. These signals or images represent the basic properties of that particular object, event or process. In come cases a sensor is designed to interact directly with the phenomenon being measured. In the case of remote sensing the gathering and recording of information occurs without the sensor coming into direct contact with the object or event being investigated.

The sensing of environmental phenomena by sensors is based on the idea that all materials, processes, and physical objects either radiate or reflect electromagnetic energy at certain frequencies or wavelengths. The sensor itself serves as a receptor for this energy and translates this energy into a specific electrical or analog property. The output of the sensor depends on its function and the phenomenon being monitored.

There are basically two types of sensors: interactive and remote. Both types of sensors are designed to transform energy from one format to another. This transformation process implies an information or measuring function rather

than an energy modification. Information, not energy, is the primary output of a sensor.

Interactive Sensors: As the name implies, interactive sensors relate directly to the phenomenon being measured. A sensor - as we have already noted - is designed to transform one form of energy (the input) into another form (the output of a sensor) in order to expedite the measurement of certain properties or to enhance the transmission of that energy to another location. Consequently, the output of a sensor always differs in some degree from its input. The amount of change between the input-output relationship will have a direct bearing on the sensor's ability to interact with and measure the phenomenon being investigated.

An interactive sensor may be envisioned as a combination of three major components. The first component is the sensing unit itself. The sensor picks up the energy-physical, chemical or electrical-characteristics of the phenomenon being investigated and responds to these characteristics in a certain way. The second component is the circuitry. The task of this circuitry is twofold: First, the sensor's immediate output is converted into a desired voltage or current; and then it is amplified and prepared for transmission to a central receiver. The third component of the sensor is the recorder/transmitter. This component functions both as a data storage unit and as a transmitter. When the sensor is

interrogated the transmitter is activated and the stored data is transferred to another point.

This interactive function is extremely important but it also poses some difficult technical problems. In order for a sensor to interpret the quantity and quality of a particular environmental condition it must be extremely sensitive to only that condition. At the same time, it must also minimize its influence on that perceived condition. Steven E. Summer noted that a sensor interacting with its environment also changes the physical phenomena that it attempts to sense. Consequently,

> ...it is desirable for a sensor to effect its environment only in a minimum way. If it senses incident light, it should block off as little light as possible. It it senses a fluid flow, it should impede the flow as little as possible. If temperature is to be measured, the sensor should not contribute to the heat.[10]

He goes on to point out that:

> This property of non-interaction is not related to the sensor's sensitivity. However, the amount of interaction should be kept as slight as possible or the sensor will consume the phenomena it is trying to control or detect.[11]

The primary function of this sensor is to measure the phenomenon being sensed. Measurement in this sense is defined as a process of applying a dimensional or numerical relationship to an environmental condition. A measurement system is conceived of as a network of specialized instruments designed to respond to a set of specific environmental conditions.

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[10]Steven E. Summer, Electronic Sensing Controls, (New York, Philadelphia, London: Chilton Book Company, 1969), p. 19.

[11]Ibid.

Measurement in this context is defined as a process of "mapping empirical properties or relations into a form of mathematical abstraction."[12]

In order to design and implement a system to measure a set of specific environmental conditions we must first of all determine the types of sensors to be used, their required output forms, and their relationship to the total system. Peter K. Stern classified interactive sensors into three broad categories:

1. By the function they perform in the measuring system. This manner of classification generates the following categories:

   a. Input or measuring transducers.
   b. Modifying transducers.
   c. Output or readout transducers.

2. By the input requirements of transducers. This division results in two basic classes of transducers:

   a. Self-generating (active) devices, which produce an energy output for a single energy input.
   b. Non self-generating (passive or impedance based) devices which require two energy inputs in order to produce a single energy output.

3. By the energy types involved in the transduction process.[13]

Using this classification scheme the sensor system can be briefly outlined as follows. The system will use mainly input or

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[12] H. M. Nelson, "Measuring Systems: Conception and Design" The Collection and Processing of Field Data, eds. E. F. Bradley and O. T. Denmead (New York: Interscience Publishers, 1967, p.313.

[13] Peter K. Stern, "Classification Systems for Transducers and Measuring Systems", Symposium: Environmental Measurements, Valid Data and Logical Interpretation, (HEW Publication, July 1967), p. 66.

measuring type sensors. This interactive system is designed to detect six broad energy bands - sound, heat, light, electrical, magnetic and chemical - on a highly selective basis. Their output formats will depend on the phenomenon measured, the type of energy detected in relation to that phenomenon and their internal circuitry. The system will utilize a combined amplitude and frequency modulation transfer method to transmit data from the sensor unit to a central receiver.

The relationship between the individual sensor units and the total sensing system is governed by their:

(a) Mode of operation, which may be either continuous (1. continuously acting systems) or intermittant (2. sampled data systems); or,
(b) Internal organization, which may be either in the form of a progression of cause and effect (1. open chain systems) or a system with regression (2. closed loop systems); or,
(c) Nature of output, which may be either in the form of an analogue of the required measurement (1. analogue output) or a digital representation of the measurement (2. digital output).[14]

Using these operational configurations we can characterize the IMP/S interactive sensor system as a continuously acting system. Its internal organization will be open based on a relatively simple cause-effect or stimuli-response relationship. The output will be either analog or digital depending on the type of measurement being taken, the energy source, sensor type and user requirements. Digital data will be used mainly for computational and analytical functions. Digital data will also serve as input for the ongoing simulation and early warning subsystems.

[14]Nelson, "Measuring Systems:Conception and Design,"p.318-320

The basic structure of the interactive sensor system and its relationship to the total system is outlined in Figure 2.2. The major components of this system are the sensor unit, amplifiers and supportive transducers which transform the sensor input into a suitable format for transmission. Each sensor unit will also have the capability for storing and conditioning its own input. Conditioning denotes the initial processing required to make the output signal of the sensor suitable for transmission. It also filters the signal so that unwanted data elements are not transmitted.

Once the signal has been conditioned it is coded. This coding operation is basically a process of quantizing or digitizing the amplitude of an analog signal. It is also known as an analog-to-digital conversion process. This conversion process is outlined in Figure 2.1.

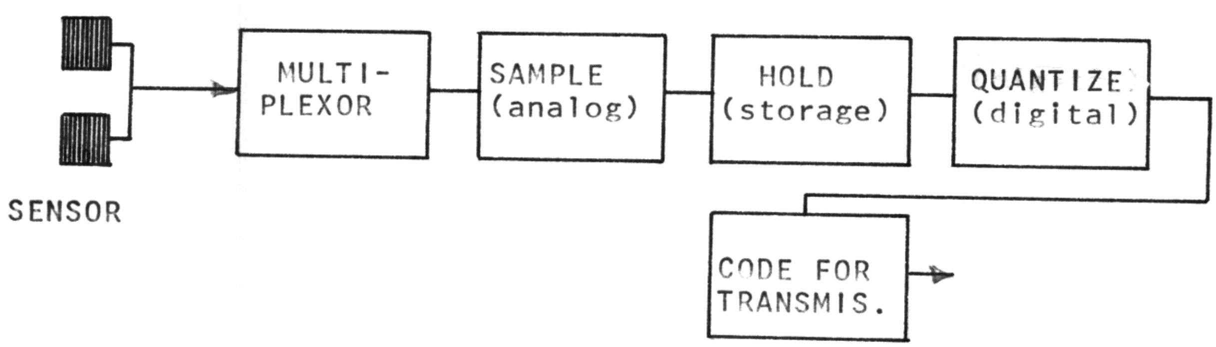

FIGURE 2.1

The conversion process consists of three successive operations--sampling, quantizing, and coding. G. E. Barlow describes these operations as follows:

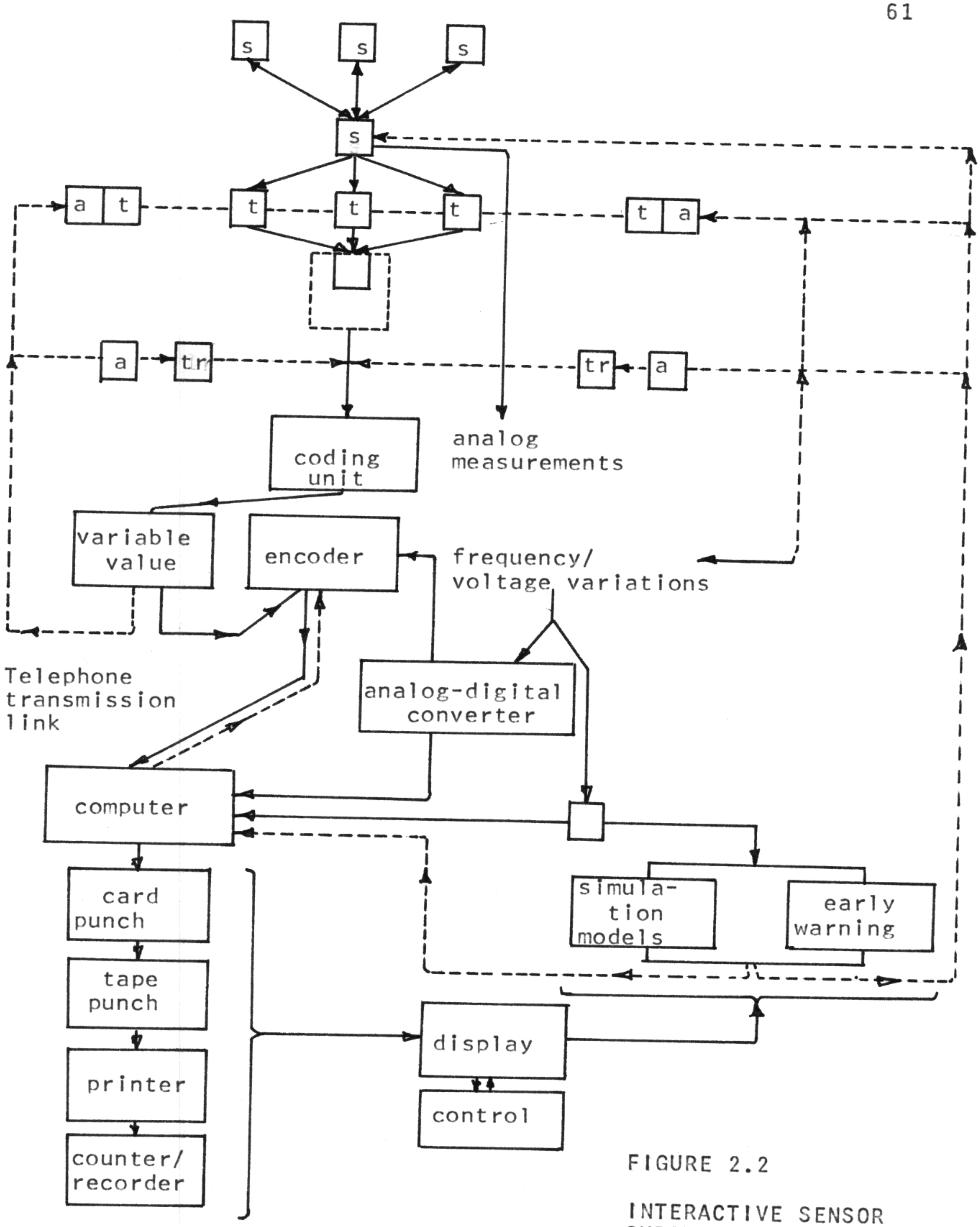

FIGURE 2.2

INTERACTIVE SENSOR SUBSYSTEM

S - Sensor
T - Transducer
A - Amplifier
Tr- Feedback Transducer

----- Feedback Flow
——— Direct Flow

> Sampling refers to the capture of the value of a continuous signal during an interval in which this value changes insignificantly. This is often associated with a suboperation holding or storage of this value while the succeeding operations take place. Quantizing is the splitting of the value of the sample into a number of levels, the number defining the resolution of the converstion process. The third process, coding, describes the labelling of the quantization levels in some systematic fashion, frequently normal weighted binary code.[15]

The value of converting analog signals to a digital mode is that:

> ...we can reconstruct the transmitted message with negligible error, provided that any noise amplitude is small compared with one quantum step. The process is termed regeneration, by virtue of which we can transmit digital signals over very large distances without significant distortion. Analog and semi-analog signals cannot be regenerated in this sense.[16]

The transmission link consists of the transmission medium and its input and output devices. Once the data has been collected, conditioned and coded, it is converted into a signal which can be telemetered. Telemetry, in this case, is defined "as the measurement of data occurring at a remote point."[17] The term is often qualified by the mode of transmission (e.g. radiotelemetry, commercial telephone links, etc.,) utilized. This telemetry function is "generally accepted to

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[15] G. E. Barlow, "Instrument Data Processing Systems" The Collection and Processing of Field Data, eds. E. F. Bradley and O. T. Denmead, (New York: Interscience Publishers, 1967) p. 412.

[16] A. E. Karbowiak, "Elements of Information Theory" The Collection and Processing of Field Data, eds. E. F. Bradley and O. T. Denmead, (New York: Interscience Publishers, 1967), p. 347.

[17] P. O. Gillard, "The Use of Telemetry in Field Data Collection," The Collection and Processing of Field Data, eds. E. F. Bradley, and O. T. Denmead, (New York: Interscience Publishers, 1967), p. 375.

include both the display and recognition of data and any primary recording that permits the data to be displayed or computed at some subsequent time."[18]

High reliability in telemetry systems is generally obtained by recording data at the earliest opportunity in the data transformation chain. This recording function is initiated at the detection phase and continuously monitored throughout the whole data transfer/modification process. In pre-detection recording

> ...the signal in the receiver is converted to a signal having a frequency suitable for recording. It is then recorded linearily with bias. Such a record can be replayed through the receiving equipment or through special replay equipment for optimum detection of the data. On the other hand, the data after demodulation, demultiplexing and/or decoding can be recorded using one of the many methods of recording data (galvanometer, paper tape, punched card, magnetic tape, etc.).[19]

While the coding process is used to quantize the amplitude of an analog signal, decoding "is used to reproduce the original signal to the nearest quantized level."[20] This process involves the identification of each data element or bit telemetered from the sensor unit. This operation consists of four sub-operations which involve;

> (1) bit synchronization, usually by means of a feedback oscilator whose phase is synchronized using a servo loop

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[18] Ibid.

[19] Ibid.

[20] Ibid.

to that of the bit rate, (2) reconstitution of bits to their original width, (3) word synchronization, by recognition of the synchronization pulse, and (4) error detection, by making use of parity.[21]

As the incoming data is decoded and demodulated it is prepared for processing and data presentation. Data presentation or display may be "on-line" or "off-line" depending on its priority status. On-line data display is defined as the display of data as it is being received. It is usually provided to permit an immediate evaluation of data or of the performance of the equipment. Off-line data processing and display is usually for low priority data which is summarized and presented to the user at regular intervals.

Remote Sensing Systems: A remote sensing device operates in one of three general ways: "(1) it detects reflected sunlight; (2) it detects energy emitted as a property of certain matter: or, (3) it records energy bounced off of the substance by an energy source carried along with the sensor."[22] Unlike interactive sensors, remote sensors gather data without coming into direct contact with the object or event being investigated. At the same time, these devices offer the potential for wide area coverage whereas interactive sensors are restricted primarily to small area or point measurement. However, both

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[21] Ibid.

[22] National Aeronautic and Space Administration, Remote Sensing: State-of-the-Art and Applications to Urban and Regional Planning, (Washington, D.C.: Government Printing Office, 1970), p. 1.

systems are designed to compliment each other by providing supporting data inputs on particular environmental conditions. This capability gives the IMP/S a multi-dimensional quality which is essential for monitoring and evaluating large-scale environmental processes.

Two basic ideas underlie the use of these sensors; the electromagnetic spectrum and the multi-spectral concept. The electromagnetic concept is best defined in terms of;

> ...wavelength (distance between wavecrests), wave velocity (speed of a wavecrest), wave frequency (number of wavecrests passing a point per unit time) and energy level (measured in photons). Much of the energy of an ocean is propagated in the form of ocean waves; similarly, electromagnetic energy from the sun is propagated as electromagnetic waves. This latter form of energy moving at approximately 186,000 miles per second in a harmonic wave pattern can vary according to wavelength or frequency and therefore constitute a spectrum of energies--called the electromagnetic spectrum. The terms gamma ray, X-ray, ultraviolet, visible, near infrared, thermal infrared and microwave constitute common nomenclature for various positions of the electromagnetic spectrum each of which can provide useful information when multispectral remote sensing techniques are utilized.[23]

The multispectral concept, on the other hand, is based on the idea that any object (e.g., a tree, a river or a group of houses)...

> ...transmits, reflects, absorbs, emits and scatters electromagnetic energy selectively with regard to wavelength. The tone or brightness with which the object is registered on a multiband photo is in direct proportion to this

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[23] Donald T. Lauer, "Forest Vegetation Analysis Using Multispectral Remote Sensing Techniques," <u>Papers From The 34th Annual Meeting</u>, (American Society of Photogrammetry, Falls Church, Virginia, March, 1968), p. 166.

> energy. Therefore, two objects which may be difficult to discriminate on imagery obtained in one spectral band, because they have similar reflection or emission characteristics in that band, may have very different tones when imaged in another band of the spectrum. The technique of simultaneously obtaining imagery from more than one spectral band is termed "multiband spectral reconnaissance".[24]

Remote sensors are designed to function in both the visible and near-infrared spectral bands. The primary process involved here is the recording, directly on a film emulsion, of reflected electromagnetic radiations of wavelengths in the visible and near-infrared spectrum. By using proper film-filter combinations these wavelengths of radiation can be imaged in their entirety or in a wavelength bands as narrow as a few millimicrons. Remote sensors can be classified as either imaging or non-imaging depending on the parts of the spectrum used to investigate a particular event or object.

The actual differences between imaging and non-imaging remote sensors are mainly one of degree. Imaging type sensors operate in the visible electromagnetic spectrum whereas non-imaging devices operate in the non-visible spectrum. The derived image is the basic output of both kinds of sensors. The image itself is an expression of the spectral sensitivity of the film or detector, the filter combination and the reflectance or emission properties of the object. It should be emphasized that the output of both types of sensors can be

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[24] _Ibid_.

processed to produce a pictorial result. Conversely, images can be converted and recorded on magnetic tape as electronic pulses for subsequent computer analysis and processing.

Multispectral Scanning: An integral part of the proposed IMP/S will be a combined aerial and orbital multispectral system which will be used to monitor large areas of the earth's surface by registering the spectral characteristics of the phenomenon or objects to be monitored. This technique is based on the concept that each phenomenon or object tends to reflect or emit energy within a certain specifie wavelength. Using special scanners multispectral photographs can be taken, processed and interpreted in order to detect significant changes in the environment over time.

An aerial multispectral scanning system is shown in Fig. 2:3. This system is designed to operate within a selected set of spectral bands and records data on specific phenomena as it passes over a target area. The spectral band radiation picked up by the sensor is converted into electrical signals. These signals are then amplified and recorded on tape. The processing system converts the recorded signal into a recognizable image. This image is then prepared for further computer analysis or display. Figure 2:4 describes the overall process involved.

A processor system is used to pick out those elements in the derived image that are important to the user. One such processor system currently in operation is the SPARC(Spectral

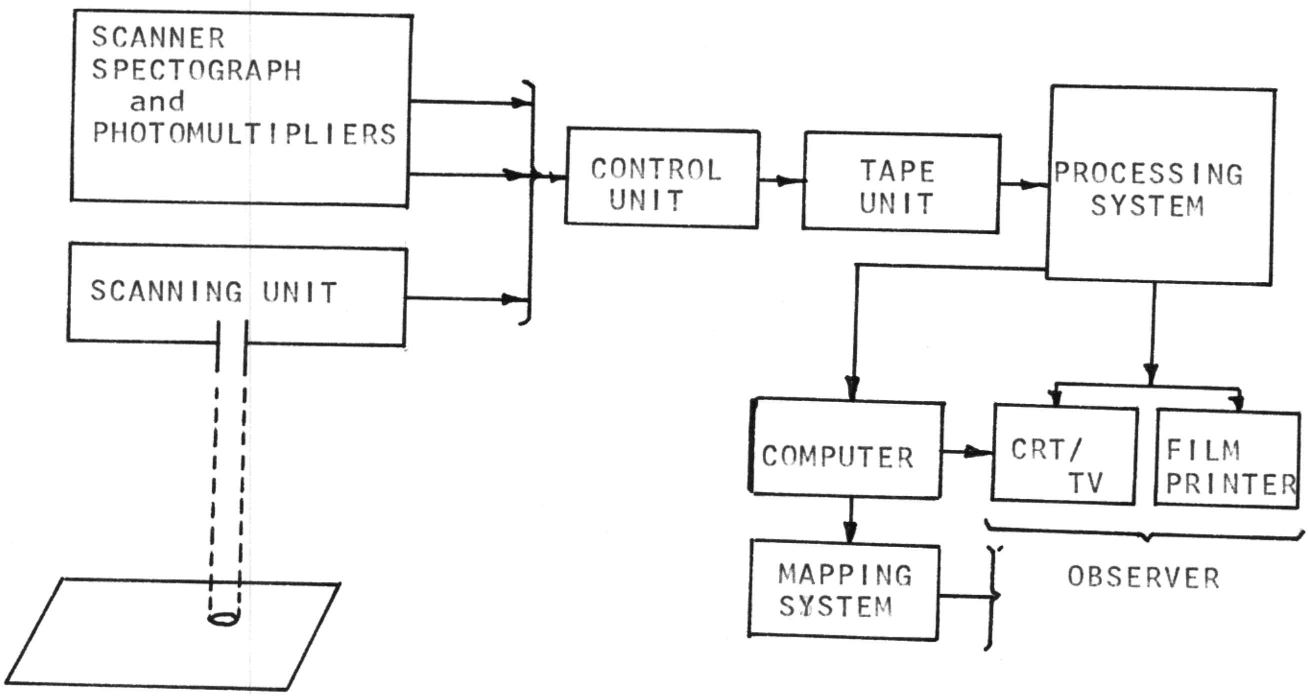

Fig 2:3 MULTISPECTRAL SCANNING SYSTEM

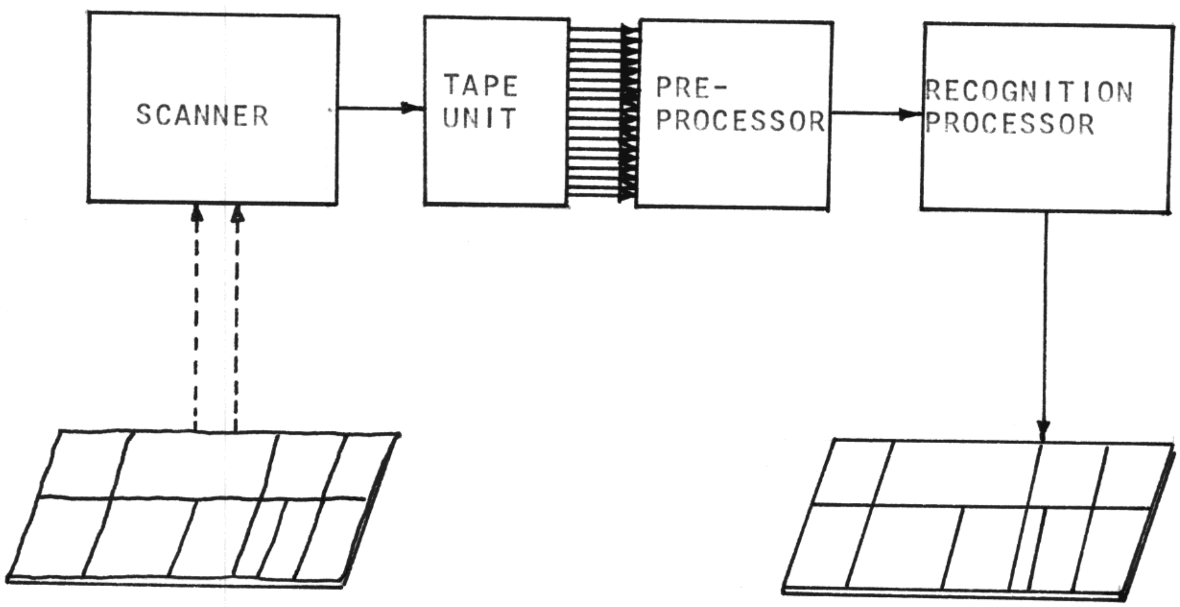

Fig. 2:4 MULTISPECTRAL REMOTE SENSING AND PROCESSING SYSTEM

Analyzer and Recognition Computer) operated by the University of Michigan. The purpose of this system is to distinguish

> ...automatically targets from backgrounds at real time rates by the statistical discrimination of multispectral signals. The fundamental operational principal of the computer is based on a likelihood ratio; this mathematical quantity is used in a statistical decision rule which tests whether a given "instantaneous sample" belongs to the target or to one of the backgrounds. The sample may consist of voltages produced by the reflected powers in N spectral bands from a particular resolution element in the scene being observed...[25]

Once the spectral signals are modified it is displayed on a display unit for further interpretation.

Multispectral data can be evaluated by one of three techniques: (1) visual interpretation, (2) densitometric measurements, and (3) through automatic methods. Because we are mainly concerned with processing a wide range of photographic and multispectral data in the fastest time possible, we will concentrate on automatic evaluation systems emphasizing the spectral response classification method developed at Purdue University's Laboratory for Applications of Remote Sensing better known as LARS. This method is based on a pattern recognition technique. By pre-programming a computer with spectral characteristics representing various materials the computer is able to automatically classify input spectral data upon recognition by a selection and comparison process.

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[25]R. E. Marshall, _et al_. "Use of Multispectral Recognition Techniques for Conducting Rapid Wide-Area Wheat Surveys," _Proceedings of the Sixth International Symposium of Remote Sensing of Environment,_ Vol. I (Center for Remote Sensing Information and Analysis, Willow Run Laboratories, the University of Michigan, Ann Arbor,Michigan, October, 1969), p. 4.

This spectral response method is built around three basic computer programs. The first program "PICTOUT" produces gray level printouts of each spectral band recorded by a scanning unit. The second main program is called "LARSYSAA". This program monitors the whole process and selects the most optimum spectral bands for display. A "DISPLAY" program transforms the classified data into a map or tabular format.

Fig. 2:5 describes an automatic multispectral data analysis system. The system described here is similar to the LARS approach. The major difference is found in the display subsystem. The LARS system is based on a passive display mode which provides computer printouts or maps either upon demand or automatically. The IMP/S, on the other hand, is geared for a more fully interactive mode which allows the user to work directly with his data. For example, the spatial data derived from aerial or orbital scanning can be converted into electronic pulses and combined with other data formats or routed into special processing subsystems which enable the user to relate this data with aerial photographs, land use, demographic and/or environmental maps as desired. This ability to integrate and arrange various data formats and/or mapping systems can serve not only to enhance multispectral data but also to present a more powerful analytical tool to the research analyst, administrator and regional or urban planner.

Multispectral recognition techniques are invaluable for conducting rapid agricultural surveys, investigating soil

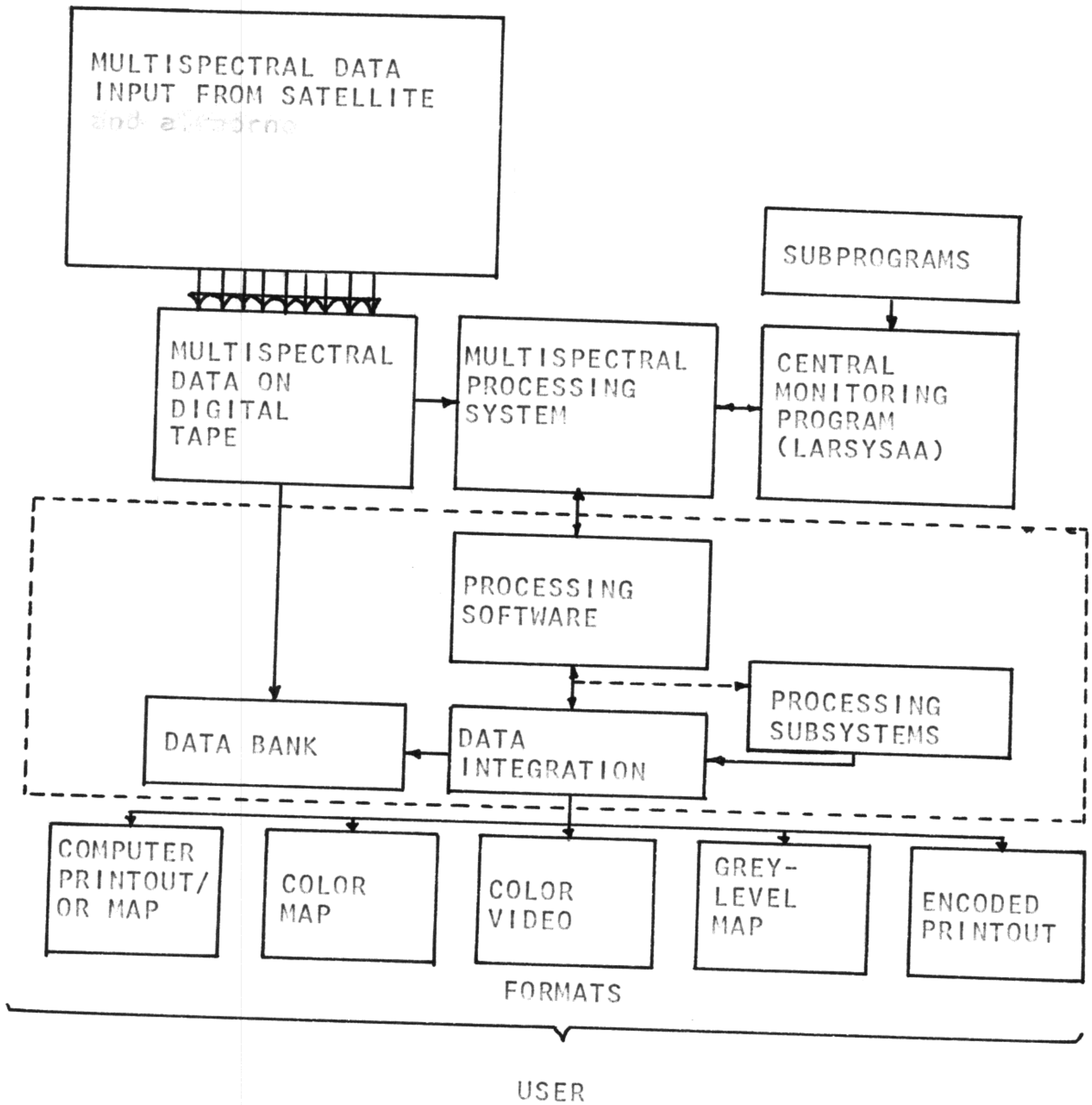

FIGURE 2:5 AUTOMATIC
MULTISPECTRAL DATA
ANALYSIS SYSTEM

types, detecting temperature ranges for various materials, observing special geological formations, detecting geological faults and land collapse areas, conducting hydrogologic surveys and facilitating topographical mapping. However, multispectral imagery cannot totally replace photography. There are many conditions that are enhanced and more easily detected on aerial and satellite photographs than on spectral imagery. Consequently, both techniques will be used in the IMP/S in order to optimize the monitoring function of the total system.

Although these two sensor systems--the multispectral scanning and the aerial/satellite photographic systems--will be the major data acquisition modes for large area measuring and observational purposes they will be supplemented by other more specialized systems. These systems will consist of Vidicon cameras which are designed to operate in the visible spectrum for real-time observation of the earth's surface; and, side looking radar, which utilizes high frequency radar beams to record reflection patterns. Radar imagery is used primarily for night observation and where cloud cover precludes aerial or satellite photography. In addition, the less commonly used radiometers, radar scatterometers and spectrometers, which are used for analyzing soil and atmospheric composition by spectrographic analysis will be employed. Special composite systems encompassing a number of individual remote sensing devices into special packages will also be used for multi-purpose, observation and measurement requirements.

Multispectral Photography: Multispectral photography like scanning detects reflected sunlight or radiation throughout a wide electromagnetic spectrum. This reflected energy carries with it the spectral characteristics of the object or event being sensed. Using these spectral characteristics, the user or user agency can then interpret and analyze certain elements or relationships occurring within a specific environment.

The multispectral or multiband photographic concept is based on the fact:

> ...that each type of earth resource feature tends to reflect and emit radiant energy in distinctive amounts at certain specified wavelengths. Consequently, when multiband photography is acquired simultaneously in each of several wavelength bands, each type of feature theoretically becomes identifiable by virtue of its multiband "tone signature" or "spectral response pattern.[26]

By relating these spectral patterns to known conditions it becomes possible to monitor and identify fairly subtle changes occurring in the environment. For example, multispectral photography can be used to detect such diverse phenomenon as pollution sources and their dispersion patterns, the condition of crops and vegetation, the extent of phytoplankton concentrations and suspended non-organic particulant matter in coastal waters and soil conditions over large goegraphical

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[26] Robert N. Colwell and Jerry D. Lent, "The Inventory of Earth Resources on Enhanced Multiband Space Photography," Proceedings of the Sixth International Symposium on Remote Sensing of Environment, Vol. I, (Center for Remote Sensing Information and Analysis, Willow Run Laboratories, The University of Michigan, Ann Arbor, Michigan,October, 1969), p. 134.

areas. In addition, this technique can be used to assess the condition of rivers by noting the spectral patterns given off by various chemicals in the water, the location and quality of timber resources, the kinds of land use occurring in a particular region, potential environmental hazards such as flooding conditions, slide and earthquake zones, and the condition of housing in a metropolitan area. The key factor here is knowing the unique spectral characteristics associated with each object, process or phenomenon being monitored.

This remote sensing technique enables the user to select a series of spectral bands in the near ultraviolet, visible or near infrared region of the spectrum in which to collect photo images. A viewing device serves to combine these spectral images into one color presentation. This viewer also allows the user to manipulate his images in order to enhance certain relationships he is seeking. Thus, multispectral photography has the unique capability of enabling the observer or analyst to create a number of composite images by increasing the density of one image in relation to the others in order to serve the specific purposes of his discipline or requirements.

The basic instrumentation comprising this system consists of a multispectral camera and a viewer. The camera is designed to take a series of spatially identical photos. The images are recorded on film at precise locations with respect to a common coordinate system. This enables the camera to align itself correctly in relation to the object or phenomenon being sensed.

Filtration into different spectral bands cause density differences in the images when there exists variations in the spectral reflectance of the object. The viewer optically superimposes these images into a single image in which the density, differences appear as colors. Using this superimposition method it is possible to expand the relatively few perceivable density differences into many perceivable color differences.

The derived image and its contrast (i.e., the differences in tone or color between an image and its background) is a primary criterion that governs the spectral relationships and the subsequent interpretation of the imagery. Donald T. Lauer of the Forestry Remote Sensing Laboratory located at the University of California, Berkeley, noted the following with respect to multispectral photography:

> The image tone or color of a terrain object as seen on multispectral imagery is an expression of the spatial sensitivity of the film or detector, the spectral transmittance of the filter, the spectral reflectance and/or emittance from the object, the spectral distribution of the energy source and the spectral scattering by atmospheric haze particles.[27]

In selecting optimum film-filter combinations for environmental analysis, it is necessary that the above factors be taken into consideration. In addition, the spectral characteristics of the object or objects being photographed or scanned must be accurately known. This prerequisite means

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[27]Lauer, "Forest Vegetation Analysis Using Multispectral Remote Sensing Techniques,", p. 167.

that samples of the representative objects must be secured for spectral analysis before any extensive multispectral photographic effort is made. The reason for this is that each object has an unique spectral signature. Without a prior knowledge of this signature the interpreter could not accurately identify the object or event nor determine the relationships occurring within a particular environment. However, even if an adequate sample is secured the almost daily changes in environmental, observational and sensor conditions can produce variations in the sensed radiation that tend to distort the underlying relationships being sought. Special programmed processing systems can, to some extent, overcome this distortion effect by relating photo density/tonal patterns to specific spectral signatures. By carefully scanning several images simultaneously, a tone signature for each digital spot is automatically determined and compared with known tone signatures. Once a comparison is made and the tonal pattern established, an image can be accurately reproduced for further interpretation.

Multispectral photography, through the proper selection of films and filters, can cover the whole electromagnetic spectrum. Because this system can work within a wide spectrum range it can overcome certain major constraints in recording data during adverse weather conditions or during nighttime hours. For example, infrared photography can be used at night to detect and measure thermal radiation beyond the visible

spectrum. The objects or targets sensed by infrared survey methods can be divided into two basic categories: "1. high temperature targets (i.e., active volcano craters, the efflux of hot springs and hot gases, subsurface and forest fires, etc.), 2. targets which possess a temperature contrast with the background as a result of solar heating."[28] This thermal radiation is sensed by special electronic equipment which converts the invisible infrared radiation from the target to visible radiation on a film emulsion or a cathode ray tube.

The value of multispectral photography is based on its unique capability for providing a graphic display for almost immediate interpretation. This display has the additional advantage of encompassing large areas at one time freezing, in effect, land use, crop status, weather conditions, traffic patterns, etc. as of the moment. Because the images derived from these sensors can be readily transformed into electronic signals and stored on magnetic tape it is possible to use a single frame of imagery or computer tape for a variety of analytical purposes. Imagery can also be used to show interrelationships between various elements on a single frame. For example, the image can be disaggregated in order to emphasize

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[28] B.V. Shilin, et al. "Infrared Aerial Survey of the Volcanoes of Kamchatka," Proceedings of the Sixth International Symposium on Remote Sensing of Environment, Vol. I (Center for Remote Sensing Information and Analysis, Willow Run Laboratories, The University of Michigan, Ann Arbor, Michigan, October, 1969), p. 175.

open spaces, cultural features such as highways and houses, bodies of water or any other distinctive attribute of the scene. Once these elements have been disaggregated, they can be stored in computer files for analytical and mapping purposes.

The reason for measuring environmental conditions is to determine both the nature and the magnitude of the prevailing physical, biological, ecological and climatic forces active in a particular environmental setting. In addition, we are interested in analyzing and correlating these conditions in relation to known social, economic and technological variables in order to facilitate an effective basin growth policy and environmental management practices.

The assumption underlying the above is based on the idea that if a planner, research analyst, or environmental administrator knows the primary cause-effect relationships governing certain environmental conditions they should be able to respond to these conditions in a more effective manner. This response can take one of three directions. They can take steps that will either alter that condition, make it more acceptable, or prevent it from occurring by eliminating the causes of a particular condition, event, or series of events through effective planning and management. The key factor here is that their ability to detect or anticipate certain thresholds is greatly enhanced before they reach critical levels.

CHAPTER III

THE SENSOR NETWORK

This chapter and the two succeeding chapters will have two major objectives in mind: first, to elaborate further on the previous chapter dealing with environmental sensing; and secondly, to provide a stronger foundation for a more complete definition of the IMP/S. The format or approach to be used in this and the next two chapters will be as follows: First, the network concept and its application to sensor systems will be defined in more precise terms. After this initial defining process is completed the data collection systems to be used in the IMP/S will be examined in greater detail. Chapters four and five will examine the telemetry network, and the computer system with its related processing, analytical, interpretation, and information dissemination functions.

A network is generally defined as an "interconnected or interrelated chain, group or system."[29] Using a slightly different interpretation, a sensor network can be described as consisting of a number of data collection systems linked together by a series of nodes, and terminals which serve to

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[29] Websters Seventh New Collegiate Dictionary (1969)

expedite the flow of data from one point to another. A somewhat simplified concept of an operational sensor network is illustrated in Figure 3:1. As conceived here, the network consists of four major systems; a satellite data collection system, an airborne surveillance system, a surface sensor system, and a subsurface data collection system. Each of these systems encompass four basic components: a sensor component consisting of remote and/or interactive devices designed to monitor and measure environmental conditions; a telemetry subsystem for transferring sensor data to a central receiver; a computer system which automatically interrogates the various data collection systems at certain time intervals, records and subsequently indexes, codes, analyzers and interprets the sensor data; and, a display component which facilitates the dissemination of data to a user group.

Each of the data collection or observation systems included in the IMP/S sensor network is designed to gather information from a particular environmental setting. As a result of this partitioning of the total environment into four different, but related operational environments--atmosphere, surface, eco/systems and subsurface--each system has its own sensor configuration and functional requirements. The communications or telemetry framework will provide the essential linkage element which integrates these individual sensor systems into one operational system. However, in describing these data collection systems one should not perceive them as being totally independent from one another; in fact, the sensor

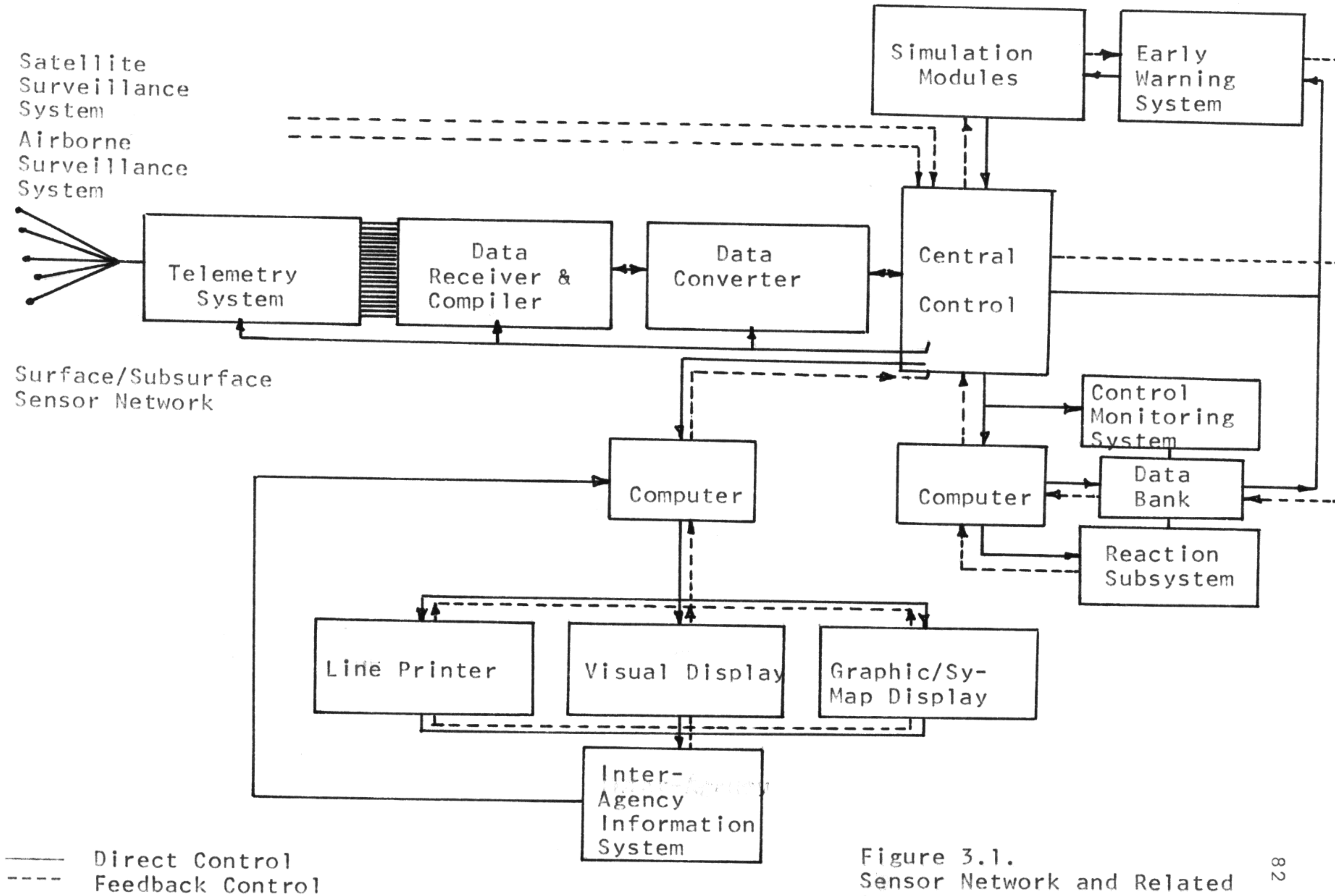

Figure 3.1.
Sensor Network and Related Systems

network is designed to maintain a large degree of interdependency between the systems in terms of their coverage, sensor compatibility, and computer hardware. Keeping this interdependency function in mind we can now proceed to briefly examine each of the data collection systems that will be used in the IMP/S sensor network.

The satellite data collection system will be used to maintain coverage over large geographical regions with a minimal cost factor. In addition, it will serve as a secondary communications link designed to receive data input signals from surface and subsurface sensors andthen transmit that data to a control center. The advantages of this system are two-fold: first, it has the capability to survey large areas while at the same time it is able to focus in on specific regions for in-depth surveillance and monitoring; and, secondly, it is able to monitor regions on a continuing basis in order to get time series data which is essential for long range planning.

The specific functions of this system will be to survey and monitor environmental conditions, urban and regional land use patterns, transportation networks, crop conditions, air and water pollution sources. It will also provide data for assessing natural resources, ecological conditions, regional growth patterns and potential environmental hazard areas.

The satellite data collection system will include the following sensor devices:

1. Spectrometers: This sensor will be used to determine refraction indexes of certain materials within narrow spectral bands. This spectrometer will be particularly useful for analyzing the composition of air and soils in various spectral bands.

2. Multispectral Scanner: This device is used to record spectral patterns emitted or reflected from various objects and/or processes. Its primary functions will be to detect various forms of air and water pollution, their sources and dispersion patterns, cultural features, land uses and land use intensity factors, spatial patterns and agricultural conditions.

3. Radiometer: This sensor is used to measure electromagnetic, radiant and acoustic radiation. It will be used primarily for surveying crops and for measuring the thermal or heat factor in various environmental processes.

4. Radar: This device emits a high frequency beam and subsequently records the reflection patterns defined by the beam. It will be used mainly for regional mapping, geological surveying, detecting urban spatial patterns and recording certain cultural features such as transportation networks, surface pipe and electrical transmission lines and structural characteristics. Because of the weight and power constraints of current satellite systems this device will be used only on a limited basis. However, it will be used extensively in the airborne surveillance system.

5. Panoramic Camera: This camera device is designed to operate in both the visible and near infrared spectral regions and it is used to record reflected solar radiation. Its primary function will be to photograph large areas of the earth's surface for analysis and interpretation of environmental conditions and trends over long time intervals.

6. Multiband Camera: This camera is designed to operate in a wide range of spectral bands. Because it affords a finer degree of detail, it will supplement those photographs derived from the panoramic system. The multiband camera will be used primarily for environmental analysis, land use, agricultural and natural resource assessment.

7. Vidicon: This device can operate in a number of spectral bands and it generates an image by recording reflected solar radiation. As the radiation is detected by the camera it is immediately converted into electronic pulses, and subsequently stored on magnetic tape and prepared for transmission to central control. After the electronic image has been received it is reconstructured and disseminated as a photograph. This system will be used primarily as a real time device for interpreting current environmental conditions on a recurring basis.

The aircraft surveillance system will operate primarily in the lower atmosphere (2,000 to 50,000 feet). Its sensor configuration will be similar to the satellite system with the

exception that it will not carry panoramic or vidicon cameras. Although both systems will have similar sensor configurations the aircraft system will be able to achieve greater detail in its imagery. In addition, it is extremely flexible in its application being able to gather data on a highly selective basis whereas the satellite system is used primarily for continuous or repeated coverage. Because of its ability to move quickly and almost anywhere and operate in a variety of weather conditions, the aircraft system can also maintain a flexible survey and monitoring plan for multiple and complementary sensors. This inherent flexibility and adaptability will enable this system to concentrate on certain areas of the environment zoned for intensive surveillance such as river basins, industrial complexes, forests and urban areas. It will also allow the IMP/S to effectively supplement satellite and surface data inputs for more effective environmental analysis.

The surface monitoring system is designed to monitor and measure phenomena on or near the earth's surface. It will utilize both remote and interactive sensors distributed within an environmental grid. The grid serves as the basic framework for distributing permanent, mobile, and expendable sensors in the environment in order to maximize data flow and provide for optimum environmental coverage.

The surface data collection system is primarily concerned with measuring a wide range of phenomena in terms of the

prevailing physical, dynamic and biological conditions of a particular environment. To accomplish this mission the system will have the capability to measure not only surface phenomena but also atmospheric conditions as well. Sensors designed to monitor and measure air quality, meterological parameters, water quality and biological conditions will be used. The data derived from this sensor system will then be correlated with supplemental social, economic, demographic and medical data derived from an inter-agency information system. In addition, environmental data provided by the other systems will be integrated into the information framework so that a fairly comprehensive profile of the environment under surveillance can be provided to the user group. An example of a sensor configuration for this data collection system will be as follows:

1. Robot Water Monitoring System: This system is designed to collect large volumes of data concerning the characteristics of water resources and for detecting water pollution before it reaches a critical level. Each remote unit is this system will be equipped with sensors to measure: oxidation reduction potential, chloride content, dissolved oxygen, conductivity, temperature and turbidity.

The system, as conceived here, is primarily an interactive one. In many respects it will be similar to the Ohio River Valley's Sanitation Commissions (ORSANCO) robot monitoring network. The ORSANCO network consists of fourteen

stations dispersed along the Ohio River and its major tributaries. These stations are linked to a central receiving station and a data processing center. The receiving station automatically interrogates each remote unit at certain time intervals. In response, each unit transmits readings on quality conditions as they are being measured at the moment. Data received at the data processing center are punched on tape for storage in the computer and are typed on a log chart in conventional units for visual examination. The frequency of interrogation is based on the need to interpret relationships between certain quality characteristics. The designers of the system noted that in order to study these relationships "we need at least 20 pairs of values to get statistically meaningful results on a daily basis. From a practical standpoint, this requirement indicates the desirability of interrogating stations at least once an hour."[30] This requirement would also apply with little modification to the IMP/S water monitoring system.

The computer system used by the ORSANCO network also has the capability for integrating water quality data from other sources. For example the U. S. Weather Bureau and the U. S. Geological Survey supply data on daily river flow to the ORSANCO computer files. In addition, information is supplied by the Public Health Service and Corps of Engineers to ORSANCO

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[30] William L. Klein, David A. Dunsmore, and Robert K. Horton, "An Integrated Monitoring System for Water Quality Management in the Ohio Valley," Environmental Science and Technology, (October 1968), p. 766.

to develop and continually upgrade water quality criteria and waste control measures. The IMP/S network would have a similar but more comprehensive inter-agency linkage to supply additional data inputs.

The ORSANCO monitoring system has had a number of practical applications beyond its monitoring function. For example, one important application has been the tracing of oil spills and accidental discharges into the river flow. The monitoring system has also been used to detect unusual conditions of dissolved oxygen and to develop a better understanding of the relationships between dissolved oxygen, river flow and sewage treatment processes. In terms of specific applications the authors stated that,

> ...the ORSANCO robot monitor and data processing system is being used to determine cause-and-effect relationships with regard to river quality changes, to trace the effect of spills and accidental discharges for the protection of downstream water users, and to improve opportunities for tailoring waste treatment practices to river quality conditions. The essential contribution of the system lies in the opportunity it provides to apply a systems-type operation to water quality management problems.[31]

2. Automatic Water Analyzer System: This system is used to make multiple parameter measurements of water quality in high pollution areas. The basic network is built around a Technicon CSM6 water quality analyzer. Connetta and Adelman of the Technicon Corporation described this sensor unit as a device where a "sample is automatically introduced and prepared; reagents are added in their proper sequence; a reaction ensues

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[31] Ibid., p. 771.

and is finally read out in some form."[32] This unit is capable of analyzing "6 parameters continuously and simultaneously on either a monitoring or individual samples basis."[33] The CSM6 like the ORSANCO system uses a telemetry transmission mode controlled by a central station. This capability enables the water analyzer sensor to transmit data using one of two procedures: an automatic procedure which telemeters data to a central receiver on a real-time basis; or, a store-then-transmit procedure which allows the sensor/analyzer unit to gather data over a number of hours and then upon command from the central receiver transmit the stored data in compressed signals. It should be noted that this analyzer system will not only be important for routine monitoring and analysis but also for controlling environmental systems. For example, the Minneapolis-Saint Paul Sanitary District applied early in 1967 for a demonstration grant to use advanced techniques to control and monitor sewer problems. The "Regulator Demonstration Program" as it is known, proposed to install:

> ...control gates at key points in the collection system, along with sewer level monitoring and telemetered rain gauges to allow optimum utilization of the existing collection system on a real-time basis. The central operation position will use a real-time process

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[32]A. Connetta and M. H. Adelman, The CSM6: A System for the Multiple Analysis of Water Parameters, (Technicon Corporation, New Jersey, 1970), p. 125.

[33]Ibid.

> computer, with multiprogramming capabilities to acquire data on rainfall, runoff, and system status, and to allow real-time application of modeling techniques to determine operating strategies.[34]

In addition, five river monitoring stations employing the CSM6 Auto Analyzer systems were installed to measure 6 parameters or chemical constituents in 24-hour samples collected at various locations in the sewer system. The data derived from these analyzers were then telemetered to a central processing point for further analysis and integration with other data formats.

3. River and Shallow Water Buoys: This system is designed to complement both the robot monitoring system and the automatic water analyzer system. Specifically, it will be used to detect area precipitation and evaporation rates, runoff conditions, discharge rates, water temperature, the amounts of solar radiation falling on a particular area, river oxygen demand, stream velocity, pollution dangers and potential flooding conditions.

The buoy system will be primarily an active detection sensor network utilizing radiometers, photodiodes, water analyzers and other devices designed to measure environmental conditions occurring in the immediate vicinity of the sensor. The basic sensor device will be a radiometer instrument. This

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[34] James J. Anderson, et al., Application of the Auto Analyzer to Combined Sanitary and Storm Sewer Problems, (Technicon Corporation, New Jersey, October 1967), p. 1.

device will use two steerable detectors, electronic equipment and recording devices all of which are stored within the buoy. By generating controlled optical signals the radiometer can detect water evaporation and local heat radiation. The data is then recorded, and processed by a small, solid state, on-board computer. As the data is processed it is also conditioned for transmission to a central receiver. Power for the buoy system will be provided by solar batteries backed-up by on-board chemical batteries in order to maintain sensor operation in case of a malfunction in the solar powered system.

4. River Gauge Network: The river gauge network is concerned with gathering stream flow data such as stream velocity, water temperature, biological oxygen demand (BOD) and conductivity. These gauges are designed to operate in remote areas and provide point data for long term analysis. The data is stored in the sensor unit on paper tape and regularly picked up by special teams. Once the data tape is secured, it is automatically key punched and placed into a computer for processing. This processing operation transfers the data onto magnetic tape and which can then be used as input for planning and pollution investigation studies. In addition, it is used as input for the various simulation modules utilized by the IMP/S.

5. Turbidimeters: This device is designed to measure water clarity at selected points by utilizing controlled optical signals. The water is continuously monitored by allowing it to flow between a series of photoelectric devices. The

photoelectric cells detect the amounts of suspended particles passing through a light beam. These particle contacts are subsequently recorded on tape and prepared for further processing. Since the turbidimeter will be integrated with the buoy system it will be able to use the same on-board computer system and telemetry unit. However, in some cases--especially in high pollution sectors--this device will be combined with the water analyzer system.

6. Oil Spill Detector System: This detector is a highly specialized sensor unit designed to sense oil slicks and other water pollutants of a similar nature. The oil spill detector like the turbidimeter will be part of the buoy system and will alert the on-board computer if an oil slick is sensed. Once the alert is received by the central station, additional sensors can be brought into action or if the area is readily accessible investigating teams can be sent to the scene.

In designing a highly sensitive and flexible water monitoring system, it is extremely important that the sensor units be located in those areas which can give a good sample of the river flow and its quality characteristics. These units must also be dispersed in sufficient numbers in order to give the water monitoring/analysis system adequate coverage. In addition, consideration must be given to the dynamic response of the sensors to fluctuating conditions. In relation to this particular point, Duane G. Chadwick of Utah State University noted that:

> Because of the high variability of hydrologic data, a particularly useful system must have a sufficiently smaller error factor in order to allow measurement of the variable under scrutiny to a satisfactory accuracy. Errors caused by time and space problems have been cited as being very significant to the usefulness of the data. To reduce these errors to an acceptable level there needs to be a sufficiently large number of stations and data should be taken sufficiently often at each station.[35]

7. Air Monitoring System: As an integral part of the Surface Data Collection System the air monitoring system will be primarily concerned with monitoring and measuring the air quality over particular regions. Data collected from this system will be continuously combined with other sensor data outputs in order to create a multi-dimensional picture of the air quality in a specific environmental context.

This multi-dimensional concept is extremely important because air quality is dependent on a vast number of interacting variables and conditions. This complexity was noted by Robert R. Ryder in his articles describing New York City's air quality monitoring system where he stated: "Air pollution, particularly in metropolitan areas is a function of widely distributed sources of contaminants and meteorological conditions which prevail over a large geographical area."[36] Consequently, the effective measurement of air quality requires a

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[35]Duane G. Chadwick, "A Hydrologic Monitoring System" Proceedings of the IBM Scientific Computing Symposium on Water and Air Resource Management, (IBM Data Processing Division, White Plains, New York, 1968), p. 51.

[36]Robert R. Ryder, "New York City Automated Air-Quality Data Collection Network," IEEE Transactions on Geoscience Transactions, (April, 1970), p. 81.

rather extensive network of monitors covering the entire area under surveillance. He also pointed out:

> A broad-based monitoring network, operating on a continuous basis is necessary for proper management of the city's air resources for several reasons: first, the nature and extent of pollution in the atmosphere must be known in quantitative terms; second, the dynamics of the air and its pollutants must be known; and third, the effects of air pollution control measures must be charted as these measures are placed into effect.[37]

In addition to monitoring air quality, the system is able to supply information for future analysis of medical data, provide data for testing air quality prediction models and supply data for a real-time air quality early warning system.

Since the New York City network will serve as a model for the proposed IMP/S air monitoring network, a closer examination of this particular system is in order.

The New York air quality monitoring network is built around a core of 37 remote stations with ten of these stations being fully automated. All of the stations are linked together by a central control unit which can exercise selective control over each station if desired. The data derived from this monitoring system can be divided into three major categories in relation to data utilization:

(1) Direct visual presentation for monitoring current conditions and alarm situations.
(2) Statistical analysis for the development of historical summaries (monthly and seasonal averages).

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[37] Ibid.

(3) Correlative analysis leading to information on cause-effect relationships between meteorological patterns, automotive and commercial fuel consumption, etc., and the New York City air pollution situation.[38]

The network is served by an automated telemetry system. This system is designed to operate continuously and automatically under full control of the central unit. Data derived at each remote station is transmitted to a main computer for additional processing. In addition, other data such as emission inventories, medical statistics, air quality and meteorological data are correlated with the sensor input.

The telemetry system utilized by New York's monitoring network is based on a duplex wireline linkup which integrates the ten remote stations into one system. Each station measures up to six air quality parameters on a continuous basis. At certain time intervals the data is transmitted to a central station where it is processed and displayed. There are three major display modes-teleprinter, punched paper and digitized map.

The present six parameters being measured at each station are as follows: "wind speed, wind direction, temperature, sulfur dioxide (SO_2), carbon monoxide (CO) and particulates."[39] These parameters are continuously monitored, converted into a signal suitable for wire-line transmission and sent to the central station for processing and display. The system is operated through a three-function communications link: "the primary data flow link to the central station, a

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[39] Ibid.

command link from the central station to each remote station, and an alarm link from each remote station to the central station."[40] All three functions are accomplished on a single communications path to each remote site using time and frequency multiplexing techniques.

The proposed IMP/S air monitoring network will be similar to the New York City system. The major differences will be in the increased coverage offered by the IMP/S, the number of parameter values measured, and the telemetry system. In addition, and early warning system will be integrated into the IMP/S network design along with pre-programmed reaction subsystems and an array of simulation modules.

Specifically, the IMP/S is designed to cover a large geographical area. This means that both urban and rural remote stations will have to be included in the network. The system will be fully automated with each station designed to measure twelve parameters such as: wind speed, wind direction, temperature, precipitation, relative humidity, sulfur dioxide (SO_2) concentrations, carbon monoxide (CO) and carbon dioxide (CO_2) concentrations, nitrogen oxide (NO) and nitrogen dioxide (NO_2), hydrocarbons and particulates. Each of these parameters will be recorded on special magnetic tape recorders. Because of the large number of parameters being monitored a selective interrogation system will be used. This selective system will

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[40]<u>Ibid</u>.

enable the central station to receive all twelve parameters at one time; or, it will allow the user/user agency to interrogate individual sensors at any time in order to isolate critical parameters. For example, if a meteorologist receives an alarm from the early warning system indicating the sulfur dioxide concentrations appear to be excessive in a certain area, he would manually interrogate those stations in the area for additional measurements on SO_2 concentrations. If the situation is indeed critical or if air quality standards programmed in the reaction subsystem indicate that the SO_2 buildup is too excessive, additional steps can be taken to reduce this environmental hazard.

In addition to the remote stations, the air monitoring system will include a number of meteorological stations and mobile units. The meteorological stations are designed to supplement data derived from the air monitoring network and satellite systems. The basic parameters to be measured by these stations are: temperature, relative humidity, wind direction and velocity, precipttation, atmospheric pressure and solar radiation. These stations will be located primarily in remote, rural areas and those areas where current data are non-existent. Data from these meteorological stations will be transmitted to the central station and integrated with the other data inputs derived from the satellite, aircraft, surface and subsurface systems.

Mobile units will be used to investigate critical areas detected by the remote and interactive systems. In effect, these units will focus in on the area and serve to concentrate data gathering efforts. These units will also circulate throughout the region to check emission standards, water quality, potential environment hazards, excessive pollution sources, etc.

CHAPTER IV

THE TELEMETRY/COMMUNICATIONS NETWORK

The IMP/S telemetry-communications network is designed to coordinate both the acquisition of sensor data and its subsequent transmission to a central computer facility. Figure 4.1 outlines the basic sensor-telemetry concept for the IMP/S. The structure of this network is based on a geo-coded environmental grid which is used to define the monitoring zone, and facilitate the deployment of both remote and interactive sensors within a specific geographical area.

A standard grid will encompass a land area of approximately 125 cubic miles. Section A in Figure 4.2 describes a typical environmental grid. Each grid contains its own geo-coded framework which is related to a specific data file stored in the data bank. Section B depicts a grid structure on the earth's surface. Section C illustrates a sensor cluster deployed within a grid. These sensors are linked to a data concentrator either through a direct telephone cable link, or through a microwave system.

The sensor telemetry-communications network will operate as follows: as the sensor measures an event or object it immediately records the incoming signals and stores the impression on tape. On command the stored data is transmitted

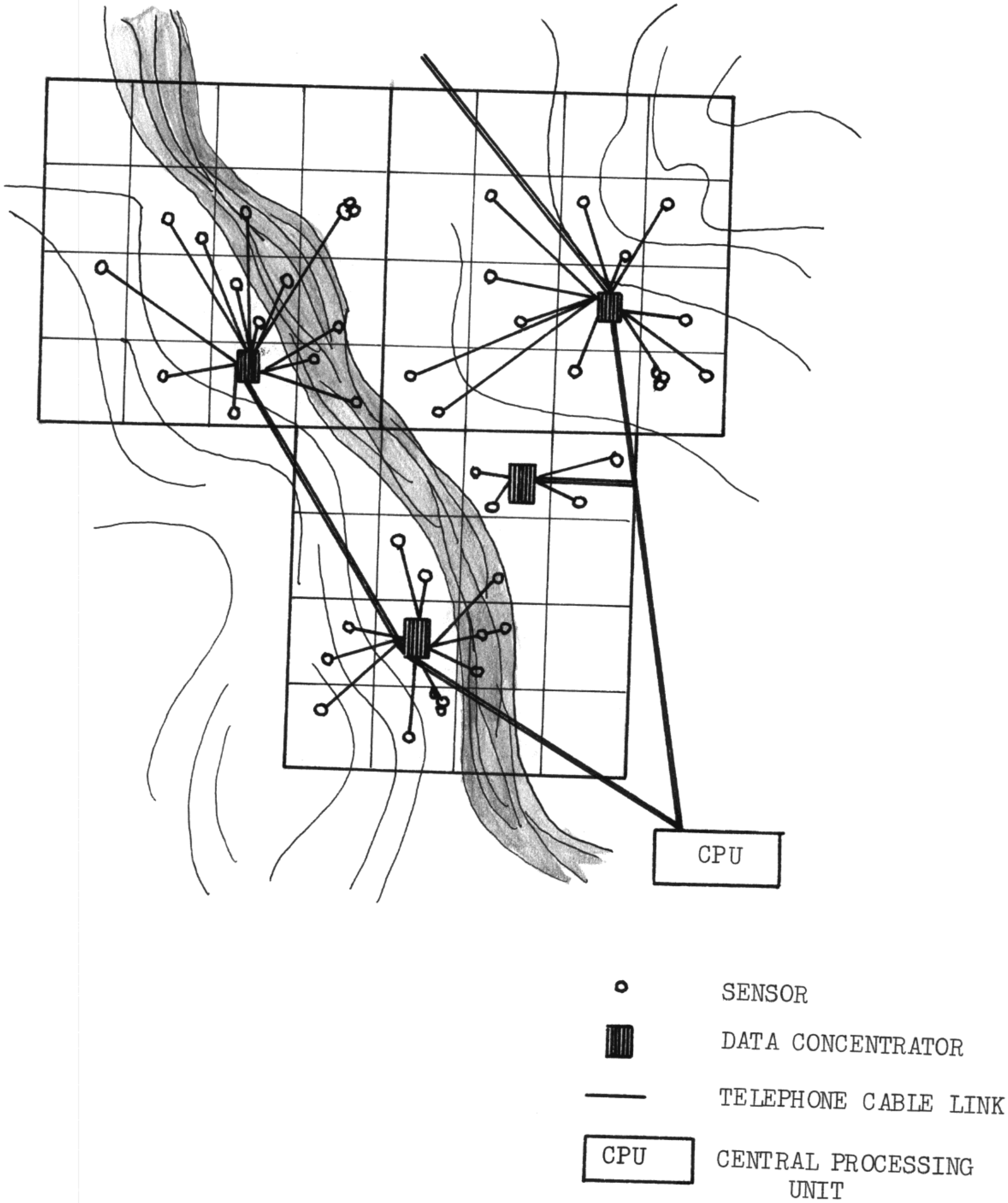


FIGURE 4.1

SENSOR-TELEMETRY NETWORK

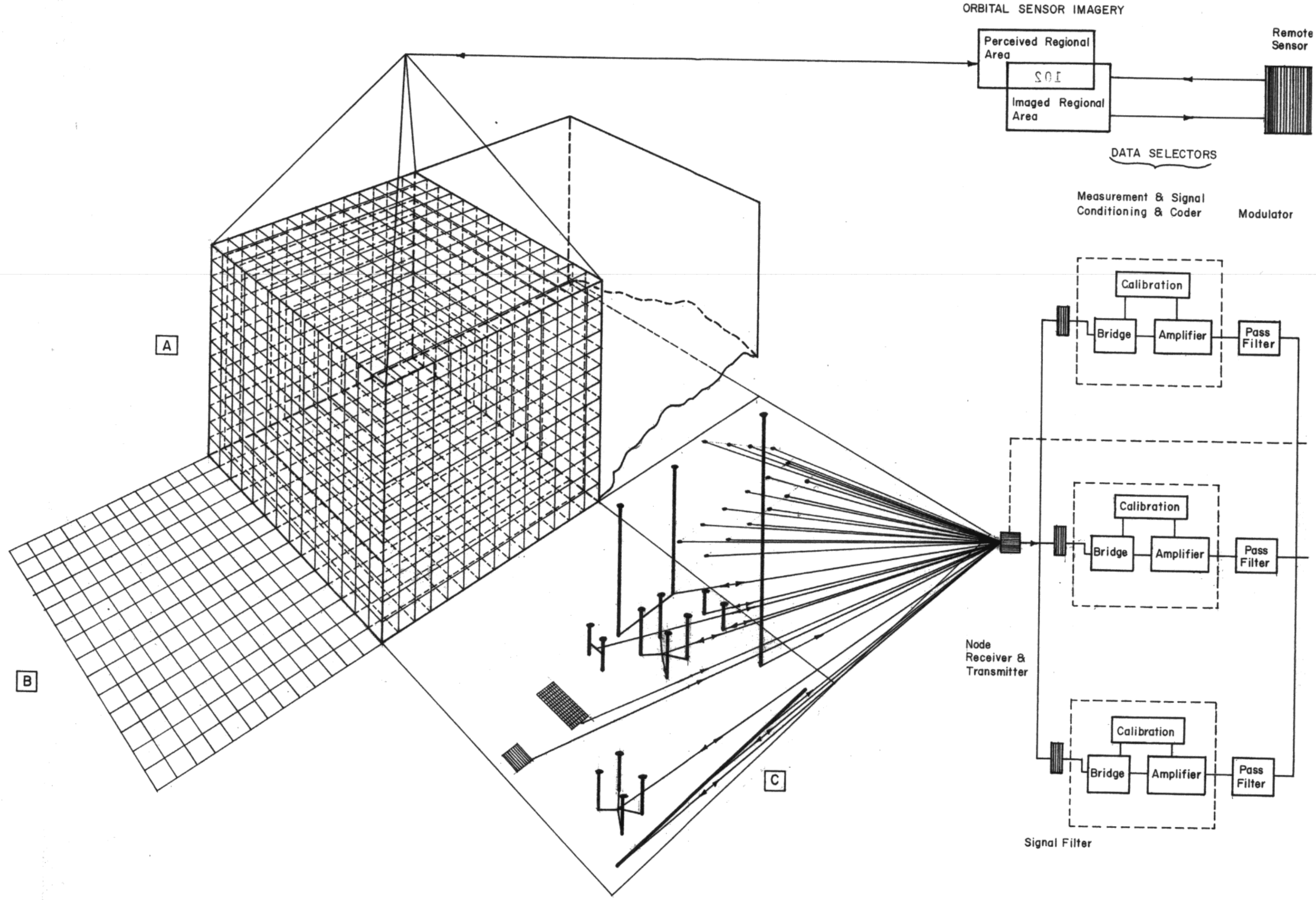


FIGURE 4.2

ENVIRONMENTAL GRID

to a data concentrator. The concentrator, in turn, collects and integrates all incoming sensor data originating from the grids. It also serves as an exchange point or terminal where all transmission connections are made between incoming and outgoing signals. The incoming signals are primarily command and control signals from the Central Processing Unit (CPU), whereas the outgoing signals are mainly data transmissions to the CPU.

The data concentrator, which consists of small computer and magnetic tape recorders, combines the multitude of data signals being transmitted from the individual sensor units into concentrated messages. These messages are then transmitted by microwave or cable to a node receiver/transmitter station. This station serves as the main link between the grids and the telemetry network. Besides integrating the individual grids with the network the station also stores all data transmissions from the concentrators and prepares them for retransmission to the CPU. This preparation involves a conditioning process which concentrates the signal through a special buffer arrangement. A buffer is designed as an intermediary storage area which links two or more storage or data transmission systems with different access times or formats. In addition, a buffer may be used to amplify a signal for microwave transmission. On command from the CPU, the node station transmits its data in highly concentrated

bursts of energy to a Central Station. A receiver located at this facility picks up the signal and channels it into a computer interface which again modifies the signal in order to make it compatible for computer processing.

In designing a telemetry network for the IMP/S the following elements should be considered:

a. The overall structure of the network.

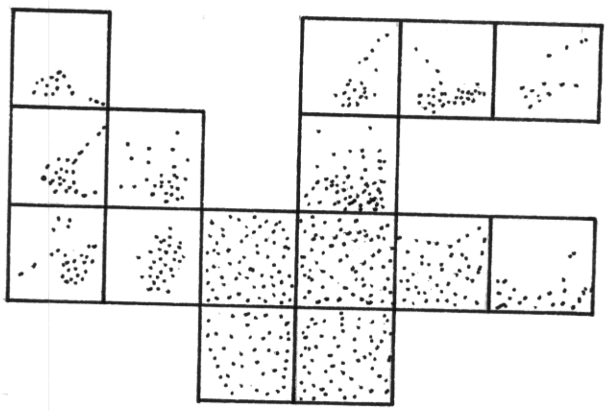
b. Types of sensors to be used and their characteristics.

c. Transmission speeds to be utilized.

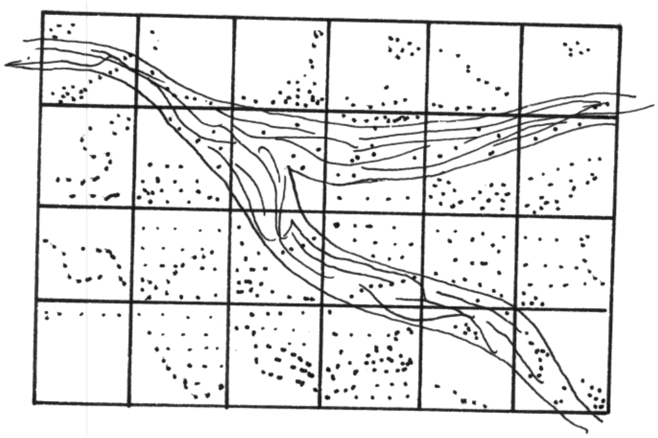
d. Communications control techniques.

The structure of the sensor-telemetry network is dependent mainly onthe arrangement of the grids and their locations with respect to the Surveillance Center. The grids will be arranged or assigned according to a predefined plan. Because of the inherent flexibility offered by the grid concept almost any kind of deployment plan will be feasible.

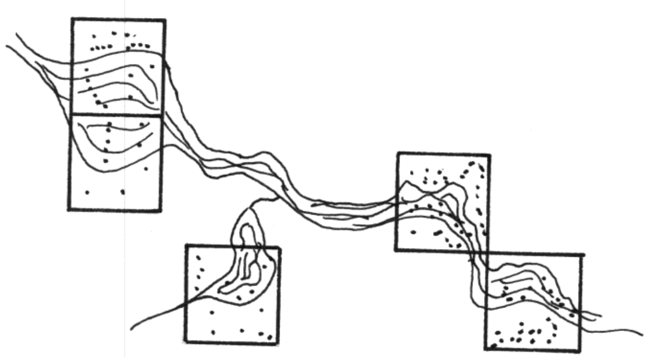
Figure 4.3 describes three basic grid deployment patterns-high density, even density, and low density. High density deployment will involve the clustering of sensors into very compact cells. This deployment pattern will generally be used in critical surveillance sectors such as urban areas or transportation corridors. Low density deployment described in Figure 4.3 will involve the placement of individual sensors at scattered sites throughout a particular sector. This pattern will be used to maintain surveillance over isolated



HIGH DENSITY DEPLOYMENT PATTERN



EVEN DENSITY DEPLOYMENT PATTERN



LOW DENSITY DEPLOYMENT PATTERN

FIGURE 4.3

SENSOR DEPLOYMENT PATTERNS

areas within the basin such as reservoirs, watershed areas, and lakes. The even density pattern is an intermediate deployment pattern. This pattern involves the deployment of sensors in such a way as to establish a relatively comprehensive coverage over a particular geographical area. Those areas not covered by sensors will be monitored by either the airborne or satellite systems.

The network will be controlled through the Surveillance Center. The optimum number of sensors in any sector will largely depend on the capability of the computer system. The major design criteria for the telemetry-communications network are: the total number of grids assigned to a sector, the location and types of sensors, information flow, types of data inputs, message volume, CPU reserve capacity, network flexibility and reliability.

The types of sensors, their dispersal and subsequent linkages will have a direct effect on the operation of the telemetry network. With this impact in mind, the major elements that should be considered in the process of selecting and placing sensors within the grid structure are as follows:

1. The detection-measurement capabilities and the data acquisition and transmission formats required by the IMP/S will determine, to a large extent, the types of sensors to be used and their placement within the grid. There are basically three categories of detection-measurement capabilities; (1) passive, (2) intermittent,

and (3) continuous. In addition, each category will have a particular data acquisition and transmission format. For example, the passive system will acquire data only upon activation. Once activated, data acquisition and transmission will be continuous until the sensor unit is shut down by a command signal from the CPU. The intermittent system will be designed to continuously monitor, measure and record data. However, data transmission will be programmed to occur once every 60 minutes over a twenty-four hour period. The continuous system, on the other hand, will acquire data and transmit it once every 10 minutes. This type of sensor device will usually transmit its stored data to a node receiver/transmitter, by passing the concentrator where it will undergo a buffering operation. This operation is designed to concentrate incoming data and prepare it for transmission to the CPU once every hour.

2. The amount of detail required by the user or user group will also govern the types of sensors to be used, their data acquisition and transmission modes and their location. The level or degree of detail will be, in part, determined by the amount of coverage required. Local coverage, for instance, will be able to generate an extremely high degree of detail at a very large scale and resolution factor. Intermediate and area

detection coverage, on the other hand,will have a smaller amount of detail. However, these coverage factors will allow for a larger area to be surveyed. These coverage factors will also facilitate a more comprehensive picture of the environment than the local coverage will allow.

The detail required will ultimately depend on the objectives and implicit information requirements of the IMP/S. In addition, the scale and resolution factors along with the degree of coverage will be designed to overlap and compliment each other. This will enable the IMP/S to attain a high multi-dimensional surveillance capability.

3. Sensor deployment and utilization will depend, to a large extent, on the sensor's ability to maintain a high degree of unattended operation. The primary factors to be considered here are (1) sensor unit accessibility, (2) the availability of a reliable power source or linkage, (3) low maintenance and, (4) the permissible time lapse between maintenance calls and fault warning. These factors will require that each sensor device be capable of transmitting, real-time, calibration data and data concerning the status of the sensor unit. It will also require that each data collection system have a high degree of built-in redundancy in terms of backup systems, in order to maintain surveillance operations. This capability is needed

especially for the remote surface and subsurface sensor units and for the satellite data collection system.

Table III summarized the major elements that characterize the overall sensor network and its data acquisition and transmission formats. As noted previously, each of the data collection systems is designed to overlap so that a multi-dimensional surveillance capability can be attained. Consequently, the overall telemetry network must be able to coordinate these diverse systems and control their data inputs so that the IMP/S will be able to function properly.

In determining the transmission speeds of the various sensor devices deployed in the surface and subsurface data collection systems it is convenient to consider a typical 24-hour day as being divided into three eight hour segments. Each segment can then be further divided into three principal operational phases: (1) a preparation phase which includes such activities as sensor activation, calibration and check-out, (2) a measurement phase, which detects the phenomenon and records its significant characteristics at specified time intervals; and (3) the data conditioning and transmission phase.

Although the operational characteristics of the sensor unit are divided into distinct phases they are actually concurrent operations or processes. For example, while the sensor is detecting and measuring a phenomenon it is also

	A	B	C	D
Seismic Probe	Passive	Continuous on Activation	Inter-mediate	Low Detail
Underwater Sensor Module	Inter-mittant	Continuous	Local	High Detail
Remote Meteorological Station	Continuous	Continuous/ Buffered	Inter-mediate	Low Detail
Particle Analyzer	Inter-mittant	Continuous	Local	High Detail
Infrared CO, CO_2 Analyzer	Inter-mittant	Continuous	Local	"
Analyzer SO_2 & NO, NO_2	Inter-Mittant	Continuous	Local	"
Air Monitoring System	Continuous	Continuous/ Buffered	Inter-mediate	Low Detail
Oil Spill Detection System	Passive	Continuous on Activation	Local	High Detail
Turbidimeter	Inter-mittant	Continuous	Local	"
River Gauge	Continuous	Continuous/ Buffered	Local	"
River/Shallow Water Buoy	Inter-mittant	Continuous	Local	"
Water Analyzer System	Continuous	Continuous/ Buffered	Local	"
Water Monitoring System	Continuous	Continuous/ Buffered	Local	"
Airborne Multiband Camera	Inter-mittant	Continuous	Area	Low/High Detail
Airborne Radar	Inter-mittant	"	Area	"
Airborne Radiometer	Inter-mittant	"	Inter-mediate	"
Airborne Scanner	"	"	Area	"
Airborne Spectrometer	"	"	Inter-mediate	"
Satellite Vidicon	"	"	Area	"
Satellite Multiband Camera	"	"	"	"
Satellite Pan Camera	"	"	"	"
Satellite Radar	"	"	"	"
Satellite Radiometer	"	"	"	"
Satellite Scanner	"	"	"	"
Satellite Spectrometer	"	"	"	"

A - Measurement-Detection Mode
B - Data Acquisition-Transmission Format
C - Coverage
D - Scale/Resolution

TABLE III

SENSOR SYSTEM CHARACTERISTICS

preparing the data for transmission. The data will usually be stored within the sensor unit until either an automatic timer activates the transmitter; or, the sensor unit receives a command signal from the CPU instructing it to transmit data to the concentrator. However, some sensor units such as the seismic probes, oil spill detection systems, water and air monitoring systems can be individually programmed to transmit data automatically at predetermined time intervals to the node station or directly to the CPU.

Transmission speeds will vary according to the mode of transmission, the transmission frequency, and the priority rating of the phenomenon being monitored. Generally, data from the sensor unit will be transmitted every 60 minutes in 30 second bursts to the data concentrator. A number of high priority sensor units such as the river/shallow water buoy system and the water monitoring system will transmit at a higher rate. In these cases, transmission will usualy occur every ten minutes. These transmissions will, in turn be buffered and conditioned by either the data concentrator or node station. Consequently, all data will be sent to the CPU from the node stations in a 60 second transmission every 60 minutes. The CPU itself will control the transmission sequence so that it will not overload its own receivers and computer capability.

Normally, data will be transmitted to a concentrator and integrated with other sensor data inputs. Once the data

has been combined it is transmitted to a node receiver/ transmitter station. At this point the transmission speed is controlled by the CPU on a programmed priority basis. However, if a critical situation develops or appears to be developing in any one of the grids, the CPU can bypass the node receiver/transmitter and the data concentrator to interrogate the sensor unit directly. In this case, the sensor data will be directed into the CPU on a continuous basis for real-time, on-line, processing and interpretation.

When there is a direct connection between any of the sensor units and the CPU either by wire or radio links, these sensors are said to be operating on an on-line basis. When all components in the communications link are on-line the network may be said to be operating in real-time. G. E. Barlow used this term to define processing systems having

> ...sufficient speed so that the output may be used to affect the course of the process which produced the input stimulus.[41]

He also noted that a real-time process

> ...may still involve a considerable amount of data recording, but in parallel to, rather than in series with, the main data flow.[42]

Transmission speeds between the various components will vary according to the transmission mode and the type of

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[41] G. E. Barlow, "Instrument Data Processing Systems," <u>The Collection and Processing of Field Data</u>, eds. E. F. Bradley and O. T. Denmead (New York: Interscience Publishers, 1967), p. 400.

[42] <u>Ibid</u>.

terminal used. There are three basic modes or grades of data transmission: (1) low speed, (2) voice grade and (3) broadband. Low speed data transmission ordinarily includes all speeds less than 600 bits per second (bps). A binary digit or bit is a single element in a binary number and it may be represented by a single electronic pulse in a group of pulses. This low speed transmission mode is designed to use typewriter-like output devices such a teletype terminals and card punches.

Voice-grade and broadband data transmission rates are much higher. Robert L. Brewster, a computer/communications system consultant with Digital Systems Corporation noted that:

> The communication lines of the ordinary telephone network are referred to as voice-grade lines; they can be operated at a wide range of speeds, depending on the modem (a combination modulator/demodulator device). Voice-grade lines are usually used with communications equipment such as multiplexers, message switchers, and buffered terminals.[43]

He went on to state that:

> The standard speeds for voice-grade operation are 600 X N bps, where N is an integer from 1 to 16. Broadband speeds go higher than 9,600 bps. Examples are AT&T's private line service known as Telpack A, B, C, and D, having capacities of 12, 24, 60, and 240 voice grade lines.[44]

Broadband systems are used primarily for high data transmission rates. These systems generally use a microwave transmission mode which can transmit data at a higher rate than either low speed or voice grade lines.

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[43]Robert L. Brewster, "Designing Optimum Data Networks," Data Processing, (November, 1970), p. 19.

[44]Ibid.

The IMP/S telemetry data transmission network will use two types or modes of transmission, voice-grade and microwave. Voice-grade transmission will be used to link the individual sensor units with the concentrator. In cases where the sensor units are located in extremely remote areas, a microwave system will be used for data transmission. Because of the larger amounts of concentrated data being transmitted from the concentrator's nodes and then to the CPU, a microwave broad-band system is justified. In the case of both the airborne and satellite data collection systems a microwave telemetry system will be used for transmitting data directly to the CPU.

The network is designed to enable a single sensor unit to communicate directly with the CPU or indirectly with the other nodes. This branching capability will enable the CPU to select high priority sensor units out of the network for maximum surveillance of a particular event or object. It also creates an opportunity for the CPU to receive data from alternate nodes by command. Consequently, data may be accepted from any sensor unit or node and transmitted directly to a display unit for analysis.

The major controlling element in the network is the CPU. This computer facility serves as the monitor for the entire data transmission network. However, because there will be four different data collection systems in the IMP/S, network, transmission characteristics and rates will vary. For example, the satellite system, due to its orbital characteristics, will pass over a particular point on the earth's surface once every

eighteen to twenty days. This means that all of the data received by the satellite on a single pass over a target area will be transmitted to the CPU once every eighteen days in a highly concentrated data transmission. The airborne data collection system, onthe other hand, will seldom transmit data directly to the CPU. Normally, data received by this system will be transferred, in bulk form, to the Central Station for processing.

The only continuous monitoring systems will be the surface and subsurface data collection systems. Figure 4.1 described, in very general terms, the major components of these systems. Both will be controlled through the CPU by a selective data acquisition program. This program incorporates a polling system that is designed to continually interrogate each node receiver/transmitter station at a predetermined time interval. This function is controlled by either an IBM-QTAM (Queued Telecommunications Access Method) or IBM-BTAM (Basic Telecommunications Access Method) software package which sets up a polling sequence. In addition, if the CPU or the Early Warning System(EWS) detects a critical condition in a certain geographical area, the EWS can request the CPU to by-pass the automatic polling sequence in order to concentrate on that condition. This bypass function can become operational without interferring with the normal operations of the system.

The telemetry structure outlined above is designed to link a complex arrangement of sensor and data collection

systems into an integrated telecommunications network. The underlying premise of this network is that it must have a high level of redundancy coupled with a cybernetic feedback flow which allows it to maintain a high degree of flexibility and responsiveness for the user. In effect, the network as conceived here, serves as the nervous system for the entire IMP/S. Although control is centralized the network itself consists of a large number of interdependent subsystems. The grid concept, in this case, rationalizes this interdependency and integrates each of the subsystems and data collection systems into a flexible and comprehensive telecommunications network. In conclusion, the key factor is control and this factor, in turn, enables the IMP/S to maintain an effective surveillance capability.

CHAPTER V

THE IMP/S COMPUTER SYSTEM

The IMP/S will be designed to operate within the context of a total information environment. This concept requires that all of the data stored in the system be analyzed in-depth and linked together in an integrated, computerized, information-communications network. This network would also be able to disseminate information on a wide range of topics and environmental conditions in a variety of display formats.

In general, the information system as conceived here, would achieve the following:

> It would provide for the timely and automatic dissemination of pertinent information to all levels of decision making in the IMP/S.
> It would have the capability for providing, on a real-time inquiry basis, information beyond what is automatically issued, including interim updating and extrapolations of periodic statistical data.
> Updating of all data inventories and data files would be done automatically.
> The system would also be able to notify all appropriate decision-making levels within the IMP/S of any out-of-line situation, data discrepancy or critical environmental conditions within the survey zone.

The IMP/S' basic computer configurations is digital. The sensor data will be communicated by telephone lines to several data concentrators. Analog to digital conversion will take place at the data concentrator and digital data is then transmitted to the central facility.

Figure 5.1 outlines one type of analog system. As an object or process is detected by a sensor unit it is immediately converted into an electrical signal and prepared for transmission via a cable link or through a broadband microwave system. This signal is usually transmitted to either a data concentrator or node receiver/transmitter which serves as a buffer and temporary data storage device. Upon interrogation or through an automatic timing device the stored data is transmitted to a computer interface. This interface acts as a transition point between the telemetry system and the data processing system. The interface transforms the incoming data signal, converts the analog measurement into a numerical value, collates and compiles the data and prepares it for computer processing.

A digital recording system is outlined in Figure 5.2. The data signals are transmitted from the sensor units via the concentrator and node receiver/transmitter to a multiplexer device which combines several distinct data signals into a single message. Once the incoming data are combined they are routed into an analog to digitalconverter which changes the original message into a digital representation. A format operation is then initiated which arranges the data into a particular organization in order to make it compatible for the computer processing system.

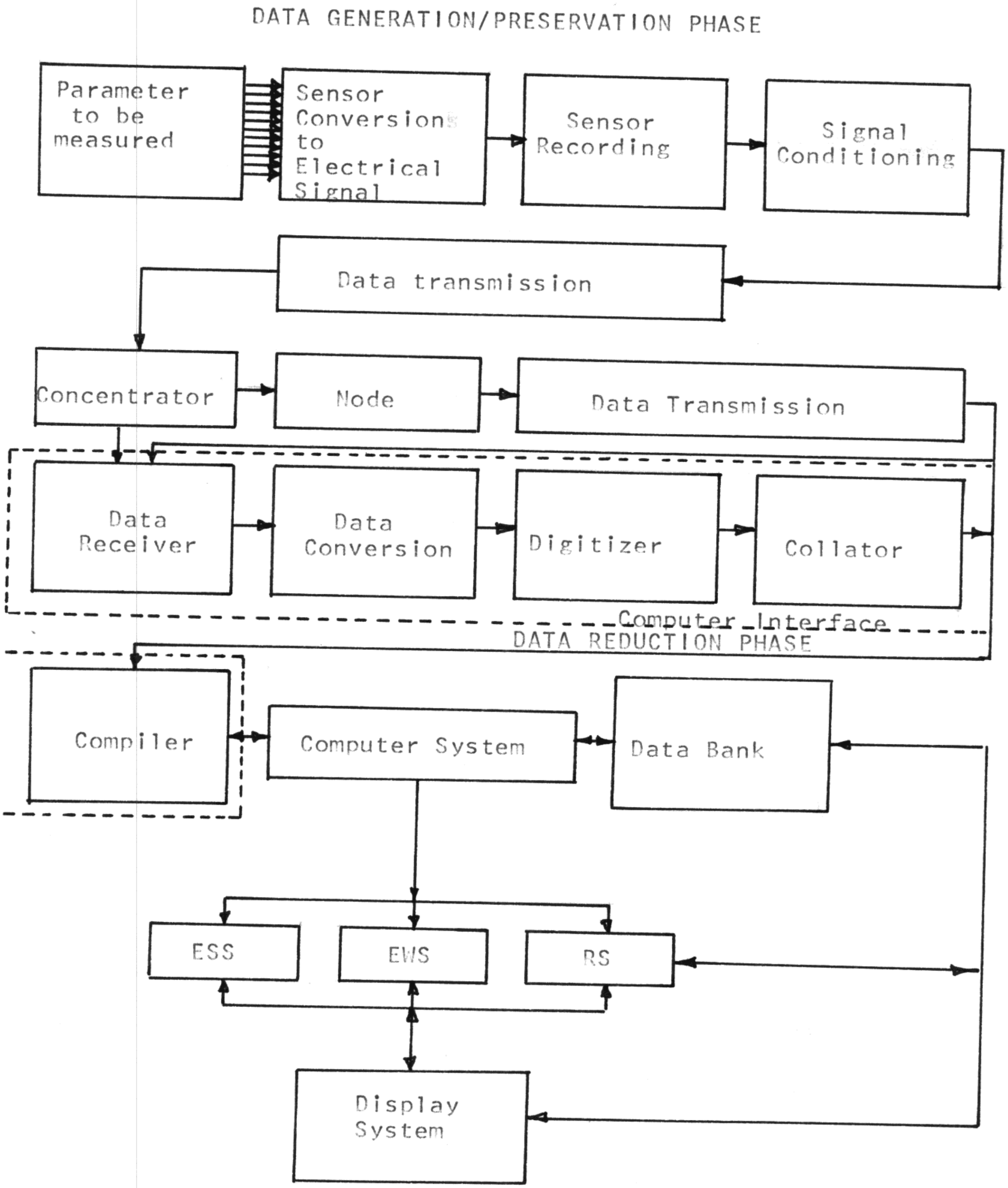

FIGURE 5.1

ANALOG RECORDING SYSTEM

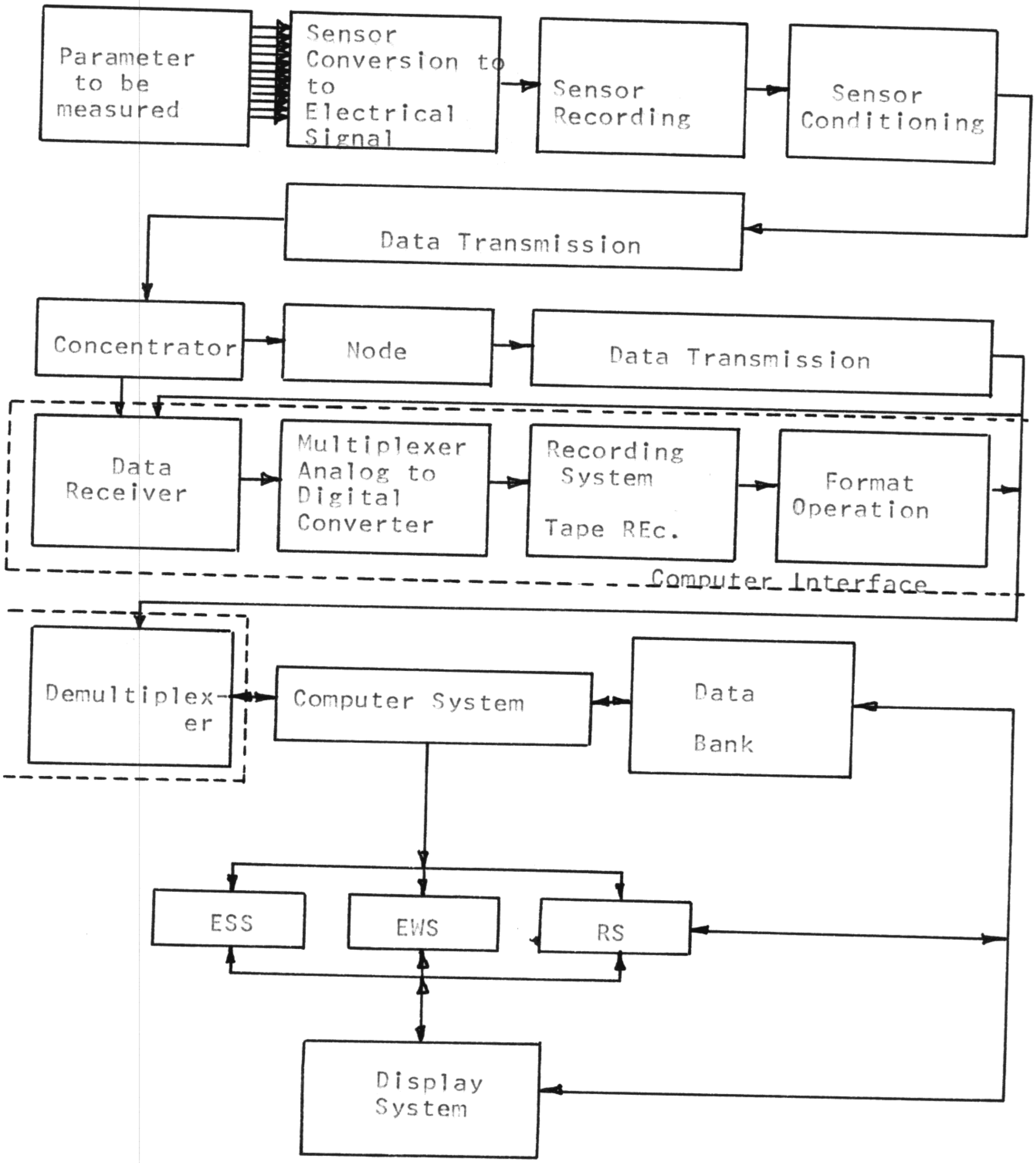

FIGURE 5.2

DIGITAL RECORDING SYSTEM

Although both analog and digital recording processes utilize similar signal waveforms and recording channels, the arrangement of data on tape in eachsystem is not the same. Richard B. Bycer, a communications systems engineer with the Radio Corporation of America noted that:

> In analog recording, the information to be recorded is generally restricted to a single channel and is referred to as a single track or serial recording. In digital recording, the equivalent information is recorded on multiple tape tracks and is referred to as parallel recording.[45]

This means that each system requires a different kind of computer. It also means that some kind of switching device must be incorporated into the IMP/S for routing specific data items. This device would serve to channel both analog and digital data to specific components within the system for processing and display purposes.

A computer system is usually designed to accept input data in a variety of forms, manipulate and link data-set structures, provide for the fast retrieval and display of data and facilitate data base documentation. Information processing, on the other hand, implies the collection of data and their organization and subsequent storage in the data base. The processing function denotes the actual manipulation of data into organized data sets.

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[45]Richard B. Bycer, Digital Magnetic Tape Recording Principles and Computer Applications (New York: Hayden Book Company, 1967), p. 11.

The computer system generally consists of a number of input and output devices, a data bank, and a central processing unit. Input devices are used to transfer data from an external storage medium, such as a data bank, into the internal storage of the computer. These devices include card readers, magnetic tape readers, optical scanners, console typewriters and analog-to-digital converters. Output devices, on the other hand, are used for transferring information from the computer after it has been processed. These display output units include card punches, magnetic-tape recorders, console typewriters, high speed printers, cathode-ray display units and plotters for graphic representation of data.

The data bank is essentially an organized collection of data values. This bank or depository includes everything actually processed by the computer, including the computer programs themselves. The data bank, as it is used here, refers only to the machine-readable data base and does not include printed documents or manuscripts, even though these media may contain data of significance to the IMP/S.

The Central Processing Unit or CPU accepts programmed instructions and data from the input devices, processes the data according to the program instructions and then transfers the processed information either to the data bank or display system via the output devices. In addition, specialized information is continuously channeled into a series of simulation models and an Early Warning System.

Engineered into the CPU are the circuits and controls that enable it to perform, at extremely high speeds, analytical and processing operations. The CPU also has a primary internal storage or memory bank which stores the program and the data which is being processed. This memory bank also monitor's all of the other components related directly to the CPU namely, the on-line input and output devices and auxiliary storage.

Because of the vast amounts of environmental data that are expected to be transmitted from the various data collection systems the IMP/S computer system will utilize at least two CPU's both of which will be IBM-360 models. One CPU will control and coordinate the data collection systems and route data into the appropriate components. The second CPU will be used exclusively for processing and analyzing the data. Smaller computers will serve as back-ups for the larger, more powerful units, especially in the simulation, early warning and display systems.

Figure 5.3 describes the basic IMP/S computer configuration and information flow. After the data from the various data collection systems have been phased into the computer for processing, analysis and interpretation it is channeled into a display system which is designed to present meaningful information to a user group. An input-output controller serves as the primary monitor for the information flow. This controller automatically regulates the processing of data as it moves

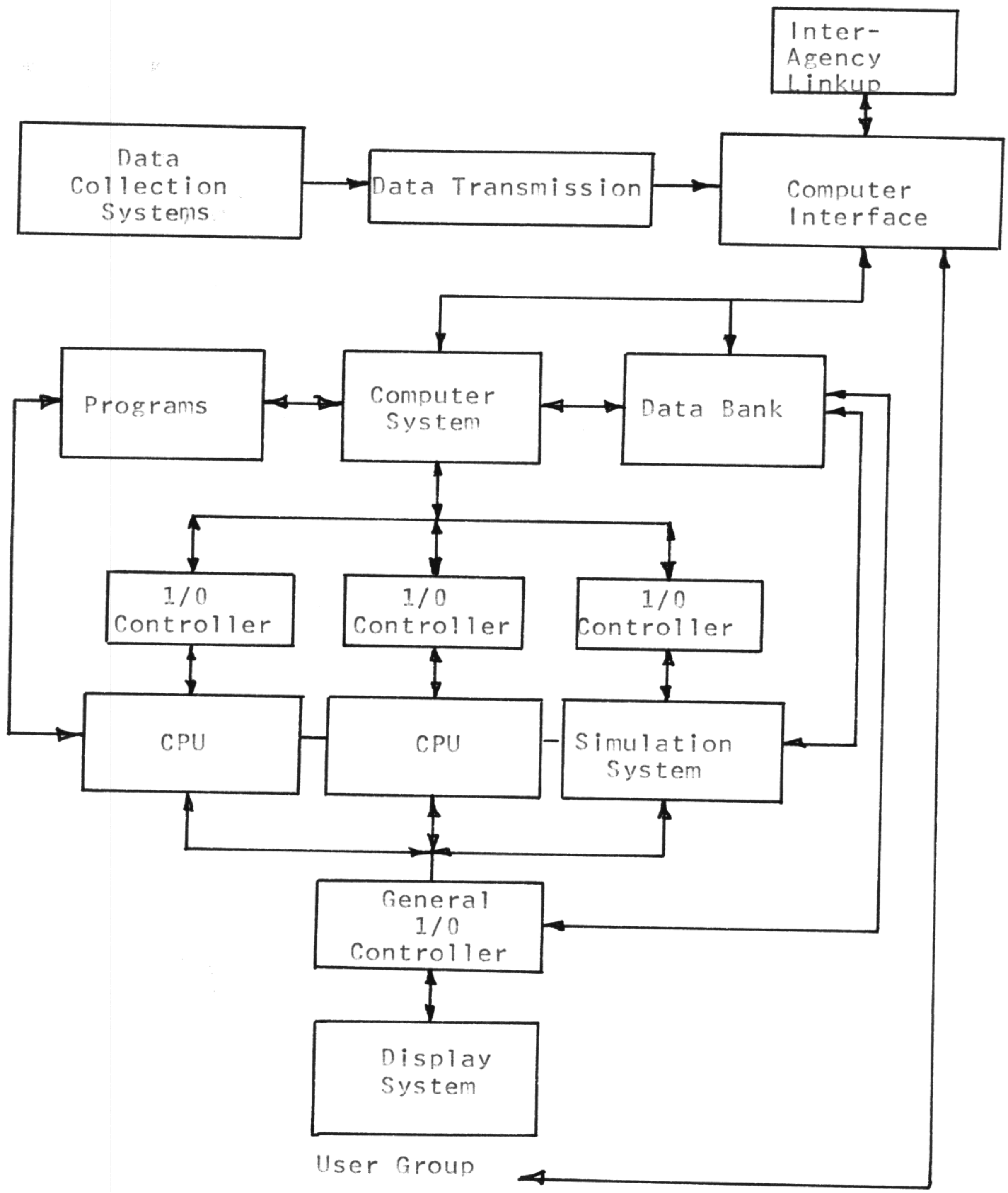

FIGURE 5.3

IMP/S COMPUTER
CONFIGURATION AND
INFORMATION FLOW

through the system. It can also hold or make adjustments in the processing operation on the basis of a predefined set of instructions.

The CPU's are used primarily for controlling, processing and analyzing input data. The information generated by these operations is usually re-routed back into the data bank for future use. Specialized data are also channeled into an Early Warning System (EWS) via an input-output controller for environemntal monitoring purposes. The EWS is designed to detect basic discrepancies in the input data by comparing that data with predefined standard values. By detecting these discrepancies the EWS would be able to determine with a fair degree of accuracy whether critical conditions are in the process of building up somewhere in the survey zone. For example, if data from a sensor unit located at a certain point on a river indicates a higher than normal flow velocity the EWS would respond by identifying the discrepancy and then automatically alert the appropriate observer/analyst via a real-time graphic or visual display.

To facilitate the detection and interpretation function of the IMP/S-EWS the analyst will be able to analyze his data by using a variety of interactive techniques. In other words, the analyst would "plug-into" the system and work directly with the data input. For example, an analyst may want to examine the probable consequences of a long term drought on the economic

development potential of the IMP/S survey zone. In order to do this he would draw relevant data from the IMP/S data bank and simulation system. Using an interactive mode the analyst would then proceed to contribute key elements and judgments in order to link the various data items together. At the same time the computer, performing rapidly and precisely, would compute and display the implied relative values that would result from various policy decisions. The interactive technique assists the analyst by allowing him to interject new variables into the model. The computer, using its extremely fast computing capability, rapidly assesses the probable outcomes brought about by these new variables and suggests new alternatives to pursue. This process can be repeated until the analyst has explored all of the possibilities inherent in this particular problem. Once the process is completed the computer compiles the results into a concise information package which can be distributed to the appropriate decision-making levels.

In essence, an interactive system creates a "dialog" between the user and the computer. This man-machine relationship will be based on a rather simple programming format. Ideally, the user with only a knowledge of the Engligh language and a skill in typing will be able to establish a rapport with the machine. However, for effective use of the system the analyst must be able to optimize his data base

structure and programming procedures. In addition, he must understand enough about how the system works in order to exercise this control. This means that while the user need not be a computer programmer he should know how to "communicate" with the computer with a user language such as SPAN.

Along this same line of thought Thomas Connors of the MITRE Corporation noted that:

> ...the user of a generalized system must become involved in it to the degree that he understands it well encough to specify, in the necessary detail the processes he initiates.[46]

He went on to state that there are three basic requirements involved here. These requirements were as follows:

> ...the user must be aware of the implications of how his data i$ structured, he must understand and control the optimation of his procedures, and the system must allow control of optimization.[47]

The type of output derived from the computer is dictated by many factors and any decision to use one in preference to the other can be made only after deciding, whether the information is required to be: (a) displayed and immediately acted upon, (b) used for the purpose of immediate corrective action, (c) stored for future use; or, (d) purged from the system. One must also ask: What is the nature of future use? and, What kind of time factor is involved? In addition, the needs

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[46]Thomas L. Conner, "Software concerns in advanced information systems," Information Systems Science and Technology, ed. Donald E. Walker (Washington, D.C.: Thompson Book Company, 1967), p. 396.

[47]Ibid.

of the user group must be considered. Since the IMP/S will encompass a multi-disciplinary approach to environemntal policy formulation, management and planning the display format will have to be designed in a flexible manner in order to respond to a wide range of special data requirements and needs.

To facilitate the flow and distribution of information from the computer system to the user, there will be four primary display components incorporated into the IMP/S. These components are as follows:

1. Line Printer-This display component will provide--on a demand basis--summaries of specific data items stored in the data bank for any time period within a preceeding 30-day period. The following are some of the data items which will be subject to display in this component: wind velocity and direction, pollution sources, particulate matter levels, pollution dispersion patterns, temperature, humidity, precipitation, stream gradients, drainage conditions, water and air quality-general, population and traffic density patterns, land use status, transportation flow andmicro-environmental status. These data items may be summarized at either the grid level or for the entire survey zone, if desired.
2. Line Printer (Special Program)-This component will provide one-hour readings on the following: wind velocity and direction, particulate matter, sulfur dioxide levels, temperature, humidity, precipitation, water quality, drainage conditions, stream flow and micro-environmental status will be automatically displayed. A 30-day cumulative frequency distribution including range values, arithmetic and geometric means and standard deviations will also be made available on the above parameters.
3. Continuous Display Component-This component will be designed to provide trend data for specific environmental parameters based on one-hour sensor interrogation rates. The parameters displayed in this component will be wind direction and velocity, temperature, precipitation, sulfur dioxide, oxdant, hydrocarbon, carbon dioxide and carbon monoxide levels at selected points, dissolved oxygen levels

at selected points, stream velocity, water clarity and water temperature at selected points and potential environmental hazards. In addition, it will be able to display graphically, and on demand, three hours of continuous data from all sensors deployed in a particular grid or grid cluster. At the same time this component will have the capability of outlining each grid for real-time status evaluation. This composite status display would include meteorological data, satellite photographs of the survey zone, air and water quality data, land use status, traffic flow and micro-environmental conditions at selected points in the survey zone. This display will be supplemented with special profile studies based on continuous simulation analyses.

4. Random Display-This component will be designed to display data pertaining to each grid on a random selection basis, at fast scan rates. It is also designed to identify all warnings generated from the EWS. Once identification is confirmed, pertinent and related data is routed into a special program which defines the perceived warning and suggests the next course of action. After this initial analytical operation is completed a programmer/analyst takes on the job of determining the exact nature and location of the problem.

In addition to the above display components the IMP/S will utilize a man-machine graphic communication system. This system is designed to enable the analyst, planner or decision-maker to interact directly with his data through a variety of communications media such as graphics, mathematical symbolic statement or ordinary English. A variation of this technique is the Sketchpad interaction system developed by Steven A. Coons, associate professor of Mechanical Engineering at the Massachusetts Institute of Technology. Basically this system allows the user to enlarge a three dimensional image or simulation on a display screen, rotate it inspace to reveal its

shape more clearly, and then adjust its size in order to focus in on certain elements of that image. The user would also have the capability to manipulate and change its dimensions by introducing new variables into the system. Image modification and manipulation is generally done by using light pens. Once the modification is made the image structure becomes an "archetype". This structure can then be replicated at any time.

There are basically four interaction-display formats used in a graphic communications systems. These formats are usually defined as being either static, dynamic, comparative or non-graphic. The static format is used mainly to produce a hard copy drawing for planning use. Conversely, the computer through an interface arrangement, such as an optical scanner, accepts a drawing or map and stores it in memory for future replication.

The dynamic communications format is used to modify maps, plans or drawings appearing on a display screen. Using the computer the planner or analyst is able to test various alternatives and simulate certain conditions on a real-time basis. For example, a regional planner could simulate transportation patterns, movements of all kinds, density variations and facility placement in a particular regional framework. At the same time this format would allow the planner to interject new variables into the simulation process to test alternate configurations.

The comparative format is used to compare two displays through a computer generated overlay in order to determine

differences and similarities in their information content. The non-graphic format, on the other hand, is used to provide alphanumeric information, and decision responses to the computer for further processing.

In conjunction with the interactive graphical systems the IMP/S will also utilize two types of plotting systems: a mechanical system and a cathode-ray tube (CRT) system. The mechanical plotter is designed to yield a hard copy drawing which can be observed and modified while the plot is still in progress. This system will be used mainly for simulation and planning purposes. The CRT system, on the other hand, will be used for continuous monitoring operations. Although the CRT plot cannot be interpreted immediately nor modified while the plot is being created it is extremely fast and responsive to new data inputs. A variation on the CRT system is the Geospace plotter. This plotter consists of a large rotation drum to which photographic film or photosensitive paper is attached. A lens system projects the image from the face of a CRT onto the photographic material on the drum. Rotating the drum brings every area of the film into a position where it can be exposed by the CRT. The advantage of this plotter over the CRT system is that it is able to develop a large plot image while keeping the fast response advantage of the CRT. In addition, the Geospace plotter can be programmed to draw anything a cartographer can draw.

There are essentially four elements involved in plotting data. These elements are:

1. Selecting and specifying the data to be mapped;
2. Linking the data file to a geographic base file;
3. Manipulating and organizing the data to fit available programs and equipment; and,
4. Deciding on the cartographic features of the map to emphasize the significance of an important set of data.

In selecting and specifying the data to be plotted the user must first of all define his problem or objectives. Once he has defined his needs he can program the computer to retrieve and process the data he needs. In order to facilitate this retrieval function all data in the data bank will be linked to a geographic base file or GBF. This GBF relates all data to a grid coordinate system. Grid coordinates, in this sense, are basically a set of numbers which serve to locate a point in terms of its distance from two given axes.

In designing a grid system for the IMP/S a careful distinction must be made between urban and rural areas within the survey zone. The reason for making this distinction is that each area will have a different type of coordinate system. In urban areas the coordinate system will be based on the Dual Independent Map Encoding or DIME system developed by the Census Bureau for the 1970 census. For those areas not included in the DIME system a geographic grid system based on

latitude/longitude coordinates will be used. A special software program will be utilized to merge these two systems together for processing, analytical and display purposes as the need arises. In addition, all data items in the data bank will be given a geographic code number in order to expedite the plotting process.

These coordinates are extremely important because they make possible the automatic production of graphic displays. They also facilitate the development of data which can be used for the construction of three-dimensional displays.

Along with the interactive graphical and plotting components outlined above, the IMP/S will also use a video display system for real-time monitoring operations. This video system would be designed to use both satellite and ground based television cameras to monitor strategic areas in the survey zone on a long term basis. Signals from these cameras will be transmitted directly to the IMP/S display system. The data derived from these cameras will then be immediately displayed and taped for future reference and analyses.

In conclusion, the systems described in this chapter are designed to process, interpret, store and disseminate data to a wide range of specialists. The nature of the data that are fed into these systems and subsequently stored in the data bank is extremely important. In order to optimize this data acquisition and facilitate its display, data priorities and

schedules will have to be formulated along with a data acquisition plan. Without these elements the processing, interpretation and display operations could become overburdened due to the sheer magnitude of the data input. With these factors in mind the next chapter will outline the IMP/S data base and file structure. It will also suggest a data acquisition plan; and, expand on some of the concepts presented here especially in the areas of merging diverse data items and software systems.

CHAPTER VI

THE IMP/S INFORMATION BASE

Information is generally defined as a "collection of facts or other data especially as derived from the processing of data".[48] Data, to distinguish it from information, is a term used to "denote any or all facts or estimates--expressed in letters, numbers, or other symbols--that refer to or describe an object, idea, condition, or situation."[49] It also denotes the basic elements of information which can be processed or produced by a computer. Thus, information is essentially data that has been processed, analyzed, interpreted and presented on a selective basis in a manner useful for understanding and decision-making. An information or data base, on the other hand, is simply a logical organization of distinct data entities.

This chapter will be mainly concerned with outlining the major components of the IMP/S information base and determining its primary data elements. In the process of describing this information base we will also discuss the integration of data

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[48]Gardner F.Landon, "Automatic Data Processing Glossary," Datamation, (1968), p. 16.

[49]Werner Z. Hirsch and Sidney Sonenblum, Selecting Regional Information for Government Planning and Decision-Making. (Institute for Urban Studies, Washington University, St. Louis: Holt, Rinehard and Wilson, 1970), p. 24.

formats, the processing of data into special information packages for user applications and the management of data. The final section of this chapter will briefly examine the IMP/S information system and its relationship to environmental policy formulation, planning and management.

1. The IMP/S Data Base

In order to facilitate the dissemination of data, the data must be properly documented and organized. One way of organizing it is to develop a data base. A data base, in this sense, is defined as "a collection of information, arranged in some orderly fashion, about some basic unit which is being studied."[50]

In the IMP/S system, four "building blocks" can be used to describe the data base. These "building blocks" represent a very simple description of the file organization scheme and they can be described as follows:

A. Data Entity: Entities are used to define the basic units of data being studied. Types of pollution, monitoring zone designations, land use codes and environmental system codes are some examples of separate entity identifiers.

B. Data Item: A data item is a named property of an entity. In other words, it is an item of information that describes the nature of the entity. It is the fundamental base element or category designation and it is usually defined by the user.

C. Data List: A data list is essentially an ordered group of named data items describing a set of entities.

D. Data Set: Data sets are collections of data lists. These lists, in turn, refer to the logical ordering of information in the data base.

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[50]Michael J. Kevany, An Information System for Urban Transportation Planning: The BATSC Approach (Systems Development Corporation: Los Angeles, California, May, 1968), p. 46.

The information base will consist of four general files or data categories. These categories are as follows:

I Environmental Files

II Module Files

III Derived Data Files

IV Model Generated Data Files

Each file classification is based on the type of information included, the intensity and extent of coverage, its origin and its intended use. This classification scheme is used mainly for ordering data inputs. Consequently, any data generated within the IMP/S or derived from external sources will be placed in one or more of these files. The environmental files consist of data listings which cover broad environmental entities. These listings include such information as regional pollution emission sources, environemntal quality status, ecological balances and relationships in a given geographical area, regional land uses, natural resource inventories and multi-regional climatic conditions. These listings are further described by more specific data elements that outline their major parameters and variables.

These files will have two functions. Their major function will be to serve as a means for evaluating current environmental conditions active in the survey area. This evaluation process will operate as follows: Each file will contain a set of predefined threshold values or critical parameters that are

designed to indicate the current status of a particular set of phenomena. As the sensor data are processed and translated the derived input or analog values will be compared with the values in the data base. If discrepancies are noted between the incoming data and the base values indicating a real or potentially critical condition the system will be automatically alerted. Once alerted, an analyst-programmer will begin to analyze and interpret the data and define possible courses of action to modify or alleviate the problem or its direct ramifications.

In addition to their monitoring/detection functions, these files will be used to supply data to develop and operate simulation models and produce specialized information packages for specific user applications. This latter function is particularly important. In many instances the planner, administrator or politician requires immediate data on a particular area of concern relating to rather specific geographic or governmental entities. The files outlined above are designed to expedite this process by allowing the user - through the use of special software programs - to merge diverse data entities into one document or series of documents. For example, a regional planner or planning team may need information relating to the feasibility of establishing an economic development program for a poverty area. In order to determine its feasibility the planner could request the IMP/S to provide data concerning

regional population shifts, demographic characteristics and industrial activity in the area, and combine them with housing, employment and transportation data into one report. Since all items and entities in the data base will be geo-coded, data can be easily pinpointed in relation to relatively precise geographical areas.

There will be four environmental files included in the data base: (1) an atmosphere status/quality files, (2) an eco/systems files, (3) a water resources/quality file, and (4) an urban/regional status file. The atmosphere status/quality file will include pertinent data relating to atmospheric, meteorological and air quality conditions for the region being surveyed. It will also include quality criteria for evaluating current pollution levels and dispersion patterns occurring in the designated airshed. The water resource/quality file will contain pertinent and related information pertaining to regional water resources. This file will maintain data on water quality conditions, soils, drainage conditioning, rainshed characteristics and water pollution sources. The eco/systems file, on the other hand, will contain data relating to regional geological, climatic, water resources, agricultural and environmental quality conditions. In addition, this file will include data and quality criteria needed for monitoring the ecological balances of specific geographic areas. This file, in turn, will relate to the urban/regional status file.

The urban/regional file will maintain current data on quality of both environments within the survey area. This file will include information on urban and regional micro climatic conditions, urban and regional physiography, land use patterns, pathological conditions and infrastructures.

Each file will be divided into three major categories: environmental system, vector and subvector. The environmental system denotes the primary environment or system being monitored. It also defines the file and indicates its range of application. The vector category represents the phenomenon class included in the file. The subvector denotes the basic data category. The specific file structure for each of the environmental files will be as follows:

System	Vector	Subvectors
1. Atmosphere Status/Quality File		
	1.1 Wind Patterns	Topography Wind Velocity Wind Direction
	1.2 Air Pollution	Pollution Sources Haze and Smog Particulate Matter Sulfur Dioxide Oxidents Hydrocrabons Carbon Dioxide Carbon Monoxide Dispersion Patterns
	1.3 Dispersion Factors	Wind Patterns Temperature Humidity Solar Radiation Wind Velocity

System	Vector	Subvectors
2. Eco/Systems File		
	2.1 Geological	Morphology Soils Lithology Physiography Subsurface Geology Erosion Patterns
	2.2 Climate	Physiography Temperature Relative Humidity Precipitation Wind Direction & Velocity Atmospheric Pressure Solar Radiation Cultural Features
	2.3 Wildlife	Types Distribution Movement Patterns Condition of Species Settlement Patterns
	2.4 Plant Life	Types and Distribution Forests/conditions Soils Environmental Conditions Climate Wildlife
	2.5 Water Conditions	Precipitation Runoff Soils Environmental Conditions Vegetation
	2.6 Agriculture	Subsurface Geology Climate Soils Drainage Slope Solar Radiation Crop Disease/Conditions Water Resources
	2.7 Land Use	Geological Conditions Climate Land Use Characteristics Water Resources Physiography

System	Vector	Subvectors
3. Water Resources/Quality File	3.1 Water Resources	Rainshed Characteristics
		Precipitation
		Stream Gradients
		Discharge Rates
		Soils
		Drainage Conditions
	3.2 Water Pollution	ph(Acidity/Alkalinity)
		Oxidation Reduction Potential
		Chlorides
		Dissolved Oxygen
		Conductivity
		Water Temperature
		Solar Radiation
		Phosphates
		Oxygen Demand
		Stream Velocity
		Water Clarity
4. Urban/Regional Status File	4.1 Urban/Regional Climate	Physiographic Features
		Temperature
		Relative Humidity
		Precipitation
		Wind Direction/Velocity
		Solar Radiation
		Urban/Regional Structure
		Land Use
		Density Patterns
		Air Qualtiy
	4.2 Urban/Regional Physiography	Land Elevation/Slope
		Surface Drainage
		Soil Drainage
		Soil Foundation
		Environmental Hazards
	4.3 Urban/Regional Land Use	Open Space Characteristics
		Land Use Patterns
		Urban Growth
		Activity Factors
		Population Density
		Transportation

System	Vector	Subvectors
		Housing Quality and Types Social/Aesthetic Factors Cultural Factors Socio/Economic Data
	4.4 Urban/ Regional Pathology	Medical Statistics Crime Statistics Air Quality Water Quality Population Density Structure Density Land Use Traffic Density Micro Environment States Transportation Flow/Density Traffic Patterns Traffic Generation Areas Network Status
	4.5 Urban/ Regional Infrastructures	Urban and Regional Spatial Structure Land Use Utility Systems Topography Pattern Density of Dwelling Facilities Identification Urban/Regional Drowth Decline Patterns

The module files are designed to supplement the environmental files and provide specific data that pertain to existing conditions within each grid. Thus, while the environmental files encompass the whole survey area the module files are only related to designated grid structures. In other words, each designated grid will have its own file. As new grids are added to the IMP/S additional module files are incorporated into the data base. However, both file structures--module and environmental--can be merged for analytical and display purposes. At the same time both files can be interrogated independently from each other.

The data for the module files will be primarily derived data. That is, data from other agencies, processed data from the environmental files and results from simulation models will be incorporated into this file structure. The data for the environmental files, will be mainly processed sensor data derived from each of the data collection systems.

The rationale for maintaining two file systems in the IMP/S data base is based on the premise that it is neither technically feasible nor desirable from a data management perspective to maintain one comprehensive file for the entire survey area. In addition, it is very important to have a flexible data base that can respond to changing needs. The module file enhances this flexibility by allowing the IMP/S to maintain a multi-leveled data base that is able to relate to specific areas while the environmental file covers the whole survey area. The user, depending on his needs, could interrogate both files simultaneously or independently. If the user needs specific information relating to an individual grid or series or grids, he would simply supply a grid designation number and describe the data categories desired to get an updated report on the status of this grid. At the same time he could also merge both files to get additional information on the environmental conditions active in the grid.

Each grid will generally have thirteen distinct data files. These files will include, population, building structures,

agricultural, natural resource, effluent, economic, meterological, efflux, land use and transportation data. In addition, a number of files will be used to evaluate policy decisions and plans as they related to each grid. All data items and lists in these files are geo-coded for easy location and documentation. Each file will also have a master sequence number which is used as a reference and merging device to relate other data items to the files being processed. The specific data items for each file are as follows:

File 1 Population Record
- 1:1 Master Sequence Number
- 1:2 Geographic Coordinates - Grid Designation
- 1:3 Population Data
  - 1:3.1 Number of people
  - 1:3.2 Sources of change in population
  - 1:3.3 Population characteristics
  - 1:3.4 Household characteristics
- 1:4 Socio-Economic Data
  - 1:4.1 Income characteristics
  - 1:4.2 Education data
  - 1:4.3 Employment - Unemployment data
  - 1:4.4 Labor force characteristics
  - 1:4.5 Labor participation rate
  - 1:4.6 Labor commuting patterns

File 2 Building Structures Record
- 2:1 Master Sequence Number
- 2:2 Geographic Coordinates - Grid Designation
- 2:3 Population Data
- 2:4 Structure Census Data

File 3 Agricultural Census Record
- 3:1 Master Sequence Number
- 3:2 Geographic Coordinates - Grid Designation
- 3:3 Population Data
- 3:4 Agriculture Census Data

File 4 Natural Resource Data Record (All Resource Types)
- 4:1 Master Sequence Number
- 4:2 Geographic Coordinates - Grid Designation of known resources

4:3 Selected Resource Data
4:4 Natural Resource Ownership
    4:4.1 Private
    4:4.2 Public
    4:4.3 Undeveloped land

File 5 Effluent Data Record
    5:1 Master Sequence Number
    5:2 Geographic Coordinates - Grid Designation of known sources
        5:2.1 Industrial
        5:2.2 Institutional
        5:2.3 Private
        5:2.4 Natural
    5:3 Selected Effluent Data - priority listing
    5:4 Types: Quantity/Quality Vectors
        5:4.1 Percentage vector - 24 hour
        5:4.2 Percentage vector - monthly
        5:4.3 Percentage vector - annual
        5:4.4 Sampling weight assignment

File 6 Economic Activity Record
    6:1 Master Sequence Number
    6:2 Geographic Coordinates - Grid Designation
    6:3 Industry Indicators
        6:3.1 Output data: types
        6:3.2 Distribution of output
        6:3.3 Industrial Organization
        6:3.4 Financial information
    6:4 Selected Resource Data Record
    6:5 Selected Effluent Data Record

File 7 Meterological Model Output Record
    7:1 Master Sequence Number
    7:2 Geographic Coordinates - Grid Designation
    7:3 Coordinates of Initial Point of Module
    7:4 Effluent Quantity and Error Vector
    7:5 Average Wind Speed for Grid
    7:6 Adjusted Distance Factors
    7:7 Maximum Crosswind Distance in Grid
        7:7.1 Daily
        7:7.2 Weekly
        7:7.3 Monthly
    7:8 Meterological Variables - daily averages
        7:8.1 Temperature
        7:8.2 Wind speed and direction
        7:8.3 Solar radiation
        7:8.4 Humidity
        7:8.5 Particulate matter
        7:8.6 Sulfur Dioxide Concentrations

7:8.7 Oxidant concentrations
7:8.8 Hydrocarbon concentrations
7:8.9 Carbon dioxide and carbon monoxide concentrations

7:9 Climatic Variations
7:9.1 Hourly
7:9.2 Daily
7:9.3 Weekly
7:9.4 Monthly
7:9.5 Annually

File 8 Efflex Output Record
8:1 Master Sequence Number
8:2 Geographic Coordinates - Grid Designation
8:3 Master Sequence Number of Affecting Effluent Source
8:4 Environmental Efflex Concentrations
8:5 Quantity and Error Vector

File 9 Effects Analysis Output Record
9:1 Master Sequence Number of Pollution Sources
9:2 Master Sequence Number of Affected Areas
9:3 Selected Census Data
9:3.1 Population
9:3.2 Economy
9:3.3 Agriculture
9:3.4 Housing
9:3.5 Employment
9:4 Estimated Costs of Effects/Pollution
9:4.1 Medical
9:4.2 Structural
9:4.3 Agricultural
9:4.4 Environmental
9:5 Major Contributing Effluent Sources
9:6 Daily Output of Major Effluent Sources
9:7 Statistical Analysis - continuing
9:8 Major Type of Contributing Effluent Sources by Grid Designation

File 10 Tax Liability Output Record
10:1 Master Sequence Number of Effluent Source
10:2 Total Imputed Tax Liability With Error
10:3 Time-Phased Imputed Tax Liability By Type of Resource and Affect
10:4 Statistical Analysis of Affected Resources

File 11 Economics Effects Record
11:1 Master Sequence Number of Effluent Source
11:2 Types of Effluent Source - by geographic coordinates
11:3 Type and Magnitude of Tax Liability Assignment or Other Pollution Control Technique

11:4 Type and Magnitude of Response: cost increase per unit of product, labor force lay off, fuel substitution, new equipment, etc.

File 12 Land Use Record
- 12:1 Land Use Classification
  - 12:1.1 Standard Industrial Classification (SIC)
  - 12:1.2 Standard Land Use Classification (SLUC)
- 12:2 Geographic Coordinates - Grid Designation
- 12:3 Selected Census Data
  - 12:3.1 Population
  - 12:3.2 Economic
  - 12:3.3 Agriculture
  - 12:3.4 Housing
  - 12:3.5 Employment

File 13 Transportation Data Record
- 13:
  - 13:1.1 Characteristics of Selected Populations
  - 13:1.2 Housing - types and location
  - 13:1.3 Automobile data
  - 13;1.4 Income Characteristics
  - 13:1.5 Density of Population
  - 13;1.6 Trip Patterns
  - 13:1.7 Public Transportation Data
  - 13:1.8 Private Transportation Data
  - 13:1.9 Financial Data

In order to supplement data collected by the sensor network, data will also be derived from previous and on-going special purpose studies undertaken through independent efforts. Much of this data could conceivably be integrated into the IMP/S as long as they relate to the overall objectives of the system. At the same time data being developed by other agencies within the survey area will be processed into the data base through a data sharing arrangement. This input would include medical statistics, social, demographic, economic, political, facilities and budget data. In addition, large geographic area data such as population and employment forecasts, planning studies,

meterological data, transportation studies and regional economic base studies will be incorporated into the IMP/S data base if available.

Data derived from various model simulations will also be continually channeled into the data base. The main function of these models is to provide a framework wherein information may be defined, collected, and ordered. In addition, they will help the decision maker, research analyst, planner or administrator to visualize and comprehend the magnitude and complexity of the environments being monitored and studied.

Each model category will be designed to provide estimations of possible conditions that could occur if current conditions were allowed to persist. This data will then be integrated into the IMP/S horizon scanning and preferred solution selection techniques that will be used in the policy evaluation phase. Data derived from the model framework will also be routed into an Early Warning System (EWS). This system is designed to alert IMP/S personnel of potentially critical situations in the environment and suggest course of actions to the analyst/programmer in relation to the perceived problem.

There will be three types of models in the simulation system: (1) environmental, (2) planning, and (3) policy. The environmental models will be used to define and order data pertaining to general environmental conditions such as air and water pollution dispersion patterns, air and water quality,

land use relationships and the impact of hypothetical urban growth patterns on the surrounding region. Planning models will deal with activities that may have a direct or indirect impact on environmental planning and management. This model category will include transportation, residential and employment location models, demographic and economic projection models. Policy models, on the other hand, will deal primarily with policy variables in relation to resource allocation and management, expenditure patterns, area goals and objectives, quality criteria and pollution control. Chapter VII will describe these model categories and their functions more completely.

2. Using The Data Base

The IMP/S will be designed to meet at least five primary objectives: (1) permit a closer interaction between the user and his data and provide him with the capabilities to process and analyze data without the assistance of a programmer; (2) provide for a controlled and systematic management of the data base; (3) facilitate horizon scanning and preferred solution selection; (4) provide a framework for effectively evaluating alternative courses of action; and, (5) integrate diverse data inputs into composite information packages.

As a matter of policy the IMP/S will place the user (non-programmer) in direct contact with his data. Through the use of a user-oriented general purpose software system, the analyst

will be able to interact directly with the processing system and the data base. The software system will be built around a modified SPAN package developed by the Systems Development Corporation specifically for urban and regional planning.

In addition to the above functions the SPAN system will allow the user to specify his data requirements and formats. The processing functions in SPAN are "implicitly" programmed. In other words, the user can select through his specifications a particular configuration of preprogrammed procedural and format options allowing him to adapt program operations and/or data formats to meet his precise requirements. Consequently, the user will have an extremely flexible data management technique at his disposal. Not only will he be able to request various types of data formats he will also have the option of integrating them into different types of data packages designed to provide him with pertinent data pertaining to environmental conditions in the survey area.

The SPAN system will also be capable of detecting potentially critical environmental situations or policy/planning inconsistencies in their initial stages of development. This detection/analysis process will operate as follows:

a. All incoming data will be automatically processed and interpreted on a continuous, real-time basis.

b. As the data are being processed, they are compared with predefined threshold values already registered in both the

environmental and module files. If no critical levels are detected the processed data is routed either into the data bank or into a real time, on-line display system. If a critical reading is detected or a definite inconsistency in the data is recorded the system is alerted.

c. An analyst/programmer will then determine the exact nature of the situation or inconsistency. In order to define the problem and outline its major parameters the analyst will work directly with his data through a man-computer interface.

d. As the need arises the analyst would draw in data from the data bank. In addition, he will have access to a number of simulation models in order to test and validate his findings, or to detect new relationships in his data.

e. After the initial processing, analytical and simulation phases are completed the analyst, with the aid of the computer, will outline a list of possible alternative actions designed to modify or alleviate the perceived problem.

f. Using the environmental and module files as his major data sources the analyst would simulate each known course of action in order to determine its validity. If the alternative appears to offer a good chance for modifying or alleviating the problem it will then be evaluated in relation to its cost-effectiveness and cost-benefit ratios.

g. After this initial evaluation phase is completed all of the data will be summarized and integrated into a special

information package designed to outline the problem or situation, its probable consequences and possible courses of action to either prevent, modify or alleviate the problem.

h. The package is then presented to a decision-maker for further evaluation. The decision-maker would analyze the known data, send out field teams to investigate the problem and make recommendations for subsequent action. Once this phase is completed a proposal and an information package is sent to the appropriate agency for either further study or implementation.

It should be noted that the above process could occur only in an emergency situation. The reaction time, in this case, would be important. Depending on the situation an information package would be prepared for initial evaluation anywhere from one to three hours after a critical situation has been detected. An investigating team would then be sent out once the evaluation phase is completed. At the same time any sensors in the vicinity of the problem area would be transferred to a real-time, on-line monitoring status in order to maintain close surveillance over the problem area.

The overall process can be outlined as follows:

Incoming sensor and/or interagency data is received and processed.

↓

The data is automatically analyzed and compared with pre-defined threshold values.

↓

Detection phase is activated.

If a critical variable or condition is detected the data is transferred to the Early Warning System for evaluation and accelerated simulation.

EWS →

If no critical conditions or inconsistencies are initially detected the evaluation process continues along its normal path.

The data is further processed and transferred to one of three subsystems--the data base, simulation system or display system.

<u>DATA BASE</u>

Data is processed and stored in the data-base for future analysis.

<u>SIMULATION SYSTEM</u>

Models/procedures are defined-Two sets of models are defined-one for precise evaluation of data and one for gross or approximate evaluation of data

<u>DISPLAY SYSTEM</u>

On-line display-visual, and graphic is implemented.

Detailed Level

Evaluate data and generate a detailed study...

Outline parameters and variables-detailed

Test data in relation to predefined values

Gross Level

Evaluate data and generate a gross study...

Outline parameters and variables-gross

If a critical parameter is detected continue evaluation and define the values.

Interrogate computer for possible ways to rectify the problem.

Determine the cost-effectiveness ratio using a detailed model to test alternative-if made available.

Estimate the approximate range of the cost-effectiveness ratio using the gross model to test any alternatives.

If the alternative appears to be valid the analyst requests additional data.

The analyst compares this alternative with other alternatives derived from both the detailed and gross model categories.

The IMP/S information design will allow the analyst to project probable trends and/or consequences of the perceived problem.

The analyst arrays the alternatives in order of increasing cost and potential impact.

The information package is formulated.

The information package is transferred to a decision-maker for evaluation.

The decision-maker must now compare the "optimum" alternative found so far with the prospective payoffs of additional analysis. The decision-maker must decide to terminate analysis or generate additional alternatives.

If he decides that additional analysis is required the process is renewed.

If he decides that no additional analysis is needed an investigation team is dispatched.

Continuous evaluation of data will be maintained and an action proposal will be developed and forwarded to the appropriate agency.

At the same time all data derived from this simulation analysis process would be channeled into the data base for further analysis and integration with other simulation processes.

The process outlined above does not begin to take into consideration the complexities of the data processing, analysis and simulation/evaluation phases involved; however, it does indicate the general procedures that would take place in analyzing and interpreting input data on a continuous basis.

The data that is ultimately selected for the IMP/S data base will depend, in part, on what is relevant to the analytical functions. Two types of analytical activities are particularly important. Because decisions will have to be made concerning future conditions in the area being monitored, projections about its economic and social environments must be made; and, because decisions are almost always concerned with tradeoffs between benefits and the cost of providing these benefits, some kind of cost-benefit analytical capability should be incorporated into the information system. In addition, current environmental conditions such as daily stream flow characteristics, air and water

conditions, and sulfur dioxide concentrations will be constantly analyzed, evaluated and related to predefined threshold values. At the same time, the information design will provide a capability for projecting possible trends and conditions based on current data inputs from the sensor network. These projections will be extremely important for long range planning purposes.

3. Data Management System

The data management system is designed to (1) maintain in machine-processable form information about the IMP/S data base, (2) document the data base in terms meaningful to the users of the system, (3) integrate different or varied data elements into highly selective information packages; and, (4) route all incoming data into specific subsystems for subsequent processing, analysis and display.

All data collected by each of the sensor systems and those data derived from the inter-agency information system will be documented and stored in the IMP/S data base. The decision to document or not is made only in the case of processed data which is an intermediary step to producing other forms of data. In general, all incoming data and new data derived from the manipulation of existing data will be automatically documented.*

The documentation system will be used to maintain and update all reference files. This system will also cross-index all information in the data base. In addition, it will provide a comprehensive listing of all entities in the IMP/S information

*A data base manager will be assigned to coordinate the data base and manage all data input and documentation to prevent data overload.

design for general staff use. This listing will provide information on the types of data available in the system, their formats and their location in the data base. The several components of the documentation system are shown schematically in Figure 6.1.

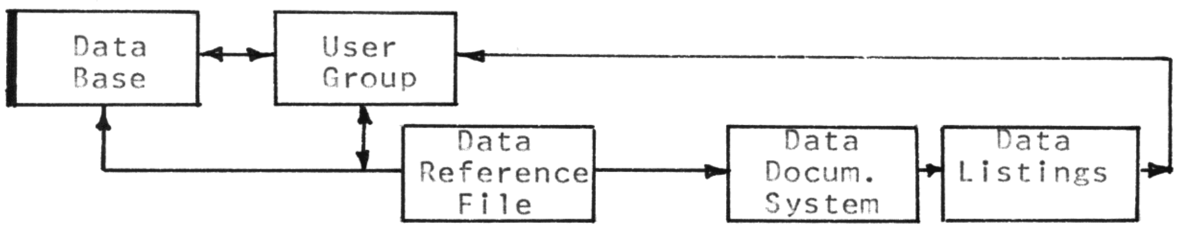

Figure 6.1

Documentation
System

The users will interact with the data base through a combined SPAN/MIDAS (Mixed Data Structure) software system. Both of these software packages have been used in San Francisco's Bay Area Transportation Study with very good results. Because of their ability to process large amounts of data while allowing for a close interaction between the user and the data base these systems can be used in the IMP/S with some minor modifications. These modifications will include basic changes in their file structures and programming formats so that they can process a continuous data input.

The SPAN program includes standard file manipulation, data reduction, statistical and plotter display capabilities. The

actual program consists of a sequence of job steps or instructions with each step involving a particular processing operation in an order detemined by the user. The data structures upon which the SPAN program operates on are self-defining. This self-definition capability will allow the IMP/S to expediate the exchange of information about data formates and coding on an automatic basis.

The MIDAS program along with the SPAN is designed to permit the processing of a large number of environmental and module files. In addition, the MIDAS processing program will categorize each data entity or phenomenon into three major components for analytical and simulation purposes. These components as pointed out above are classified as: System, Vector and Subvector. The System component defines the primary environmental category being monitored by each of the data collection systems. The Vector component denotes the subcategory or major elements being monitored in the primary system. The Subvector component describes the specific phenomenon or element category being sensed by the monitoring system. Each phenomenon in a particular Vector relates to one another and can be combined to define the status of that Vector. At the same time each Subvector element can be integrated with other Vector elements by using the SPAN system. This allows the user to study various relationships occurring in the environment and to simulate other conditions by substituting or combining different Subvectors. In addition, the output from

any SPAN/MIDAS operation may be used as input for any subsequent operation without intermediate action or modification.

An example of a SPAN/MIDAS Operation would be as follows: If an urban planner wanted to determine if traffic patterns in a particular sector of a metropolitan area had any effect on the quality of housing in that sector he could integrate the data from the Urban Pathology Vector (see pages 139-142) with the Urban Infrastructure Vector. Using both the modified SPAN and MIDAS software systems the planner could analyze the relationships between these two Vectors and simulate other relationships by interjecting new variables into the model. In addition, data derived from other sources can be added to the processing/analytical operation to make it more meaningful to the user. Thus, the planner ends up with an extremely powerful analytical and planning tool.

4. The Information Base and Environmental Policy Formulation, and Management

There are basically three classes of information needed for environmental policy formulation, planning and management. The first class or type of information is information that has a general applicability to many areas and problems. This type of information must be kept reasonably current. A second type of information has general applicability but needs to be collected only periodically. The third type is the kind that has special applications. In all three cases, the data needs

are defined first from a regional or survey area perspective and then on a grid basis. The regional data requirements are more general than the grid requirements; however, both will have similar needs in terms of content.

The information generated by the IMP/S is designed to be responsive to three major decision areas: policy formulation, environmental planning and environmental management. In formulating policy, public officials, administrators and planners must be able to perceive current trends and future conditions, and to relate them to current problems and needs. As solutions are developed or policies formulated to cope with the issues involved, officials also face the task of selecting the best way to solve the problem. This process usually requires a rather extensive cost-effectiveness or cost-benefit study of the proposed solution or solutions. These studies, in turn involve a tremendous amount of data. As a result the data base must be extensive enough and flexible enough to respond to these needs.

Environmental planning and management generally encompasses a wider area of concern than either urban or regional planning. In planning for and managing environments in their totality, the information needs are rather extensive and in many cases stricter than those required for urban planning or regional planning and development. The major reason for this difference is the tremendous number of variables involved and their interrelationships with each other. This means that the ramifications

of certain projects or policies will not only affect their immediate area of application but they may also have an impact on the surrounding region. This impact, in turn, may influence economic development, cause population shifts, increase or decrease industrial activity, determine urban growth patterns, govern transportation flows, influence the availability of water resources and determine environmental quality.

Another important factor is that these processes are not static; instead, they are dynamic in the sense that they are constantly changing and adapting to a multitude of other changes in the environment. For example, a new town or university complex located near a large metropolitan area could have a great impact on that area and the surrounding region in terms of public services, transportation, population shifts, ecological balances and general growth patterns of the surrounding urban centers. Another example of a dynamic interplay would be the development of an industrial complex in a coastal region. The potential environmental impact of this complex may be extremely important in relation to the ecological conditions found in this region. Because of these potential ramifications, the need to monitor activities that may have a long term effect on the environment is becoming more and more essential. In addition, the planning and information requirements are becoming increasingly stringent since more variables have to be taken into consideration.

Both environmental planning and management are essentially concurrent processes. In other words, once cannot make a clear distinction between these activities as one would in a business firm. Some examples of environmental planning and management would include multi-regional planning and development, multi-regional pollution control, weather modification, inter-urban transportation corridor design, the location, design and construction of new cities, range and ecological control, multi-regional water development and management. In addition, environmental management would encompass watershed, wildlife and recreation management, surveying and management of real and potential environmental hazards, multi-regional land use control and environmental monitoring.

5. Conclusion

This chapter has been primarily concerned with the orderly classification of data in the IMP/S and with the structure and content of the information design. The first part of this chapter examined the data base structure and the types of files that will be used. The second part described briefly how the system would operate; and, the third section dealt with data management and the related software systems that would be utilized in the IMP/S. The fourth section was primarily concerned with the application of this data to environmental policy formulation, planning and management.

CHAPTER VII

THE IMP/S ENVIRONMENTAL SIMULATION SYSTEM

A simulation is essentially an operating imitation of a real process. As a social science tool it refers to the construction and manipulation of a model capable of depicting a particular situation or condition, and manipulating its variables and their interrelationships. An environmental simulation, on the other hand, attempts to define a situation that is structurally similar to the phenomenon being studied. Thus a simulation, whether it is designed to depict social or economic situations or environmental conditions, is primarily concerned with developing a model that represents; or approaches, reality.

The model is the actual mechanism through which the simulation occurs. Richard J. Chorley and Peter Haggett defined a model as

> ...a simplified structuring of reality which presents supposedly significant features or relationships in a generalized form.[51]

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[51] Richard J. Chorley and Peter Haggett, "Models, Paradigms and the New Geography," Models in Geography, eds. Richard J. Chorley and Peter Haggett, (London: Methuen and Co., Ltd., 1967), p. 22.

They went on to state that:

> Models are highly subjective approximations in that they do not include all associated observations or measurements, but as such they are valuable in obscuring incidental detail and in allowing fundamental aspects of reality to appear. This selectivity means that models have varying degrees of probability and a limited range of conditions over which they apply. The most successful models possess a high probability of application and a wide range of conditions in which they seem appropriate. Indeed, the value of a model is often directly related to its level of abstration.[52]

The important factor here is that the model can be adapted to a particular situation by introducing new variables into it. The choice of variables to be included depends upon the processes to be studied or the events to be portrayed. A model, in this sense, is only relevant when the components and variables associated with it can respond in a manner comparable to that of the real world.

A model can also be viewed as a highly selective picture of reality. Morris Zelditch noted that the:

> ...real world is intricate, entangled and continuously varying. It is virtually impossible to study all variables at once, it is equally impossible to study a small subset of them while these are continuously altered by the effects of some larger set.[53]

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[52] Ibid.

[53] Morris Zelditch and William M. Evans, "Simulated Bureaucracies: A Methodological Analysis," Simulation in Social Science: Readings, Ed. Harold Steere Guetzkow (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1962), p. 51.

Thus, the real world must be simplified if one is to adequately understand the interrelationships involved. However, Zelditch and Evans also noted, that

> ...while simplification reduces the number of variables and often their permissible values; isolation removes the investigated system from the effects of a varying environment. Isolation may be accomplished ex post facto, just as the control of other factors may be. But there is a severe limit to the number of external factors that can be so controlled and, like confounding factors their number is indefinitely large and our knowledge of them is limited.[54]

It is important to understand that while a simulation can manipulate, simplify, transform and substitute other properties it is still an artificial condition. However, because it can be controlled, a simulation is an extremely useful technique for monitoring environmental processes, planning dynamic systems, projecting trends, evaluating policies and developing alternative strategies. The premise underlying this simulation concept is that the analyst or planner can "design" an environment or event that either reflects on a real condition or a possible situation. Because the analyst can control the variables that interact with this environment he can influence the models almost at will. This allows him to adapt his model to varying conditions as long as these conditions are within the predefined boundaries of the simulation.

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[54] Ibid.

The value of any simulation lies in its ability to provide a vivid and understandable picture of how a process or system works. This is important because the analyst or decision-maker usually finds himself making decisions on the basis of inadequate data inputs. A simulation system, such as the one conceived here, will alleviate this probem by providing the analyst/decision-maker with a comprehensive picture of what is occurring in the survey zone. For example, the IMP/S will include an automatic air pollution detection system in its Early Warning System in order to detect and predict impending hazardous and undesirable levels of pollution. The computer will be programmed to correlate data continuously from the air monitoring network with emission, meterological and statistical data stored in the various data files and inventories. This data would then be integrated with a diffusion model to determine whether a critical condition is likely to occur; and, if so, indicate which areas of the survey zone would be most affected, and to what degree. In addition, this system would provide a further time advantage by feeding current weather forecasts into the computer and subsequently modifying these forecasts with more specific conditions as they occur. The diffusion model itself would simulate conditions in the real world and would, in turn, be continuously bombarded with fixed and variable

data from the sensor network, data bank and other sources. The results of this simulation would then be displayed automatically, or on demand, so that the analyst/decision maker would be able to make better decisions on the basis of current data inputs.

Essentially the environmental simulation system would be designed to offer the analyst, planner, or environmental protection administrator a way to generate scientifically based estimates of current and future states of the environment. In order to facilitate the functioning of such a system attention must be directed to the problem of specifying environmental quality parameters, in quantitative terms to the extent possible.

This approach requires that all relevant aspects of environmental quality be identified and incorporated into a series of models, with each model designed to operate on an aspect of the total environment. The output of this simulation system can be looked upon as a series of environmental quality vectors which represents the state of the environment after a selected period of time. The components of the environmental quality vector would be based on predefined threshold values which would represent desired conditions for each of the identified relevant aspects of the environment.

Dr. Lowell G. Wayne, a photochemist and consultant on air pollution chemistry, stated that in order for any environmental model to produce useful predictions this model must be

> ...structurally similar to the environment, in the sense that basic units of the model correspond to basic entities of the real world, and that discernible laws which govern the relations betweenthese entities be represented by appropriate algorithms within the model.[55]

He went on to note that it is important

> ...to recognize the superior predictive capabilities of relations representing physical or biological laws, as compared with empirical relations or such statistical devices as extrapolation of trend lines or regression relations. Scientific laws are properties of nature and, when accurately known and correctly applied cannot introduce extraneous sources of error to the predictions of the environmental model. On the other hand, empirical relations and statistical devices are mathematical artifacts which in most cases reflect no real cause-effect relationships; they can give rise to very misleading predictions, especially when applied to environmental conditions which are outside the range of the data from which they have been derived.[56]

To be useful, the output of this simulation system and the EWS must be sufficiently precise to permit comparison of predicted states within the environment with desired criteria of environmental quality. As Dr. Wayne noted, models which "estimate only simple statistical parameters of time-and space-varying distributions of important variables may need to be supplemented by others giving more detailed distributions."[57] This is likely, if the simulation system has not included significant stratifying factors or recognizable associations.

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[55] Lowell G. Wayne, "Simulation: The Road to Coexistence," Datamation, April, 1971, p. 27.

[56] Ibid., pp.27-28.

[57] Ibid.

In order to be effective the model output must be very sensitive to changes in the input factors which represent the natural or artificial elements known to cause certain environmental effects and changes. Natural factors obviously affecting environmental conditions would include seasonal variations, climate,flora and fauna, latitude and hydrologic processes. Artificial factors would include effluents, wastes, emmissions, land uses, population density and transportation networks as well as other determinants of the urban environment. The IMP/S data collection system and data bank would provide the primary input factors representing both the natural and artificial elements located in the survey zone. The sensor network, on the other hand, would be designed to react to very sensitive changes in the environment. As these changes occur their analog characteristics would be channeled into the environmental simulation system. Since this system would be operating on a continuous basis subtle changes in the environment could be introduced into the model while they are occurring. This input would, in turn, enable the simulation system to continually project trends over a specific time range, thereby giving the analyst or administrator enough time to implement corrective measures or invoke protective strategies before a situation becomes critical.

The design criteria for the IMP/S environmental simulation system must take into account the dynamic changes

occurring in the environment. This criteria must also take into consideration the validity of the output. Since the output of this system will allow for a certain amount of variance, a confidence range will be included, in order to keep the data output within reasonable bounds. In addition, the system must be sensitive to changes in the environment. Finally, the simulation system must have the capability of merging together a number of models in order to construct composite simulations. This capability is important because the user of the simulation system may want to study the interrelationships occurring between various environmental elements. For example, a researcher may want to measure the status of a simulated atmosphere reflecting its effects on human health and welfare. This simulation would include both direct effects, such as those evidenced by physiological and psychological reactions to atmospheric quality wind patterns, temperature, solar radiation, etc.; and, indirect effects, such as cumulative deterioration rates in the physical and biological environments. In addition, socio-economic and selected medical data could be phased into the simulation to give it more depth and relevance to the phenomenon being investigated.

The model structure, as we noted above, provides the basic mechanism through which the simulation occurs. Francis F. Martin, a computer scientist and systems analyst with the

Hughes Company, noted that there were essentially three major phases in designing a model. He defined these phases as (1) Model Conceptualization, (2) Model Implementation, and (3) Model Execution. Each phase, in turn, included a number of sub-phases or steps. The entire process can be outlined as follows:

A. Model Conceptualization:
   1. Definition of the problem and/or issue.
   2. Analysis of the problem and/or issue.
   3. Determination of information and data requirement.
   4. Collection of pertinent information and data.
   5. Formulation of hypotheses and assumptions
   6. Establishment of the model rationale
   7. Definition of model parameters and variables.
   8. Determination of approximation procedures.
   9. Development of the conceptual model.
   10. Validation of the model structure.
   11. Model documentation.

B. Model Implementation:
   1. Development of a logical flow chart.
   2. Determination of the mathematical framework.
   3. Model validation.
   4. Determination of software specifications.
   5. Development of software components.
   6. Program development.
   7. Program validation.
   8. Implementation document.

C. Model Execution:
   1. Design finalization process.
   2. Program execution.
   3. Analysis of computer output.
   4. Data evaluation phase
   5. Data summarization.
   6. Data display.

In the initial sub-phase the problem or area of concern is defined and analyzed. Once the problem has been clearly outlined the programmer/analyst can proceed to gather and

evaluate pertinent data; make assumptions on the basis of that data; and, formulate hypothesis. This process, in turn, allows the programmer to formulate a model rationale which determines the boundaries and operational characteristics of the model. At the same time the programmer also defines the approximation procedures to be used in the simulation.

The reason for defining the problem in such precise terms is to enable the analyst to carefully construct a definitive program statement. This statement indicates the following: (1) it notes the existence of a particular problem, issue, phenomenon or object; (2) it indicates the types of questions to be answered, the parameters and variables to be encompassed, and the range of the condition or phenomenon being investigated; (3) it allows the analyst to break down the overall problem or phenomenon into its sub-parts; and, (4) it determines the types of information and data needed to operate the simulation. The collection of information and data includes the tasks of acquiring, merging and evaluating data from both the data collection systems and the IMP/S data base. Once this data has been collected it must be validated and evaluated in relation to the simulation design. This means that decisions must be made as to whether this data is relevant or germane to the problem.

According to Martin the "real world" structure in a simulation consists of three distinct elements. He defines these as:

1. A system (or operation) designed to perform certain functions.
2. The environment in which the system performs.
3. The interactions between man and the system, man and the environment; and, the system and the environment.[58]

A system, in the sense that it is used here, is essentially a series of processes or events that related to one another. For example, an ecological system is made up of a number of interrelated and inter-dependent processes that act together to modify other processes within the environment.

Francis Martin also noted that there were several basic questions that must be answered when considering the various elements listed above. He listed these questions as follows:

- What are the systems functions and how are they performed?
- Which functions are deterministic and which are nondeterministic?
- How do we approximate these functions in the model?
- What environmental factors affect system performance?
- How do we approximate the effects of environmental factors on systems performance?
- What are the interactions between man and system? Man and the environment? and, The system and the environment?
- How do we approximate these interactions in the model?[59]

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[58]Francis F. Martin, Computer Modeling and Simulation, (New York-London-Sydney: John Wiley > Sons, Inc., 1967), p. 169.

[59]Ibid., pp. 171-172.

Answers to these questions form the basis for establishing the model rationale.

In describing the structure of a model, Martin suggested that each parameter and variable included in the system be related to a unit of measurement, a range of values, and a set of characteristics which would indicate whether the parameter/variable framework is controlled, uncontrolled, single or multi-valued. At the same time each parameter/variable must be carefully related to the model structure. An environmental parameter is essentially a quality or process that may or may not vary over a certain set of values. A variable, on the other hand, is a quantity which can accept a wide range of values. For example, the concept of temperature variance may be defined as a parameter, whereas the range of values encompassed by this parameter represents its variable nature.

Another important factor in outlining the overall model framework for the IMP/S simulation system is the formulation of a set of precise measures of effectiveness for ascertaining model response patterns. To this end, the primary objective--mathematically speaking--is to "derive a function that expresses systems effectiveness as a function of all parameters and variables."[60] These functions can be expressed in a number of ways. For example, a function can be represented by a series of indices ranging from zero to one, by probability

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[60] Ibid., p. 178.

functions, by scalar numbers or vectors ranging from zero to n, or by ratio values.

The IMP/S simulation system will be designed to use three different types of modeling procedures for deriving approximations of the real world. These procedures can be classified as deterministic, stochastic and expected value models. All three procedures are applicable in computer modeling and simulation, and all three can be used in the same model when appropriate.

In deterministic type procedures there are no variations recorded in simulation outcomes due to chance elements. All probabalistic elements are either nonexistent or removed from the problem because of their irrelevance to the solution. Consequently, the outcomes derived from deterministic type models are always the same for a given set of inputs.

Stochastic procedures, on the other hand, are nondeterministic and random in nature. In this type of procedure the programmer/analyst samples from a number of probability distributions in order to determine specific outcomes in the model. For any given simulation using stochastic procedures the outcome generated is <u>not</u> always the same for a given set of inputs. According to Martin the effects of each outcome are

> ...introduced in the simulation process, which continues until completion. Randomization implies that replications are necessary in order to assign statistical confidence measures to the results.[61]

Outcomes determined by this procedure may then be used to determine model reliability, effectiveness and measurement errors. It should be emphasized that stochastic procedures are used mainly to define individual outcomes rather than aggregated outcomes.

The outcomes of expected value models are characterized by an aggregation of results. In other words, individual results within the model structure are

> ...not determined as in randomization procedures; rather the expected effects on a sample population are determined. In expected value procedures we assign mean values to the chance parameters and assign zero variance. The chance parameters may include reliability, systems effectiveness, event occurrence, functional operation time or measurement error.[62]

Once the analyst has defined the problem, determined his information and data requirements, collected the data, formulated his hypothesis, established a model rationale, defined the model parameters and related variables, formulated his approximation procedures he can proceed to describe the conceptual model, validate it and then document the model structure by formulating a concept paper. This paper would include the following information:

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[61] Ibid., p. 180.

[62] Ibid.

1. A comprehensive problem statement.
2. A complete analysis of the problem or issue.
3. A listing of parameters, variables and effectiveness measures to be used in the model.
4. The hypothesis to be tested and the underlying assumptions.
5. The model rationale.
6. A description of the model in general terms.
7. A listing of expected results and applications to be derived from the model.

In implementing the model we translate the abstract model concept into a concrete, tangible model construct. This construct is based on a series of logical flow charts which serve to outline the various functions and subfunctions of the model. The programmer/analyst then derives a number of mathematical equations which translates the logical flow charts into a precise program flow chart. The program flow chart serves as the basis for designing the software system or program for the simulation.

The model structure generally indicates a unique flow or cycle which links together a series of events that represents the conditions in the "real world". These events Martin suggests, may either proceed in a prearranged manner, or in a random manner. In order to process these events in some kind of order a programmer generally defines an "events generator". The purpose of this generator is to "generate and

store events (or processes) in what we choose to call the "events store" and to process the events in chronological order until the model run is finished."[63]

In designing an events generator routine for a specific simulation, Martin suggests the following procedure outline:

> 1. We examine the real-world and make a list of all relevant events in the system (or operation) and environment being simulated.
> 2. We define and describe each event (E) in the system or environment.
> 3. For the occurrence of each event (E) we determine all possible real-world reactions.
> 4. For non-occurrence of each event (E) we determine all possible real-world reactions.
> 5. We determine what deterministic or non-deterministic functions initiate the occurrence of event (E).
> 6. We translate real-world reactions into a logical flow chart showing the subsequent logic for occurrence of each event (E), and we translate this process into the logical flow chart.
> 8. We determine what latencies (or delays) may occur between an event (e) and the subsequent associated event or events.
> 9. We determine the mathematical procedure for computing each delay. We then determine whether the function is deterministic, random or expected value.
> 10. We select an appropriate event format for storing the events in the events store in which each event requires the following items of information: (a) time of anticipated occurrence, (b) event code (in event identifier), (c) identity of object or objects associated with the event, and (d) action statements defining event processing logic and computations and subsequent actions...

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[63] *Ibid.*, p. 194.

> 11. We determine procedure for storage and retrieval of events in the events store. The most efficient procedure is to store newly generated events in chronological order....[64]

Once the model design has been derived it must be validated so that it corresponds closely to the real-world and measures what it is supposed to measure. After the model has been validated, program specifications are defined and software is developed to operate the model. The software consists of all the programs developed to operate the environmental simulation system. These programs are also used to process, store, retrieve and document data, operate the display systems, monitor environmental sensors and operate the early warning and response simulation systems.

In the third or final phase-model execution-the model is put into operation. However, prior to making production runs on the computer, Martin recommends that:

> ...an experimental design should be constructed giving the parameter levels and combinations of parameters to be incorporated in the production runs. The choice of the experimental design depends on the results expected from the simulation. A properly constructed experimental design should yield a maximum amount of information with a minimum amount of computational effort. Statistical techniques are utilized in the experimental design to yield the most efficient and economical design.[65]

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[64] Ibid., pp. 194-195.

[65] Ibid., pp. 227-228.

After the simulation is completed the programmer/analyst proceeds to evaluate and draw conclusions on the results. At this point additional variables can be incorporated into the model in order to study alternative reactions and policies. Once the simulation is terminated the programmer/analyst transfers the information to the appropriate decision-making level for further analysis, evaluation and implementation.

In defining the criteria for the IMP/S model design one must take into account their individual operational and functional characteristics. These characteristics will vary according to their construction, the problem at hand, the types of information sought, model rationale, the parameters and variables encompassed by the model, their approximation procedures and their data input. Although individual variations will exist, one can generally outline certain elements or criteria that should be common to all of the models to be used in the IMP/S environmental simulation system. These criteria will be as follows:

1. Each model in the environmental simulation system should be based on a theoretical statement of the mechanisms involved in the phenomenon being simulated. Although these models will not usually simulate individual or specific areas within the phenomenon they should be able to give results which correspond to the real-world.

2. All of the models in the system should be either incremental and recursive, or projective. The recursive models will use past data to simulate current patterns. Projective models, on the other hand, will be able to utilize current data to project trends and future conditions. Incremental models move from one time interval to the next. Each incremental step depends on the situation of the preceeding state.

3. All of the models should be relatively simple in order to minimize the difficulties of data acquisition and processing.

4. Each model should be designed to accept alternative measures or indices. This will provide the flexibility needed for situations in which one measure is particularly appropriate to a given activity or phenomenon type while a different measure is best suited to other activity types.

5. Each model should be able to accept data from a variety of outside sources. This operation can usually be handled as a preliminary updating (internal to the model) of the data, or it can be done within the main frame of the model.

6. All of the models included in the IMP/S simulation system should be capable of being calibrated. This will allow the analyst or programmer to simulate a variety of trends and environmental conditions using the same model structure.

7. Provisions for sensitivity analysis should be incorporated into the simulation system. This will enable the programmer/analyst to evaluate the effect of changes in a given parameter on all facets of the model.

8. The simulation system should provide for a variety of display formats. For example, graphic outputs could be used for comprehending and evaluating alternative model outputs. Tabular outputs, on the other hand, could be used for sensitivity analysis and calibration. Real time display systems using CRT or Video display consoles could be used for man-machine interactive techniques for simulate manipulation and modification.

Figure 7.1 outlines the total IMP/S Environmental Simulation System. The IMP/S-ESS will consist of three major components: the Early Warning System (EWS), the Response System (RS); and, the Environmental Simulation System or ESS. Each component, in turn, will have its own model framework. These frameworks will serve as model processors allowing the programmer/analyst to build upon a core model by adding integral blocks to its structure. In other words, the programmer could construct a "composite" model by simply integrating a series of individual models or blocks into one larger model. For instance, an economist may want to study the potential impact of certain types of economic development on the overall air quality of the survey zone. After carefully defining

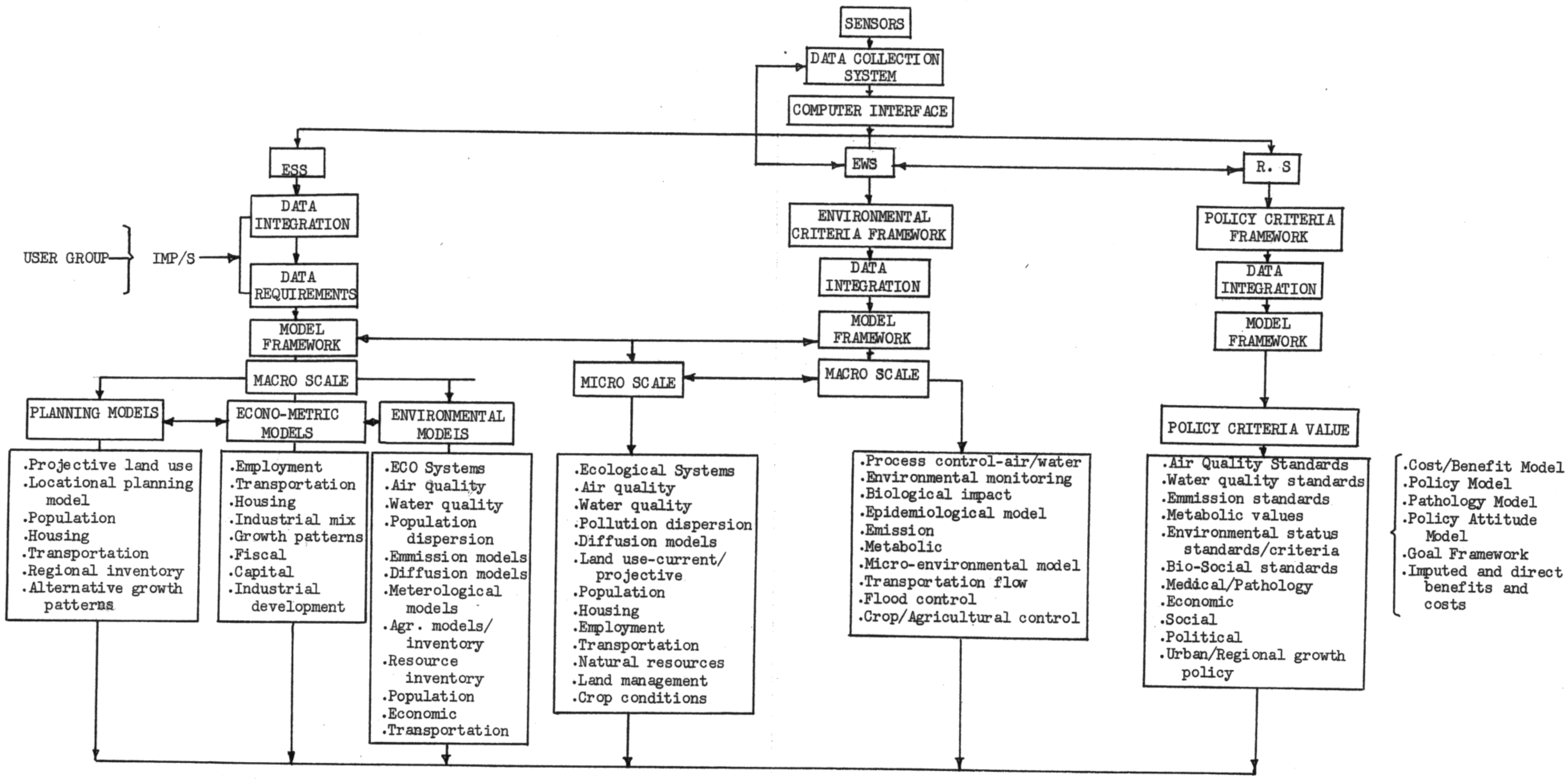

FIGURE 7.1

MODEL INTEGRATION AND DISPLAY

his area of concern, and the related parameter/variable structures, the economist, using a projective land use model as his core, could merge an industrial development and/or regional emission model to study possible pollution dispersion patterns. In addition, macro-diffusion, meteorological and regional growth models could be added to provide the economist with a more comprehensive model structure.

The key element in this concept is that each model initiates a unique flow or cycle through the logical structure of the core model. Upon completion of its particular activities control of the model reverts back to the original model framework or processor. The overall structure of the final model construct is selected according to a predetermined design format initiated by the programmer/analyst. It is important to note that the logic of the program determines the design of the model. The program pulls out the individual blocks and integrates them with the core model. All the user has to do is specify the particular model or models to be used, indicate their order of integration, identify their parameter/variable structures and outline their action statements, define their event processing logic and computation format. The software would then initiate all subsequent processing operations.

The Environmental Simulation System is designed mainly for simulating a wide range of environmental and socio-economic

conditions. The system is divided into two major categories, or levels: macro and microscale models. The macro category is used for simulating conditions active at a zonal or regional level. This distinction is essential because the scale of each type of simulation will vary. In addition, the degree of model integration or the number of blocks that can be combined with the core model will depend onthe complexity of the simulation. A metabolic simulation for a grid or even a cluster of grids will not be the same as a simulation dealing with regional or zonal metabolic factors. Not only are the causal chains different but the level of complexity increases as the scale increases. Thus the major difference between these categories lies in their complexity. The macro system will be able to handle many more elements than the micro system. The micro system, on the other hand, will provide the programmer/analyst with a very precise technique for testing basic assumptions. Together they offer the user a multi-leveled, analytical framework that can be used for simulating a wide range of conditions in the ecological, biological and man-made environments.

The macro system is further divided into three subcomponents or model categories: planning, econometric, and environmental. Planning models will be used mainly for determining optimum regional growth patterns, designing transportation corridors and intra-urban movement systems, formulating

population projections and trend analysis, facilitating projective and alternative land use studies, and for planning open space corridors. In addition, these models will be used to outline optimum locational patterns for various functions in order to enhance or reduce their impact on the natural environment. For example, a regional planner may want to determine the best location for a regional industrial center while taking into consideration its impact on the natural environment and the surrounding communities. By carefully combining a number of appropriate model structures provided by the ESS the planner could conceivably determine not only the potential impact of this industrial center on the total environment but also its impact on other communities in the region in relation to their growth patterns, employment, transportation and housing needs. It should be emphasized that this model category is designed explicitly for helping the physical planner or environmental protection administrator to prepare urban and regional plans. In order to enhance this capability other model categories will be able to provide inputs into the planning sub-component as part of the building block process noted above.

Econometric models will be used primarily for testing and evaluating economic and manpower development policies, industrial growth patterns, employment trends and regional input/output functions. These models would provide the

physical planner, economist, manpower expert and other related specialists with the means for testing various assumptions underlying regional developmental policies and priorities. In addition, this model category will provide input data for both the planning and environmental simulation components of the ESS.

The environmental model sub-component is designed to provide the environmental protection administrators, planners and other specialists with data on environmental conditions in the survey zone. The emphasis here is mainly on defining long range trends and implementing environmental impact studies. Each model in this sub-component will be able to link up with other models as the need arises. This capability will enable the environmental model sub-component to achieve a comprehensive, multi-dimensional approach in analyzing current and projected trends in the natural environment.

The ESS micro system is designed to simulate environmental, ecological, land use, agricultural, economic and social conditions at the grid level. This system, unlike the macro system, is geared to implement very precise simulations dealing with only a few variable inputs. Each grid in the survey zone will be individually mapped and coded. All data collected for the grid will also be coded. This will enable the software program to route specific, non-aggregated data into the system. The purpose of this micro system is to supplement the more

general macro system as the need arises. It is also designed to give the user of the ESS more flexibility in outlining his scale and operational requirements. In addition, the micro scale models will be able to "plug into" or integrate with the more comprehensive model structure. THis integration process should increase the simulation capabilities of both systems.

Both the Early Warning and Response Systems are defined as real-time simulation systems. These systems differ from the ESS in that their data inputs are derived directly from the sensor networks and merged into a series of on-going simulation models. The EWS is designed to detect real or potential environmental hazards such as critical pollution levels, ecological disruptions, biological imbalances in the environment or potentially dangerous pathological conditions. As analog data from the sensor systems are received by the interface component it is immediately channeled into the IMP/S. This input data is then processed, analyzed and compared to predefined threshold values or environmental standards. If a discrepancy occurs, or a critical value is detected, the system would automatically alert the appropriate policy or action level. A programmer/analyst then begins the task of defining the problem and outlining its causal relationships and variables. At this point the Response System(RS) is brought into operation.

The RS is programmed to process, analyze and interpret EWS data by means of a man-machine interaction format. This format or mode is designed to allow the programmer/analyst to carefully assess his data and develop alternative courses of action in response to the problems detected by the EWS. This format or technique enables the programmer/analyst to interact directly with a specific computer simulation. It also allows him to evaluate alternative policies and plans by using cost-benefit and policy models. In addition, a pathology model is included for defining certain biological parameters. These parameters, in turn, can be used for determining the environmental status of a specific area in the survey zone.

The model framework of the RS also includes a wide range of policy criteria for evaluating problems, data discrepancies and/or environmental hazards. This criteria framework encompasses air and water quality standards, emission standards, metabolic values, bio-social standards such as optimum population and structure densities, crime, welfare and employment values, rates of mental illness in a certain geographical area, normal/abnormal pollution levels, accident and criminal rates, etc.. These criteria are used for deciding a particular course of action or policy. By using cost-benefit, pathological, policy and cost-effectiveness models the programmer/analyst will be in a better position to provide the decision-maker with a number of alternative policies, programs or management plans.

The Response System will operate as follows: A programmer/analyst, using the output from the EWS simulation prepares a series of problem statements. This can be done either manually by the programmer, or automatically through a special software program. If done manually, the programmer translates the problem into FORTRAN or some other programming language. The problem statement is then transferred directly onto magnetic tape and loaded into the computer memory. Once the statement is stored in memory the analyst can instruct the computer to perform certain processing operations. While the computer is processing the data into an on-going simulation the programmer/analyst can modify the input variables through a complex feedback process. The results of this simulation are then immediately transferred to both the display system and data bank.

The Policy Criteria Values, as noted above, provide the basic input variables for the RS model framework. This framework, in turn, consists of six model structures: cost-benefit, policy, pathology, policies and attitudes, inputted and indirect benefit costs models. The programmer/analyst would be able to use any one or combination of models depending on his requirements. Each model structure will have its own set of functions. The cost-benefit model, for example, will be used to evaluate current proposals, plans and management procedures on a cost basis. The objective of this analysis

is to isolate the alternative or combination of alternatives that either gives the greatest expected effectiveness or benefit for a given expected cost, or a given expected benefit for the least expected cost. In other words, this model structure will be used to determine the costs of alternative proposals, plans and/or procedures in achieving a stated benefit, or, conversely, the effectiveness of alternative policies, plans and/or procedures for a given cost.

The benefit-cost model proceeds on the reasonable assumption that in any public-decision problem we should attempt to maximize the net benefits occurring to society. Benefits can be measured as the total willingness of all individuals to pay for a project, or goods, rather than have no project at all. Costs are measured by the monetary value of the goods that are devoted to the project. Neglecting service, administrative and distributional considerations, the decision to undertake a project or course of action would be governed by the benefit-cost relationship. In determining an optimum relationship the model structure would encompass a maximum/minimum criteria framework. The maximum framework would be used to direct the decision-maker to select a course of action which offers the highest security level. The minimum framework, on the other hand, would allow the decision-maker to assess the opportunity loss of an incorrect decision. Specifically, this criterion states that one should choose a course

of action which minimizes the maximum possible expected regret for any strategy selection. The choice of criteria to use would be determined by specific policy guidelines.

The policy model will generally be used in conjunction with the cost-benefit model to aid the decision-maker in the assessment and evaluation of alternative policies and plans in relation to general policy variables. In this case a careful distinction is made between decisions and the decision process itself. A decision process describes a complex sequence of events beginning with the recognition that an action will have to be selected, and ending with the implementation of that action. A decision is then simply defined as the selection of an action. The policy model is designed to give the decision-maker, administrator or planner a number of feasible alternatives so that he will be able to determine the best course of action to pursue.

The pathology model structure is designed to assess all pertinent demographic, biological and environmental data from the EWS by using a comparative process utilizing standard environmental, biological, social, economic, health, ecological and planning parameters stored in its memory banks. For example, if a random search conducted by the EWS indicates that excessive air pollution levels are building up in a specific sector it would automatically alert the appropriate decision-making component in the IMP/S. Once alerted, the

component begins to utilize the RS. The problem statement is formulated and applied to the pathology model structure. Input values from the EWS are entered into the model simulation and processed. Other pertinent data are transferred from the data bank and routed into the model. All computations are then compared with standard values to indicate negative and positive means, standard deviations and correlations. The results of this process are then transferred directly to the display system for further evaluation.

The heart of this model structure is a regional inventory matrix. This matrix includes the location and magnitude of each significant environmental element or factor in the survey zone. For example, it would include emission factors for determining pollution levels; transportation-mobile factors indicating vehicular traffic volumes and speeds, land use development and metabolic input-output flow rates. Rate factors will also be used to provide quantitative data in relation to the phenomenon being simulated.

Depending on the phenomenon and/or system to be analyzed, the environmental pathology model will be used to:

- predict the rate of a particular process;
- aggregate data by a factor or combination of factors (or variables);
- manipulate certain control variables to facilitate the evaluation of various causal relationships;
- develop diffusion diagrams for specific phenomenon;
- determine alternative courses of action to alleviate or modify the perceived problem;
- help determine inter--as well as intra--system cost/time factors; and,
- identify areas of functional overlap between causal chains.

The policies and attitudes model would be used to help determine optimum policies based on current priorities and resources. In planning large scale environments and managing their processes it is essential that the decision-maker--whether he be a regional planner, environmental protection administrator or range manager--be constantly aware of the changing priorities and attitudes of the political system. This is especially true in developing long range plans and policies for a large and extremely complex region. In complex systems, whether they be natural or man-made, long-term improvements often conflict with short-term advantages. Thus the idea of a policies/attitude model would be to allow the decision-maker to determine and analyze ineffective and/or detrimental policies before they are implemented. For example, if a regional planner wanted to determine whether the location for a new city would be feasible in relation to an overall regional plan he would construct a regional model based on existing software components, and then transfer the results of that model into a policies/attitude component. This modular approach would also give the planner the means to experiment with the large number of variables available to him.

In addition, the policies/attitude model would provide the framework for assessing policies. Thus if a decision-maker wanted to implement a certain program or policy which

would have the greatest impact on the community he could--through the use of simulation techniques--manipulate the numerous variables associated with the policy to optimize its impact. However, it should be understood that this process is not designed to supplant the human element, but only to sharpen it by reducing the overall complexity of the real world. The final decisions on any policy or plan must be the prerogative of human decision makers.

Any decision made within a systems context usually cannot be realistically made solely on the basis of the endogenous considerations of cost and effectiveness alone. The reason for this is that these factors are not generally amenable to an objective analysis because of their highly unpredictable nature. The chief factorsin this category that may have a significant influence on any decision are technological advances, resource availability, political sensitivity, psychological stimulus, perceived goals and psycho-social relationships.

Thus, in designing a comprehensive environmental simulation system for the IMP/S one must consider the dynamic behavior of systems. This is essential because the simulation system, as conceived here, is basically made up of many interacting subsystems such as the ESS, ESW and RS. One must also take into consideration the various interacting

feedback loops between these subsystems. For example, Jay W. Forrester stated that:

> ...in complex systems cause and effect are often not closely related in either time or space. The structure of a complex system is not a simple feedback loop where one system state dominates the behavior. The complex system has a multiplicity of interacting feedback loops. Its internal rates of flow are controlled by nonlinear relationships. The complex system is of a high order, meaning that there are many system states (or levels). It usually contains positive-feedback loops describing growth processes as well as negative, goal-seeking loops.[66]

The computer simulation is designed to reveal dynamic characteristics of both natural and man-made systems. The primary task of the programmer/analyst is to determine the best of many simulations to use. Once the determination has been made it will be relatively easy to instruct the computer to process and operate the simulate. At the same time various degrees of automation will be possible. A fully automatic simulation is one in which the entire simulation will be completely automated and thus allowing no human interaction in the model processes. A semi-automatic simulation would enable the operator to play an integral part in the model processes. A third variation would involve an integrated simulation which would allow the system to use simulated inputs generated in the computer to operate a more complex simulation. Again the

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[66]Jay W. Forrester, Urban Dynamics (Cambridge, Massachusetts and London, England: The MIT Press, 1970), p. 7.

degree of automation will be determined by the user of the system.

In conclusion, the IMP/S Environmental Simulation System will be used mainly to aid the decision-maker in defining plans and priorities for extremely complex systems. This system is not meant to do away with the human element. On the contrary, the underlying premise of such a system is to enhance the decision-making and planning capabilities of its users.

CHAPTER VIII

INFORMATION SYSTEMS

An information system is concerned with the collection, storage, processing, retrieval and dissemination of pertinent data to a user or group of users. A more comprehensive interpretation defines an information system as an integrated collection of people, computer equipment and related programs, a dynamic data base, and institutional procedures interacting in a prescribed systems pattern. It is designed to collect, store, update, and facilitate the automated use of data on a continuing basis. Such data and their processing and analysis are related to both the internal affairs of government and the external environment. The manifold purposes of such an information system are to meet operational requirements, to facilitate various summarizing or analytical techniques relevant to the definition of community problems; to assist the search for program goals; to generate cybernetic flows for evaluation and control; and to permit the exchange of information among governmental units and with the public.[67]

A number of key concepts underlying or contained in the above definition should be noted. The first major concept is

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[67]Kenneth J. Dueker, "Urban Information Systems and Urban Indicators," Urban Affairs Quarterly, Vol. VI (December 1970), p. 174.

that an information system is basically an integrated collection of subsystems with each subsystem interacting together in order to sustain a processing, analytic, and control capability. Robert E. Harshbarger has characterized this interaction process as

> ...continuous from source data gathering through the various steps of communications to a central location, automatic screening and manipulation of data, display or presentation to a user, the user analysis and evaluation process and finally the decision and action response process.[68]

The awareness of this interaction process is important in terms of implementing a comprehensive environmental monitoring and information system. To the implementing organization this awareness factor represents a series of separate though closely interdependent implementation processes. These processes demand different techniques, disciplines, technologies and supporting organizations in order to develop a responsive system.

A second major concept underlying the above definition is that the system involves a series of interfaces or boundaries relative to various "outside" agencies and institutions. This concept implies that in order for an information system to be responsive it should be able to relate with the external environment. This is done by facilitating a

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[68]Robert E. Harshbarger, "Information Systems and the Implementing Organization," Information Systems Science and Technology, ed. Donald E. Walker (Washington, D. C.: Thompson Book Company, 1967), p. 115.

"dialogue" between the decision-maker, analyst or planner and the system. This dialogue tends to be complex and often starts with the decision-maker seeking a clear definition of a specific problem or event along with its major components. The actual decision-making process in any area will depend on a number of factors such as the organizational structure of the agency, its major functions, the style of the decision-makers, and the linkages formed between the bureaucracy and the information system. For this reason, Hirsch and Sonenblum have suggested that:

> ...in any particular instance the information environment is a closed system. The argument used to support this suggestion is that identifying, generating, analyzing, and basing decisions on relevant information are all done within the framework of a specific set of institutions, and an information design relevant to one place or time cannot, therefore, be transferred to another.[69]

A third major idea presented in the above definition is the concept of feedback control. This concept is defined as that "information provided to a manual or mechanized system which enables the system to react so as to maintain its operations or adapt them more closely to the needs of its users."[70]

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[69]Werner Z. Hirsch and Sidney Sonenblum, _Selecting Regional Information for Government Planning and Decision_, p. 6.

[70]Morton F. Meltzer, _The Information Center: Management's Hidden Asset_, (New York: Vail-Ballur Press, Inc., 1967), p. 143

The importance of feedback-control is based on the idea that an information system can be modified to adapt to changing needs and priorities. In the context of a dynamic environmental monitoring and information system this idea is an important factor in the overall design. Since the system must cope with rapidly changing processes the ability to modify the internal data base and the interaction mode is essential to maintain a high degree of system flexibility.

The requirements that the IMP/S must take into consideration can be grouped into the following categories: data acquisition, data storage and retrieval, data manipulation and analysis, and the display of information to appropriate personnel.

The design of the IMP/S will include a data acquisition plan that recognizes the dynamic nature of the data base and the interactive nature of its design. The plan will delineate the procedures for acquiring, organizing and updating data from a number of different environments and geographical areas. Since the proposed IMP/S will be a completely interactive system the data input must be made compatible to the overall data base while still maintaining a highly flexible and open-ended system. At the same time the IMP/S will permit the incorporation of future data acquisitions into the data base as new needs develop.

The system will accommodate a relatively large storage capacity. The data base must also be in a form that is readily accessible while at the same time enabling the user to retrieve and manipulate data in an efficient manner.

Because the system is designed as an interactive system the load on the storage capacity will be tremendous. This is due to the increased need for additional data inputs in order to facilitate the necessary symbiotic relationships between the user and the system. In addition, a large transient data base will exist due to the almost continuous input of new data and the subsequent modification or elimination of previous data inputs.

The IMP/S will also be designed to allow the analyst or planner to quickly retrieve the data he needs for analysis. The system will utilize three basic retrieval modes. The first mode will place the user in direct contact with his data. This is defined as an interaction mode and allows the user to directly interrogate the data base, and interact with it in order to manipulate that base on a real-time basis. The second mode will be based on an automatic retrieval system where selected phenomena are continuously monitored and reported to a specific observer. This automatic retrieval of environmental data will occur at precise time intervals and will be automatically displayed.

The third retrieval mode will utilize an early warning concept. Here selected input data are passed into a simulation model which maintains a precise range of threshold values. If the incoming data indicates a potentially critical overload the system would atuomatically alert an observer. As long as the input data coming in from the sensors are within prescribed value ranges the system will remain passive although it can be interrogated at any time.

The IMP/S will display data that deals with both alphanumeric and spatial relationships. This means that the display system must be able to present data in a variety of formats encompassing both visual and graphic modes. The value of this capability lies in the user's ability to manipulate large amounts of data. To be useful the information system must allow the analyst or planner to interact directly with the display by enabling him to merge diverse data inputs into it.

In order to maintain some degree of compatibility between these diverse data inputs the system will be oriented towards a coordinated, multi-faceted file structure encompassing data that is pertinent to a wide range of user groups. In addition, the system would also have a capability for scaling varied data inputs according to user requirements. This flexibility is important because the planner, analyst, or decision-maker requires a relatively broad data base that

incorporates a wide range of diverse and often incompatible data inputs.

The IMP/S data management system will be designed to enable the user group to select and organize its own files according to its needs. In addition, since the system will have an extremely dynamic data base that will vary considerably over time the data management system will be designed to incorporate newly acquired data as well as new data arising from analysis made on existing data. Thus, in principle, any data generated by the IMP/S would become part of the data base unless or until there was no further need for it.

The data base management system will be built around a software package similar to the SPAN system currently being used by the Bay Area Transportation Study Commission (BATSC) which is charged with preparing a long-range regional ground transportation network for the San Francisco region. Michael J. Kevany of the System Development Corporation (SDC) described SPAN as a "data base management and analysis system for socio-economic, ecological, and other statistical data, designed primarily for use by non-programmer analysts..."[71] He noted that SPAN was organized as a collection of processing modules that allows the user of the system to:

> ...convert data to and from system formats; copy and dump tapes; combine files by matching and merging; sort files; summarize and tabulate files,

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[71]Michael J. Kevany, <u>An Information System for Urban Transportation Planning</u>: The BATSC Approach, p. 1.

> produce reports in standard as well as user-specified formats; perform a variety of statistical and other analyses, including factor analysis on up to 100 variables, regression analyses, point-in-polygon evaluation, etc....[72]

In addition, the SPAN package is able to handle four types of data storage:

> ...mixed data structure (MIDAS) files for hierarchically organized, mixed-record type data; simple binary (STARS) files for aggregate entity and statistical data; simple BCD files for homogeneous data input to the system; and matrix save tapes for matrices and arrays.[73]

The data base, as conceived here, will exist in several different organizations with each organization reflecting a different logical file structure. The IMP/S information system will be user-oriented which will allow non-programmers to conceive and implement file processing and analytical jobs at a relatively high level of sophistication. Although the system will be highly interactive, many of its processing and analytical functions will be fully automatic or semi-automatic. Because of the many different kinds of analytical, processing, retrieval and display formats to be utilized by this information system an extremely high level software capability must be maintained in order to allow for an effective operational configuration at all times.

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[72] Ibid.

[73] Ibid.

The major operational criteria underlying the IMP/S information system are as follows:

1. The system must be able to handle a wide range of significant parameters and related values.

2. The system must be flexible and take into account geographical and environmental differences.

3. It should be able to merge diverse data from different geographical, spatial or temporal sources such as census tracts, county, special districts or regional/basin-wide jurisdictions.

4. The information system should be simple in design.

5. The IMP/S should maintain adequate coverage in oder to determine a wide-range of environmental conditions occurring in the San Antonio River basin.

6. The system should provide for several levels of failure. In other words, there should be a high level of redundancy.

7. The information system should be designed to be as unobtrusive as possible. That is, it should not impose any major reorganizations of the planning and management components of the IMP/S. The IMP/S--referring to it as a total system--should be designed so that it will not have a noticeable impact on the environment it is to monitor.

8. All systems within the IMP/S should be modifiable in the sense that they can adapt to changing conditions and

organizational requirements. The IMP/S should also be able to incorporate new functions. It should be open-ended to allow for modular growth through the integration of new system functions.

In addition to the general criteria listed above the information system should be able to accept and disseminate data in a variety of forms. The data base itself should be very flexible, and the information system should permit a closee interaction to occur between the user and his data. The system should also incorporate effective programs for managing an extremely dynamic data base containing data from a variety of sources in a variety of formats. In order to expedite the flow of information from one point to another point within the IMP/S it should have a high level reporting and display system. At the same time, the system should also incorporate software designed to enable the user to carry on program development and experimentation concurrent with his operations, and to link up a number of remote data sources to his terminal. Finally, the information system should be able to display data in a variety of media-graphic, visual and tabulated.

In conclusion, this chapter has attempted to outline some of the basic characteristics and requirements for a comprehensive environmental information system. To this end, the overall system and its major components have been defined.

In addition, its general operational configuration and its relationship to the larger system has been outlined and described. The next chapter will be concerned with defining a planning concept to be utilized as an integral part of the IMP/S. Both the information and the planning system will be linked together in order to develop an overall environmental planning system for the San Antonio River basin.

CHAPTER IX

A CONCEPTUAL PLANNING SYSTEM

The purpose of this chapter is to outline briefly a general planning concept to be utilized as an integral part of the IMP/S. This concept implies a comprehensive planning framework that is able to encompass a large number of environmental elements. The underlying premise of this planning system is that there are a number of known environmental realities that are understood with a degree of certainty sufficient to provide a basis for rational decisions. However, it should also be understood that to perceive the environment as a totality does not imply an attempt to do the impossible by planning for it as a totality.

The perception of these environmental realities is based on the idea that all objects, events and systems can be linked together into a series of causal chains which can, in turn, be perceived and influenced as individual elements through the application of systems theory. Systems theory assumes that all individual elements tend to be governed by some form of regulated interaction that forms an organized whole. Thus by manipulating one part of a system the entire system is subsequently modified.

Planning can be defined both as an activity, and as a process. As an activity, planning seeks to anticipate events or problems, devise solutions and/or options for solving current or projected problems; and allocate resources in order to maximize the attainment of a given or developed set of goals. The planning process, on the other hand, describes the procedural format, or arrangement of a set of related activities. This process is usually characterized or reflected in the variety of options available; the variety of impacts which must be considered; and the number and complexity of interactions.

The planning process itself is basically a way of developing, selecting, implementing, monitoring and revising actions occurring in the real world. This process is described in Figure 9.1. The search activity designates any procedure used to produce one or more alternative plans of action. Once the alternatives have been carefully outlined the decision-maker must then select an optimum course of action. This selection process is usually done within a preference ordering framework. This framework encompasses the basic strategies, needs, goals, objectives, and priorities of the decision-making system. In addition, the decision-maker must also be concerned with the probabilities of success and/or non-success of the proposed course of action. Potential ramifications or consequences of a particular strategy must be carefully

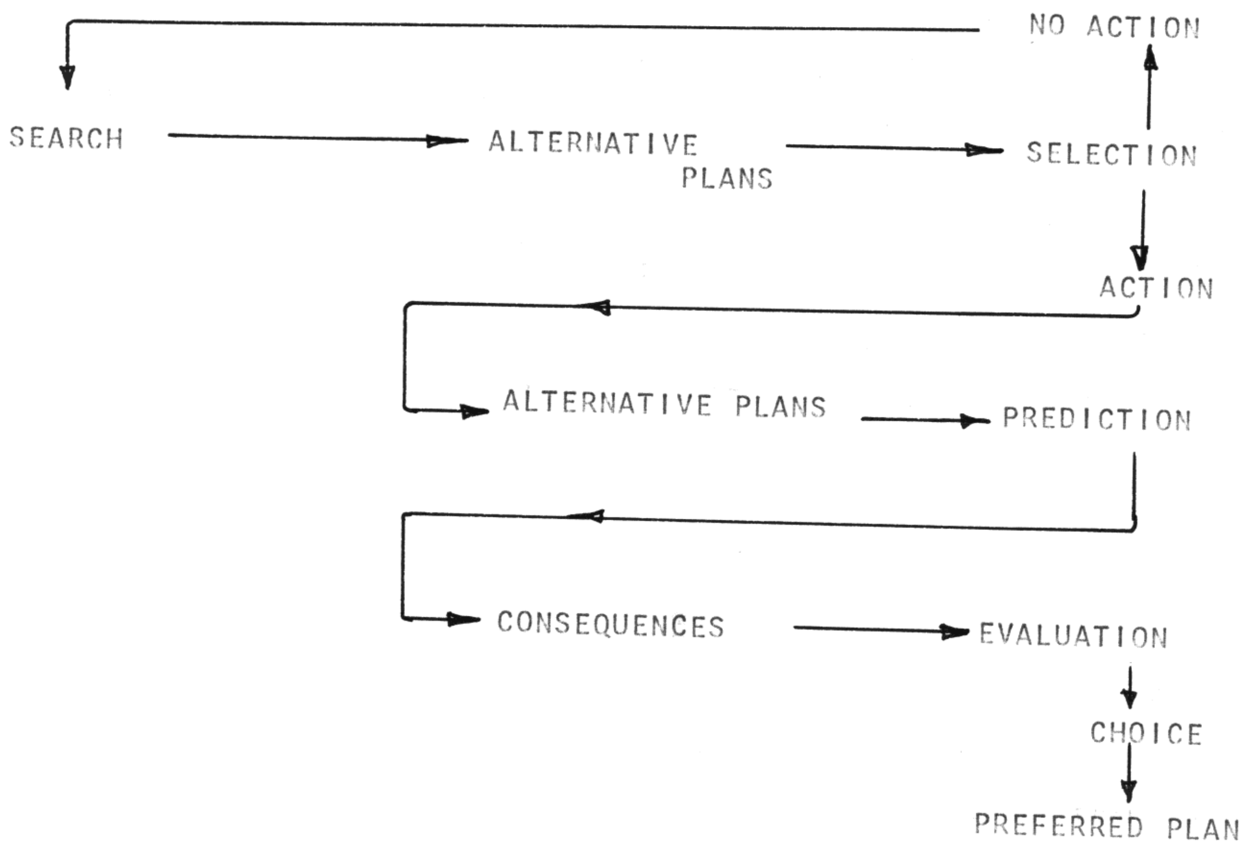

FIGURE 9.1

PLANNING PROCESS

determined, including its expected impact on the total planning region. The alternative that best satisfies the needs of the preference framework is defined as the preferred plan.

This model can be thought of as a part of a more complex process encompassing five major phases: (1) assessment, (2) objective setting, (3) planning and/or strategy formulation, (4) implementation, and (5) evaluation. This process model is outlined in Figure 9.2. The first phase represents the needs assessment phase. This phase is basically concerned with determining the precise problems or needs of the area being considered, or of the social unit involved. The objective-setting stage establishes an attainable goal or set of goals that are designed to achieve a specific end. The third phase-design or strategy formulation begins the policy and implementation phase. A strategy is essentially a series of programs, policies or plans designed to achieve a general goal. A policy, on the other hand, is a precise specification of ways and means for the attainment of planned objectives. The implementation phase denotes the process of putting into action preconceived plans. The final or evaluation phase determines the overall effectiveness of a particular stragegy, policy, decision, or plan in terms of its success or non-success; and, its costs in relation to its derived benefits. Each phase will also be related to each other by a complex feedback process which serves to modify preceeding phases.

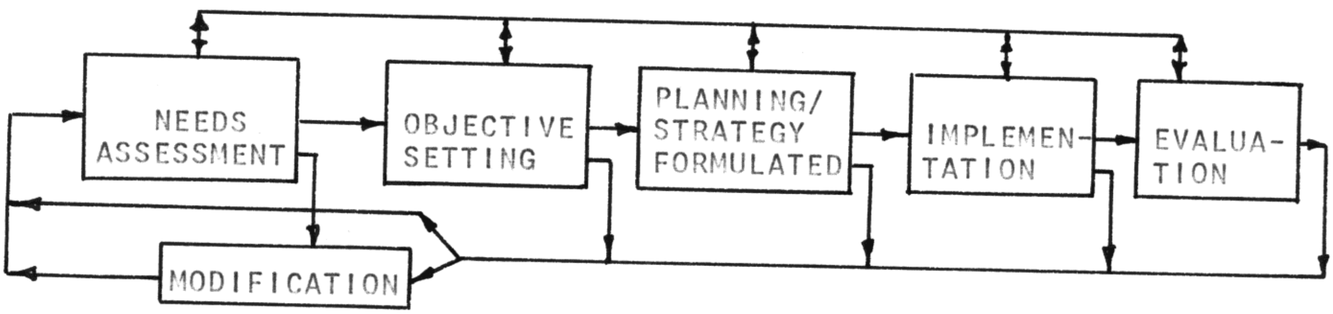

FIGURE 9.2

PLANNING PROCESS

Concurrent with the assessment process, goals and objectives are established and continually refined. It is necessary to define goals and objectives in order to properly define policies with respect to environmental planning and management. For these goals and objectives to be meaningful to the decision-maker in the proposed environmental system they should be formulated and expressed at two levels--the grid level and for the basin as a whole. They should also reflect the overall developmental and management requirements of both levels and those geographical areas contiguous to the San Antonio River basin. Simultaneously they should be formulated in terms which can be related to quantitative and qualitative parameters.

The major activity in this process is the dynamic refinement of the data and data analyses; and, their subsequent correlation with the needs or problems of a particualar unit so that more meaningful goals and objectives can be formulated. However, the findings developed within this context are not generally used as the final statement. Instead, they are used in such a way as to continually refine the original goals and objectives established by the decision-making body.

As the goals and objectives are formulated and the priorities established for the geographical unit under consideration, the planning process is initiated. The overall process

includes three major activities or phases. These can be defined as (1) the conceptualization phase, (2) the simulation and analytical phase; and (3) the operational design and analytical phase. It should be noted that these activities will not occur in a one, two, three order. Instead, at each activity there will be feedback and retracing back to previous activities.

The first phase is mainly concerned with the development of a general planning concept for a particular area. This is usually done by defining the needs and/or problems of a clearly outlined social, political, economic, cultural, or geographical unit. Once these factors have been defined the planner can then proceed to develop an approach or concept designed to alleviate the original need. The second phase uses simulation and other analytical techniques to refine the original concept, develop new planning or policy alternatives and outline more clearly the environmental parameters and interrelationships that need to be considered by the planner. The third phase is concerned with translating the refined concept into an operational plan. The actual translation process usually involves a number of decisions, compromises, and trade-offs before any plan or policy can be accepted as valid and subsequently implemented. In a real sense this design and implementation phase can be seen as a process of extending the objectives previously formulated into action.

The planning process, as noted above, begins with the extension of the original objectives and goals into a comprehensive environmental concept. By working within the already defined parameters and utilizing data from the sensor network, simulation system, and the IMP/S data base, the basic concept can be expanded to fit the requirements of any particular social, political or geographical unit. However, before any meaningful environmental planning can be done, it may be helpful to project a comprehensive plan, model, or simulation. In order to develop these, a systems approach becomes an essential element.

A planning system, as distinct from the planning process, can be conceived of as an autonomous administrative, physical, social or analytic structure that is designed to perform a set of given tasks. This system is generally composed of many activities all subject to some form of centralized control. In another sense, this system can be defined as a set of individual parts with each of these parts coordinated to accomplish a set of goals. In terms of its individual parts or components, a planning system includes an integrated complex of carefully formulated operations which interact along designated time segments. These operations, in turn, start with a determined initial condition or need. Once the initial condition is outlined the planning system converts specified categories of data input into specified end-product categories which relate

to the goals of that system. These end-product categories could represent plans, policies, limited decisions, the establishment of and the allocation of human and capital resources to implement a plan.

The planning system would be directed by a central planning unit within the IMP/S. This component--the environmental planning and management unit--is concerned with perceiving a delimited environment with the aid of certain rather specialized tools and techniques, and on the basis of a set of general goals and objectives. Since this generalized operational configuration moves within a time continuum it may be viewed as either a process occurring during a particular time period, or it can be conceived of as a state at any specific time point. A system can also be separated into functionally distinct parts or unified into a more inclusive sequence of events and activities.

There are six basic elements to be considered in formulating a systems approach to environmental planning. These elements are as follows:

1. The objectives of the planning system and, more specifically, the performance measures to be used by the system in order to evaluate its effectiveness;

2. The fixed constraints--environmental, political, legal, technological, etc., that tend to hinder or enhance the operation of the system;

3. The resources made available to the system;

4. The components of the planning system and their related activities, goals, and measures of performance;

5. The management of the system; and,

6. The external review process.

The objectives determine, to a large extent, the structure of the planning system and its related components. They also help to establish the priorities and prepare the basis for long-range goals. Thus planning can be viewed as a series of complex and related actions and decisions moving towards the accomplishment of the stated goals and objectives. How well these goals and objectives are accomplished determines, in part, the overall performance of the planning system.

The fixed constraints denote the outside parameters or boundaries of the planning system. The external environment--whether it be the natural, man-made, social, or cultural environment--makes up the elements that are fixed or given from the systems point of view. Not only is this environment something that is outside of the systems control it is also something that determines how it performs. This is not to say that the system cannot influence or even change the fixed elements in the environment. It can. In fact, the planning system would be an important factor in modifying certain environmental processes. However, if this system is to be effective, its users will have to be aware of its limitations.

The resources made available to the system are elements which are within the systems control. They are the means that enable the planning system to achieve its goals. Typically, these resources provide the system with the necessary data input, information and feedback linkages that are essential for its overall operations.

The components of the planning system make up the major activity elements or sections operating within the planning unit. The IMP/S will have three such planning components: environmental planning, environmental management, and comprehensive planning.

The environmental planning section will be mainly concerned with the physical, spatial, and perceptual elements of the environment. Its primary function will be to plan for large scale environments or geographical areas in relation to the goals and objectives--external to the planning system--established by the various political units or jurisdictions within the San Antonio River basin. Its related functions will include water quality planning, land use and open space planning, transportation, infrastructure and regional planning.

The environmental management section will formulate and implement land use policies for the area under the jurisdiction of the IMP/S. This function will also include range, forestry, agriculturel and ecological management, regional industrial development, emission and pollution control.

The third component will be mainly concerned with comprehensive planning. Its basic approach will be multi-disciplinary encompassing social, policy,economic, and physical planning. Although this component will be primarily involved with comprehensive, long-range planning for the entire San Antonio River basin it will also be concerned with coordinating all functional and project planning at the local level within the region. The important factor here is that this component will serve to link both the environmental planning and management functions so that more effective, long-range, multi-disciplinary planning can be accomplished at the IMP/S level.

The management of the total system is basically concerned with the coordination between various components, the formulation of effective linkages and the utilization of resources within the system. The management of these elements, in turn, will be the responsibility of three primary components--the political units within the basin, the regional authority, and the environmental protection administrator.

The IMP/S, as pointed out in Chapter I, will be an integral part of a larger regional authority. This authority will have the power to carry out its plans and develop regional priorities for the San Antonio River basin. It will be established as the primary planning and development agency in the basin region, and, as such, will have complete control over all areas concerning environmental planning and management. In

addition, it will operate as an external review agency for the IMP/S in order to maintain an internal organizational checks and balance framework.

The underlying concept of the IMP/S planning system is based on a systems approach to environmental planning. This approach has two important features. First, the objectives to be sought are stated clearly in performance terms rather than in particular technologies or pre-existing models. The decision-maker is thus able to delineate all of the necessary variables involved in any particular problem quantitatively and qualitatively. This delineation, in turn, allows the decision-maker to identify more effectively the real and potential alternatives available to him. The second feature that characterizes this approach is its emphasis on the inter-relationships occurring within the problem area. The usual planning approach is to divide a problem into more manageable sub-problems. The systems approach to planning, on the other hand, conceives the problem as a total entity. In short, what a systems approach implies is comprehensive planning so that the decision-maker can trace out the effects-whether they be progressive or regressive-of any set of decisions upon all other related decisions.

The question now arises: How can the decision-maker use this approach within the context of a planning system encompassing many different kinds of activities? A planning system,

system, as we noted above, implies a series of interrelating functions or operations such as the explicit determination of problem areas, the delineation of causal chains, the acquisition and assimilation of pertinent data, the selective interpretation of that data by various analytical and simulation techniques, and the integration of certain resources with the needs of a particular social, political, economic or geographical unit. The systems approach links each of these operations into a single, on-going process and provides many of the necessary feedback mechanisms to control and improve the quality of the planning and control system. One way of describing this systemic linkage is outlined in Figure 9.3. The data input indicates the increment of change occurring in a specific set of conditions. Once this data is received it is immediately processed and prepared for evaluation by the Early Warning System. This system is designed to detect the presence of certain critical or potentially critical conditions in the environment being monitored. If the system detects a critical parameter or situation on the basis of available input data it automatically alerts the appropriate action level. At this level the analyst must determine the nature and magnitude of the perceived condition (Decision Point 1). On the basis of his analysis he must also decide whether the condition is critical or non-critical. The analyst's judgment at this point is crucial.

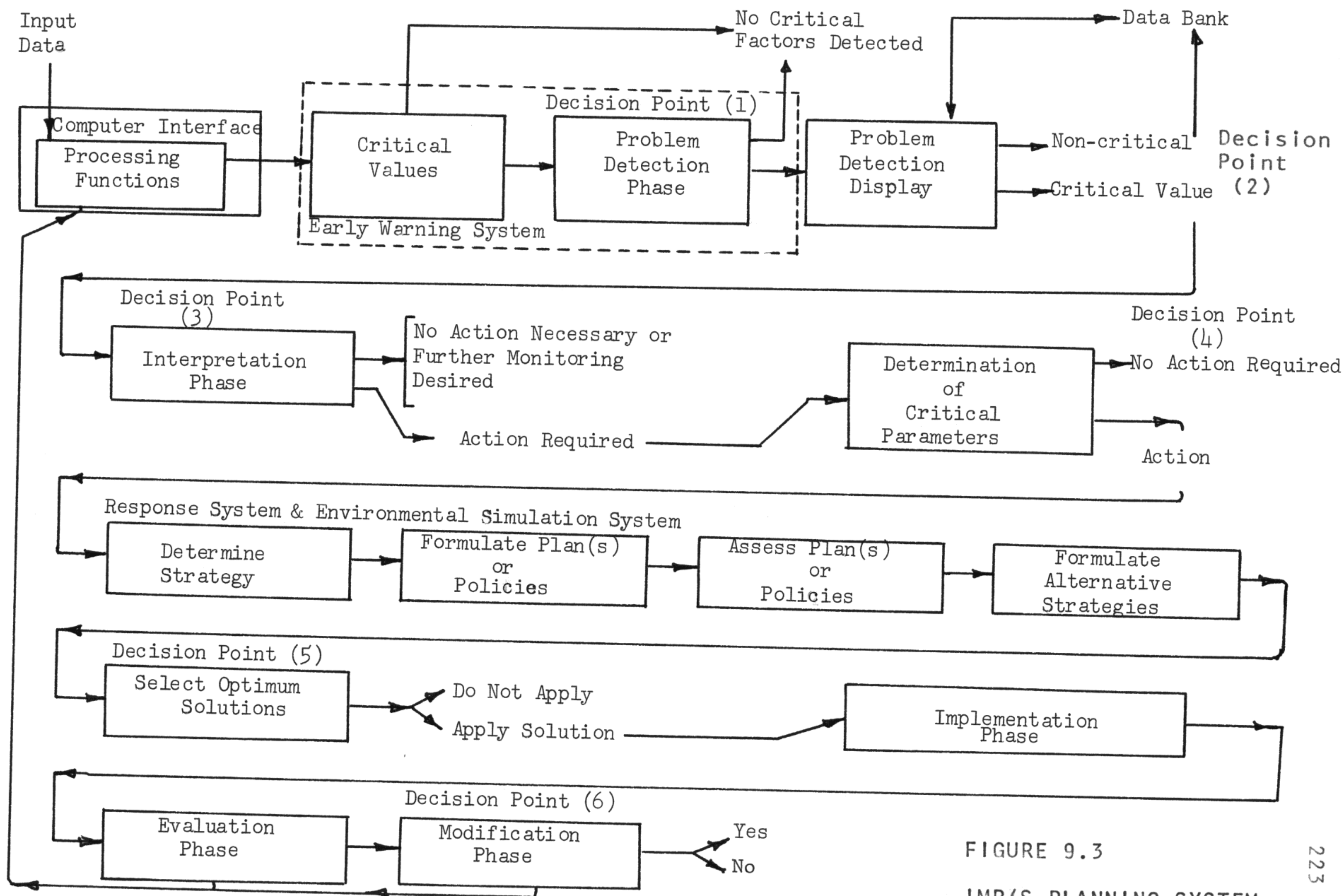

FIGURE 9.3

IMP/S PLANNING SYSTEM

Once a decision is made he must determine whether the process should be continued, or put in a hold condition until more data is received (Decision Point 2).

If the decision is made to continue, the preliminary data is channeled into an interpretation phase (Decision Point 3). After the data has been carefully analyzed and the nature of the discrepancy is fully outlined a decision must be made either to hold the data for further evaluation, continue the monitoring function, or take immediate action to modify or eliminate the perceived condition (Decision Point 4). If the decision is made to take some form of immediate action the parameters of the noted discrepancy are carefully analyzed and evaluated.

While the parameters are being assessed the initial planning strategies and priorities are established. Plans are developed and assessed in terms of their relevance to current and projected needs and resources. Alternative strategies are developed to test out different approaches. At this point the optimum solution to the perceived problem is determined. However, the decision-maker would also have the option of taking a no-action policy at this point (Decision Point 5). It should be noted that a no-action policy is a valid planning alternative in certain cases because the time factor is extremely important. This is especially true in relation to dynamic environmental systems. By waiting, the situation

defined initially as a problem may be transformed into another category and its basic impact may be altered. Another possible alternative would be to re-examine the proposed solutions in light of new variables or changing environmental conditions.

Once the course of action is decided upon it may be continuously evaluated. The length of the evaluation phase will be determined by the nature of the problem. On the basis of this evaluation process modifications can then be made on the original course of action to maximize its effectiveness.

The decisions that must be made within this system will be fragmented into logical, relatively small parts when feasible. There are five primary advantages to this fragmentation process. First, it will permit the automation of significant elements in the decision-making process. Second, it will greatly simplify the task of making decisions by reducing the difficulty of each judgment or decision. Third, because it will simplify the task of making decisions, it should reduce the difficulty of training system personnel. Fourth, it will permit the distribution of decision-making powers to several action levels rather than one. In systems with a high information load such as the IMP/S this consideration will be very important. Fifth, because the system can be highly automated it will be able to channel its information more effectively to the appropriate decision level.

In outlining a functional decision framework for a planning system it is imperative that each sub-function or operation be clearly defined. In general, there are approximately thirteen such operations. These can be listed as follows:

1. Problem recognition: This operation indicates whether a problem actually exists, or will exist in some future time.

2. Identification of pertinent elements, variables and components: Once the problem is detected its essential or basic configuration must be determined.

3. Identification of relevant states that can be quantified: This operation or sub-function assigns relevant quantities to the phenomenon being measured or monitored. If the IMP/S is to function as an effective system it must be able to quantify environmental data inputs. These inputs are crucial because they will indicate incremental changes occurring in a particular environment or phenomenon over a restricted time range.

4. Identification of value elements: Every decision or judgment is based on certain criteria. Consequently, values and value systems must be taken into consideration very early in the planning process. This operation identifies the initial value elements that must be considered in the subsequent planning activities.

5. Value judgments: These operations will occur throughout the planning process. Values, in this sense, denote the goals and objectives of the system, political, economic and social needs, and the internal value orientations of individual decision-makers.

6. Aggregation of value judgments: Within the IMP/S concept this operation will mesh diverse value judgments into a coherent system or framework.

7. Identification of data sources: This operation denotes the process of determining and then searching out the required data sources. The IMP/S will have three primary data sources: (a) the sensor network which will provide for direct data input from the environment, (b) a data bank which will serve as a depository for all pertinent data; and (c) direct input from other data sources such as local planning agencies, Census Bureau, NASA, and various governmental agencies.

8. The collection of data: This process denotes the acquisition and routing of pertinent data into the IMP/S.

9. Data filtration and display: This operation involves the processing of data and its subsequent display at the appropriate decision or action level.

10. Probability estimation: All decisions, policies or plans encompass a wide range of variables and parameters. In order to determine optimum policies and maximize the utilization of available resources some estimation of probable

impact must be made. In many cases the careful determination of success/non-success or benefit/disbenefit probabilities will enhance or limit the acceptance of a particular decision.

11. Estimate aggregation: This operation represents the analytical and assessment phase of the decision framework.

12. Decision making: The decision-making operation culminates a complex sequence of events which began with the problem recognition phase. The underlying principle of this operation is to maximize expected value returns. Although expected value returns can be determined through simulation techniques the final decision must be based on the political, social and economic priorities of the region and the availability of resources.

13. Decision/policy implementation: This operation represents the final link in the sequence of operations. Once the policy or decision is implemented an evaluation process is initiated to maintain close control over its immediate and long range impact on either the community or the environment; or, both.

To summarize, the concept of a man-machine planning system as conceived here is based on the idea that a symbiotic type relationship between the user and the system is feasible in terms of today's technology. This system and its related components is designed to enhance the planning and decision-

making capabilities of planners, politicians, sociologists, economists, water quality and transportation planners, environmental protection administrators and regional planners. It is not designed to do away with these specialists, but to increase their ability to perceive the environments with which they are working and to foresee certain problems or trends before they become critical. It is also designed to optimize certain factors such as cost, efficiency, benefits, resource utilization and environmental management in terms of criteria derived from an externally imposed value system. This external value system will enable the IMP/S to maintain its relevance to the regions and its users. It will also allow the system to change its focus in order to adapt to different needs and problems as they arise.

In conclusion, this paper has attempted to outline a comprehensive environmental information, management and planning system for the San Antonio River basin. In the process of outlining this system a number of important concepts and technologies were examined, and some new approaches for managing the total environment were discussed. The overall objective was to design an operational system for monitoring a wide range of environmental processes over an extended time period. The concept presented in this paper requires much more development; however, the aim of this paper was to develop a rather basic systemic framework which could be used as a base for further development.

The underlying premise of this study is that people are now beginning to realize a fact that ecologists have always tried to emphasize--namely, that man is an integral part of a larger ecosystem in which changes imposed on any essential component within this system produces effects or reactions of greater or smaller consequences on other components in the system. If man is to anticipate the impact of his actions on the environment he must be able to monitor these environments continually, and develop tools and techniques which will allow him to evaluate his actions so that his future actions can be modified. The IMP/S, as envisioned in this paper, is one approach designed to achieve that end.

APPENDIX A

ENVIRONMENTAL/DATA COLLECTION SYSTEM MATRIX

This matrix is designed to outline some of the more important environmental variables that will be monitored by the IMP/S. The four primary data collection systems and their respective sensor configurations are listed at the top of the matrix. The environmental variables to be monitored by these systems are listed along the side of the matrix; first by major vector, and then by sub-vector. The notation's within the matrix indicates the kinds of sensors that will be used to monitor a particular variable. In many cases, more than one sensor device or system will be used to monitor a particular variable. This overlapping of sensor input is desirable in order to develop a comprehensive multi-dimensional display of one environmental variable and is useful for verification of data. However, it should be noted that the variables listed in this matrix are not exhaustive; nor, do the sensor units listed within each of the data collection systems represent the final design configuration. The key factor in the IMP/S is its ability to encompass new functions as the needs arise; and adapt to changing requirements.

DATA COLLECTION SYSTEM	SENSOR UNITS	1. ATMOSPHERE	A. WIND PATTERNS	TOPOGRAPHIC FACTORS	VELOCITY	DIRECTION	B. POLLUTION	POLLUTION SOURCES	HAZE/SMOG	PARTICULATE MATTER	SULFUR DIOXIDE CONCENTRATIONS	OXIDANTS	HYDRO-CARBONS	CARBON DIOXIDE	DISPERSION PATTERNS
SUB-SURFACE	seismic probe														
	underwater sensor module														
SURFACE	remote meteorological station				●	●		●		●	●	●	●	●	●
	particle analyzer									●					
	infrared co+co2 analyzer								●					●	
	analyzer so2 no2 + no								●		●	●	●		
	air monitoring system							●	●	●	●	●	●	●	
	oil spill detection system														
	turbidimeter														
	river gauge														
	river/shallow water buoy														
	water analyzer system														
	water monitoring system														
AIRCRAFT	multiband camera			●				●	●						
	radar imagery			●											
	radiometer			●				●	●						
	multispectral scanner			●				●	●		●				●
	spectrometer			●				●	●				●	●	
SATELLITE	vidicon camera								●						
	multiband camera			●				●							
	panoramic camera			●					●						
	radar imagery			●											
	radiometer			●				●	●						
	multispectral scanner			●				●	●			●			●
	spectrometer			●				●	●		●	●	●	●	

ENVIRONMENTAL VARIABLES

DATA COLLECTION SYSTEM	SENSOR UNITS	C. DISPERSION PATTERNS	WIND PATTERNS	TEMPERATURE	HUMIDITY	SOLAR RADIATION	WIND VELOCITY	2. ECO/SYSTEMS	A. GEOLOGY	MORPHOLOGY	SOILS	LITHOLOGY	PHYSIOGRAPHY	SUBSURFACE GEOLOGY	EROSION PATTERNS
SUB-SURFACE	seismic probe									●		●		●	
	underwater sensor module														
SURFACE	remote meteorological station		●	●	●	●	●								
	particle analyzer														
	infrared co+co2 analyzer														
	analyzer so2 no2 + no														
	air monitoring system														
	oil spill detection system														
	turbidimeter														
	river gauge														
	river/shallow water buoy			●	●	●									
	water analyzer system														
	water monitoring system														
AIRCRAFT	multiband camera									●	●		●		●
	radar imagery									●	●	●	●	●	●
	radiometer									●	●	●	●	●	
	multispectral scanner									●	●	●	●		●
	spectrometer									●	●	●	●	●	
SATELLITE	vidicon camera									●			●		●
	multiband camera									●	●		●		●
	panoramic camera									●	●		●		●
	radar imagery									●	●	●	●	●	●
	radiometer			●	●					●	●	●	●	●	
	multispectral scanner									●	●	●	●		●
	spectrometer									●	●	●	●	●	

ENVIRONMENTAL VARIABLES

DATA COLLECTION SYSTEM	SENSOR UNITS	B. CLIMATE	PHYSIOGRAPHIC FEATURES	TEMPERATURE	RELATIVE HUMIDITY	PRECIPITATION	WIND DIRECTION & VELOCITY	ATMOSPHERIC PRESSURE	SOLAR RADIATION	CULTURAL FEATURES	C. WILDLIFE	TYPES/ SPECIES	DISTRIBUTION	MOVEMENT PATTERNS	CONDITION OF SPECIES
SUB-SURFACE	seismic probe														
	underwater sensor module														
SURFACE	remote meteorological station			●	●	●	●	●	●						
	particle analyzer														
	infrared co+co2 analyzer														
	analyzer so2 no2 + no														
	air monitoring system														
	oil spill detection system														
	turbidimeter														
	river gauge					●									
	river/shallow water buoy			●	●	●			●						
	water analyzer system														
	water monitoring system					●									
AIRCRAFT	multiband camera		●							●		●	●	●	●
	radar imagery		●							●					
	radiometer		●	●	●										
	multispectral scanner		●	●		●				●		●	●	●	●
	spectrometer		●						●						
SATELLITE	vidicon camera		●							●					
	multiband camera		●							●		●	●	●	●
	panoramic camera		●							●					
	radar imagery		●												
	radiometer		●	●	●										
	multispectral scanner		●	●		●			●	●		●	●	●	●
	spectrometer		●												

ENVIRONMENTAL VARIABLES

DATA COLLECTION SYSTEM	SENSOR UNITS / ENVIRONMENTAL VARIABLES	D. PLANT LIFE	TYPES AND DISTRIBUTION	FORESTS: STATUS	SOILS	ENVIRONMENTAL CONDITIONS	E. WATER CONDITIONS	PRECIPITATION	RUNOFF	SOILS	ENVIRONMENTAL CONDITIONS	F. AGRICULTURE	SUBSURFACE GEOLOGY	CLIMATE	SOILS
SUB-SURFACE	seismic probe												●		
SUB-SURFACE	underwater sensor module					●					●				
SURFACE	remote meteorological station					●		●			●			●	
SURFACE	particle analyzer														
SURFACE	infrared co+co2 analyzer														
SURFACE	analyzer so2 no2 + no														
SURFACE	air monitoring system					●					●				
SURFACE	oil spill detection system														
SURFACE	turbidimeter														
SURFACE	river gauge							●	●						
SURFACE	river/shallow water buoy					●		●	●		●				
SURFACE	water analyzer system					●					●				
SURFACE	water monitoring system					●		●	●		●				
AIRCRAFT	multiband camera		●	●	●	●			●	●	●			●	●
AIRCRAFT	radar imagery			●		●			●		●		●	●	
AIRCRAFT	radiometer				●	●			●	●	●		●		●
AIRCRAFT	multispectral scanner		●	●	●	●		●	●	●	●		●	●	●
AIRCRAFT	spectrometer				●					●			●		●
SATELLITE	vidicon camera					●					●			●	
SATELLITE	multiband camera		●	●	●	●			●	●	●				●
SATELLITE	panoramic camera		●	●		●					●				
SATELLITE	radar imagery			●		●			●		●		●		
SATELLITE	radiometer				●	●			●	●	●		●	●	●
SATELLITE	multispectral scanner		●	●	●	●		●	●	●	●			●	●
SATELLITE	spectrometer				●					●			●		●

DATA COLLECTION SYSTEM	SENSOR UNITS / ENVIRONMENTAL VARIABLES	DRAINAGE	SLOPE	SOLAR RADIATION	CROP DISEASE STATUS	WATER RESOURCES	G. RECREATION	GEOLOGICAL CONDITIONS	CLIMATE	LAND USE	WATER RESOURCES	PHYSIOGRAPHIC CONDITIONS	3. HYDROLOGY	A. WATER RESOURCES	RAINSHED CHARACTERISTICS
SUB-SURFACE	seismic probe							●							
	underwater sensor module					●					●				
SURFACE	remote meteorological station			●					●		●				●
	particle analyzer														
	infrared co+co2 analyzer														
	analyzer so2 no2 + no														
	air monitoring system								●						
	oil spill detection system														
	turbidimeter														
	river gauge					●			●		●				●
	river/shallow water buoy					●			●		●				●
	water analyzer system	●				●					●				●
	water monitoring system			●		●			●		●				●
AIRCRAFT	multiband camera	●	●		●	●		●		●	●	●			●
	radar imagery	●	●			●		●				●			●
	radiometer														
	multispectral scanner	●	●		●	●		●	●	●	●	●			●
	spectrometer				●										
SATELLITE	vidicon camera	●				●			●						
	multiband camera	●	●		●	●		●		●	●	●			●
	panoramic camera	●	●			●		●		●	●	●			
	radar imagery	●	●			●		●				●			●
	radiometer														
	multispectral scanner	●	●		●	●		●	●	●	●	●			●
	spectrometer				●										

DATA COLLECTION SYSTEM	SENSOR UNITS / ENVIRONMENTAL VARIABLES	PRECIPITATION	STREAM GRADIENTS	DISCHARGE RATES	SOILS	CULTURAL FEATURES	B. WATER POLLUTION	ph(ACIDITY/ ALKALINITY)	OXIDATION-REDUCATION POTENTIAL	CHLORIDES	DISSOLVED OXYGEN	CONDUCTIVITY	WATER TEMPERATURE	SOLAR RADIATION	PHOSPHATES
SUB-SURFACE	seismic probe														
SUB-SURFACE	underwater sensor module							●	●				●		
SURFACE	remote meteorological station	●												●	
SURFACE	particle analyzer														
SURFACE	infrared co+co2 analyzer														
SURFACE	analyzer so2 no2 + no														
SURFACE	air monitoring system														
SURFACE	oil spill detection system														
SURFACE	turbidimeter														
SURFACE	river gauge	●		●									●		
SURFACE	river/shallow water buoy	●		●					●	●			●	●	
SURFACE	water analyzer system							●	●	●	●	●	●		●
SURFACE	water monitoring system	●	●	●				●	●	●			●	●	
AIRCRAFT	multiband camera				●	●									
AIRCRAFT	radar imagery					●									
AIRCRAFT	radiometer				●										
AIRCRAFT	multispectral scanner	●	●		●	●									
AIRCRAFT	spectrometer				●										
SATELLITE	vidicon camera					●									
SATELLITE	multiband camera				●	●									
SATELLITE	panoramic camera														
SATELLITE	radar imagery					●									
SATELLITE	radiometer				●										
SATELLITE	multispectral scanner	●	●		●	●									
SATELLITE	spectrometer				●										

DATA COLLECTION SYSTEM	SENSOR UNITS / ENVIRONMENTAL VARIABLES	OXYGEN DEMAND	STREAM VELOCITY	WATER CLARITY	4. URBAN ENVIRONMENT	A. URBAN CLIMATE	PHYSIOGRAPHIC ELEMENTS	TEMPERATURE	RELATIVE HUMIDITY	PRECIPITATION	WIND DIRECTION and VELOCITY	SOLAR RADIATION	URBAN SPATIAL STRUCTURE	URBAN LAND-USE	DENSITY FACTORS
SUB-SURFACE	seismic probe														
	underwater sensor module		●												
SURFACE	remote meteorological station							●	●	●	●	●			
	particle analyzer														
	infrared co+co2 analyzer														
	analyzer so2 no2 + no														
	air monitoring system							●	●		●	●			
	oil spill detection system			●											
	turbidimeter			●											
	river gauge		●							●					
	river/shallow water buoy	●	●							●		●			
	water analyzer system	●													
	water monitoring system		●							●					
AIRCRAFT	multiband camera						●						●	●	●
	radar imagery						●						●	●	●
	radiometer							●	●	●					
	multispectral scanner						●						●	●	●
	spectrometer						●								
SATELLITE	vidicon camera														
	multiband camera						●						●	●	●
	panoramic camera						●						●	●	●
	radar imagery						●						●	●	
	radiometer							●	●						
	multispectral scanner						●			●			●	●	●
	spectrometer														

DATA COLLECTION SYSTEM	SENSOR UNITS / ENVIRONMENTAL VARIABLES	AIR QUALITY-MICRO-CLIMATE	REGIONAL LAND-USE	B. URBAN PHYSIOGRAPHY	LAND ELEVATION and SLOPE	SURFACE DRAINAGE	SOIL DRAINAGE	SOIL FOUNDATION	ENVIRONMENTAL HAZARDS	C. URBAN HYDROLOGY	WATER QUALITY	WATER RESOURCES	D. URBAN LAND-USE	OPEN SPACE	TYPES OF LAND-USE
SUB-SURFACE	seismic probe							●	●						
	underwater sensor module								●		●	●			
SURFACE	remote meteorological station	●							●			●			
	particle analyzer	●													
	infrared co+co2 analyzer	●													
	analyzer so2 no2 + no	●													
	air monitoring system	●							●						
	oil spill detection system								●		●				
	turbidimeter								●		●				
	river gauge										●	●			
	river/shallow water buoy					●	●				●	●			
	water analyzer system					●	●				●	●			
	water monitoring system					●			●		●	●			
AIRCRAFT	multiband camera	●	●		●	●	●	●	●		●	●		●	●
	radar imagery		●		●			●	●						
	radiometer	●				●		●							
	multispectral scanner	●	●		●	●	●	●	●		●	●		●	●
	spectrometer	●					●	●							
SATELLITE	vidicon camera														
	multiband camera	●	●		●	●	●	●	●		●	●		●	●
	panoramic camera		●									●		●	●
	radar imagery		●		●			●	●						
	radiometer	●				●		●							
	multispectral scanner	●	●		●	●	●	●	●		●	●		●	●
	spectrometer						●	●							

DATA COLLECTION SYSTEM	SENSOR UNITS	GROWTH PATTERNS	STRUCTURE DENSITY	5. URBAN PATHOLOGY	HOUSING QUALITY	AIR QUALITY	WATER QUALITY	SOCIAL/ AESTHETIC	POPULATION DENSITY	MICRO-ENVIRONMENTAL QUALITY	TRAFFIC DENSITY	6. URBAN INFRASTRUCTURE	TRANSPORTATION FLOW	TRAFFIC PATTERNS	TRAFFIC GENERATION AREAS
SUB-SURFACE	seismic probe									●					
	underwater sensor module						●			●					
SURFACE	remote meteorological station					●				●					
	particle analyzer					●				●					
	infrared co+co2 analyzer					●				●					
	analyzer so2 no2 + no					●				●					
	air monitoring system					●				●					
	oil spill detection system						●			●					
	turbidimeter						●			●					
	river gauge						●								
	river/shallow water buoy						●			●					
	water analyzer system						●			●					
	water monitoring system						●			●					
AIRCRAFT	multiband camera	●	●		●	●	●	●	●	●	●		●	●	●
	radar imagery		●												
	radiometer														
	multispectral scanner	●	●		●	●	●	●	●	●	●		●	●	●
	spectrometer					●				●					
SATELLITE	vidicon camera		●												●
	multiband camera	●	●		●	●	●	●	●	●	●		●	●	●
	panoramic camera	●	●					●							●
	radar imagery		●												
	radiometer														
	multispectral scanner	●	●		●	●	●	●	●	●	●		●	●	●
	spectrometer					●				●					

ENVIRONMENTAL VARIABLES

DATA COLLECTION SYSTEM	SENSOR UNITS	INTER/INTRA-URBAN FLOW	NETWORK STATUS	URBAN SPATIAL STRUCTURE	URBAN LAND-USE	UTILITY LINE STATUS	ENVIRONMENTAL OBSTRUCTIONS
SUB-SURFACE	seismic probe						
	underwater sensor module						
SURFACE	remote meteorological station						
	particle analyzer						
	infrared co+co2 analyzer						
	analyzer so2 no2 + no						
	air monitoring system						
	oil spill detection system						
	turbidimeter						
	river gauge						
	river/shallow water buoy						
	water analyzer system						
	water monitoring system						
AIRCRAFT	multiband camera	●	●	●	●	●	●
	radar imagery		●	●	●	●	●
	radiometer						
	multispectral scanner	●	●	●	●	●	●
	spectrometer						
SATELLITE	vidicon camera				●		●
	multiband camera	●	●	●	●	●	●
	panoramic camera	●			●		●
	radar imagery		●	●	●	●	●
	radiometer						
	multispectral scanner	●	●	●	●	●	●
	spectrometer						

ENVIRONMENTAL VARIABLES

APPENDIX B

ESTIMATED DEVELOPMENTAL, IMPLEMENTATION AND OPERATIONAL COSTS - INITIAL AND INTERIM PHASES

NOTE: These are estimated costs and the real costs--especially with regard to software--may vary considerably from those listed here.

Cost Category	Estimated Costs-Year Required Number	1	2	3	4	Total
I Systems planning and development cost figures include personnel and computer utilization		$400,00	$400,000	$300,000	$200,000	$1,300,000
II Sensor Network						
A. Planning and research-cost figures include personnel and computer utilization		$75,000	$50,000	$30,000	$30,000	$185,000
B. Procurement: Estimated Totals -						
1. Meteorological Stations (Remote)	6	3 units	3 units	- -	- -	
Costs per unit (approx.) $10,000		$30,000	$30,000	- -	- -	$60,000
2. Air Sampling Stations (Remote)	15	8 units	4 units	3 units	- -	
Costs per unit (approx.) $4,000		$32,000	$16,000	$12,000	- -	$60,000
3. Water Monitoring Stations	13	5 units	5 units	2 units	1 unit	
Costs per unit (approx.) $1,000		$5,000	$5,000	$2,000	$1,000	$13,000
4. Water Analyzer Stations	20	8 units	8 units	2 units	2 units	
Costs per unit (approx.) $9,000		$72,000	$72,000	$18,000	$18,000	$180,000
5. Underwater Sensor Units	30	10 units	8 units	7 units	5 units	
Costs per unit (approx.) $3,000		$30,000	$24,000	$21,000	$15,000	$60,000
6. Specialized Sensor Systems						

Cost Category	Estimated Costs Year		1	2	3	4	Total
Sensor Network (Con't)							
a. Particle Analyzers			10 units	10 units	10 units	20 units	
Costs per unit (approx.)	$700	50	$7,000	$7,000	$7,000	$14,000	$35,000
b. Infrared CO/CO_2 Analyzer			5 units	5 units			
Costs per unit (approx.)	$500	10	$2,500	$2,500	- -	- -	$5,000
c. Sulfur Dioxide Analyzer			20 units	10 units	5 units	5 units	
Costs per unit (approx.)	$500	40	$10,000	$5,000	$2,500	$2,500	$20,000
d. Oil Spill Detectors			8 units	2 units			
Costs per unit (approx.)	$1,000	10	$8,000	$2,000	- -	- -	$10,000
e. Turbidimeters			5 units	10 units	5 units		
Costs per unit (approx.)	$600	20	$3,000	$6,000	$3,000		$12,000
f. Buoy Sensor Units			5 units	5 units	5 units	5 units	
Costs per unit (approx.)	$900	20	$4,500	$4,500	$4,500	$4,500	$18,000
C. Deployment costs - Surface System costs include transportation, personnel and maintenance			$90,000	$75,000	$50,000	$30,000	$245,000
D. Airborne Surveillance System. This system will be operated and maintained by NASA under contract. NASA will also handle all initial processing of airborne sensor data. The processed data will be transferred to the Center for further analysis and interpretation. Costs includes only reproduction and distribution fees charged by NASA.			$20,000	$20,000	$20,000	$20,000	$80,000

Cost Category / Estimated Costs-Year	1	2	3	4	Total
E. Satellite Data Collection System - This system will also be operated and maintained by NASA under contract. All data telemetry equipment and satellite support elements will be operated by NASA. The IMP/S will use the ERTS and EROS satellite systems provided through NASA. All sensor data will be telemetered from NASA tracking stations to the Center. Thus, projected costs take into consideration only data transmission costs.	$30,000	$25,000	$10,000	$10,000	$75,000
F. Subsurface Data Collection System - This system will be an integral part of the surface system. The subsurface system will use very specialized sensors to measure water depth, flow and subsurface soil conditions. Many of the sensors used will be expendable - that is, used only once and then discarded. Cost figures for this system are broadly broken down into three primary categories:					
1. Planning and development	$30,000	$25,000	$10,000	$10,000	$75,000
2. Procurement	- -	- -	$25,000	$25,000	$50,000
3. Deployment and Maintenance	- -	- -	$100,000	$90,000	$190,000
III Telemetry System					
A. Initial research, planning and development costs - includes personnel and computer time.	$50,000	$35,000	$35,000	$30,000	$150,000

Cost Category	Estimated Costs-Year 1	2	3	4	Total
B. Installation of system components to link up all data collection systems - Costs includes personnel. Surface system will link up with existing telephone system.	$100,000	$500,000	$500,000	$200,000	$1,300,000
C. Installation of digital data collection/acquisition network - Estimated costs per sensor unit - $400. It is estimated that there will be about 250 sensor units in the surface system, and 30 in the subsurface system. The Airborne Surveillance System and the Satellite Data Collection System are not included in this cost category.	88 surface	70 surface	39 surface	38 surface	
	10 sub	10 sub	5 sub	5 sub	
	Total 98 sensors	80 sensors	44 sensors	43 sensors	
	98x400	80x400	44x400	43x400	
	$39,200	$32,000	$17,600	$17,200	$106,000
D. Total operating costs. This category includes all data collection systems as it relates to the IMP/S.					
1. Personnel: It is estimated that about 24 specialists will be needed to operate the telemetry system on a 24-hour, 7 day per week basis.	$360,000	$360,000	$400,000	$400,000	$1,520,000
	(cost based on $15,000 per year salary for average employee)				
2. Maintenance. It is estimated that 30 people will be needed to maintain the entire network.	$300,000	$300,000	$350,000	$360,000	$1,310,000
	(cost based on $10,000/year per employee)				
3. Research and development costs.	$30,000	$30,000	$30,000	$30,000	$120,000
4. Software development and special programming costs for upgrading data acquisition and telemetry.	$25,000	$25,000	$25,000	$25,000	$100,000

Cost Category	Estimated Costs-Year 1	2	3	4	Total
IV Central Processing Facility-Surveillance Center					
A. Facilities - rental costs. Costs based on standard rates for San Antonio.	$25,000	$25,000	$28,000	$30,000	$108,000
B. Procurement/Rental of specialized data acquisition, processing, retrieval and display equipment.					
1. IBM 360 Computers-estimated cost range $500,000-800,000 per unit. Costs include peripheral equipment such as card readers, keyboard printers, paper tape readers, and CRT keyboard system. Monthly lease cost estimated at $8000. This figure does not include maintenance costs. It is estimated that two IBM (or comparable systems) will be needed to operate the IMP/S. One system will be made operational during the Initial phase. The second system will be activated during the Interim phase. Both systems will be leased. Projected costs also include maintenance at $300/per month per system, and all other related costs.	$160,000 (Second computer is made operational during year 3)	$160,000	$220,000	$220,000	$760,000

Cost Category	Estimated Costs-Year	1	2	3	4	Total
2.	Mino-computers-it is estimated that 5 small, special purpose computers will be needed to support the larger systems and for handling specialized data processing tasks. Cost range for these computers is $5000 to $30,000 per unit (purchase price). Estimated costs for a 16K memory unit is $7,350 per unit. Maintenance cost is estimated to be $300 per month, per unit.	$8,000 Costs 1 unit	$16,000 2 units	$8,000 1 unit	$8,000 1 unit	$40,000
		Maintenance Costs $3,600 1 unit	$10,800 3 units	$14,400 4 units	$15,000 5 units	$43,800
3.	Remote Terminal Work Stations - It is expected that ten such stations will be included in the Center. One system called Decdatacenter (Datamation July 15, 1971, p. 59) developed and sold by Digital Equipment Corporation includes CRT, typewriter, keyboard and function keys. Estimated costs-basic system is $45,000. Additional terminals cost $8,000 per unit.	$45,000	$40,000 5 units	$40,000 5 units	- -	$125,000
4.	Specialized Equipment					
	a. Plotting System-system is linked to a mini-computer - estimated cost per unit $60,000.	$60,000	- -	$60,000	- -	$120,000
	b. Multi-Image display system - estimated cost is $25,000 per unit: Dicomed Corporation, Minneapolis, Minn.	- -	$25,000 1 unit	- -	$25,000 1 unit	$50,000

Cost Category	Estimated Costs-Year 1	2	3	4	Total
c. Processor System. 8 station shared processor system. It is estimated that one system will be required. This system can be leased for $50 per month for the Control Unit. This cost includes maintenance -- (INFOREX Intelligent Key Entry System).	$960 per system/per month $13,000	$13,000	$13,000	$13,000	$52,000
d. Disc System for data storage - estimated cost for a three disc system is $15,000. A total of nine disc units or three systems are estimated to be needed for implementing the Data Bank.	$15,000	$26,000	- -	- -	$41,000
e. Optical Character Recognition Equipment IBM 1287 - I unit with CRT scanner. Base price of this unit is approximately $130,000 per unit.	$130,000	- -	- -	- -	$130,000
C. Development of special software systems - costs include personnel and computer time.	$200,000	$200,000	$200,000	$150,000	$750,000
D. Procurement of special photogrametric equipment for analysis and interpretation of imagery data.	- -	$50,000	$100,000	$80,000	$240,000
E. Development and implementation of specialized display systems and related software.					

Cost Category	Estimated Costs-Year	1	2	3	4	Total
V Personnel Costs						
A. Center personnel-it is estimated that about 100 people will be needed to staff the Surveillance Center on a 24-hour basis. This total does not include communications and maintenance personnel. Average salary is expected to be $15,000 with a range of $4,000 (11,000-19,000). During the first year 20 people will be hired. During the next three years 40, 20 and 20 people will be hired. All figures quoted would include fringe benefits.		$300,000 (20)	$900,000 (60)	$1,000,000 (80)	$1,400,000 (100)	$2,700,000
B. Training costs		$15,000	$30,000	$45,000	$60,000	$150,000
C. Research and development		$15,000	$15,000	$15,000	$20,000	$65,000
D. Special services for personnel transportation, travel, per diem costs, etc.		$30,000	$40,000	$50,000	$50,000	$170,000
VI Center Activities						
A. Reproduction and distribution of data		$100,000	$200,000	$250,000	$300,000	$850,000
B. Special services/projects - analysis and interpretation of data		- -	$10,000	$20,000	$20,000	$50,000
C. Management functions - does not include personnel		$10,000	$20,000	$30,000	$40,000	$100,000
D. Administrative costs - does not include personnel.		$15,000	$20,000	$30,000	$35,000	$55,000

Cost Category	Estimated Costs-Year	1	2	3	4	Total
E. Planning functions - does not include personnel.		- -	- -	$25,00	$30,000	$55,000
F. Authority functions - includes personnel, clerical and administrative staff.		$40,000	$48,000	$50,000	$50,000	$188,000
Total per year - -		$2,926,600	$3,894,800	$5,088,200	$4,293,000	

The total estimated cost of designing, implementing and operating an IMP/S for the San Antonio River basin for the first four years will be $16,202,600. It is expected that by the fifth year of the systems operational costs will begin to level to about $4,000,000 a year. At its most efficient state (approximately six years after initial development) operational, developmental, and maintenance costs should level out to about $3,500,000 a year.

DEFINITIONS

DEFINITIONS

Analog: Representation of a physical quantity by another physical quantity, e.g., sound by magnetization on tape.

Comprehensive Planning: The continual establishment of objectives for a community or region as a whole. It is by its very nature, coordinative, inclusive and projective.

Computer System: A computer system is an organization designed to complete certain predetermined information processing tasks and to accomplish clearly specified goals and/or objectives. Its hardware encompasses the central processing unit (CPU) and all peripheral equipment and supportive elements.

Data: A general term used to denote any or all facts, numbers, letters and symbols; or, facts that refer to or describe an object, idea, condition or other factor. It denotes basic elements of information.

Environment: Everything outside a system that either affects the operation of the system or is affected by the system; the complex of climatic, edaphic and biotic factors that act upon an organism or an ecological community and ultimately determines its form and survival; the aggregate of social and cultural conditions that influence the life of an individual or community; the situation, physical and social, in which a person finds himself.

Horizon Scanning: Looking into the future to identify potential stresses and opportunities and to determine possible solutions.

Information: A collection of facts or other data especially as derived from the processing of data.

Information System: A system concerned with the collection, storage, retrieval and dissemination of pertinent data to a user or group of users. A complete system includes all subsystems, equipment, services, personnel and related facilities

Information/Management/Planning System (IMP/S): A comprehensive system designed to supply a broad range of users the detailed information needed for environmental planning, policy formulation, and decision making.

Interface: The common boundary between parts of the system, and/or between the system and the external environment.

Model: A physical or symbolic representation of an object or process designed to incorporate or reproduce those features of the real objective, event, process, or environment that the researcher, planner or decision-maker deems significant for the problem at hand. Theoretically, the model reduces the real or hypothetical situation to a number of essential and manipulative variants.

Parameter: A numberical constant which remains unchanged during some calculation, process or event.

Planning: A process leading to the development of a solution relative to a given problem in a given social or environmental milieu and an active application of that solution.

Preferred Solution Setting: Selecting the most desirable solution to an existing or potential problem on the basis of various alternatives.

Region: A region is a geographical area having more internal interaction than with areas external to it. Regions differ for different interactions. In another sense a region may be thought of as a system consisting of many elements that interact together to form a total structure.

Remote Sensor: An instrument that receives input energy, measures it and delivers the resulting information as its output. Such a sensor may be designed to pick up any form of energy.

Remote Sensor System: An array of remote sensors arranged in a logical manner, and related to one another with the capacity to channel data to a specific point.

Remote Sensor System--Composite: A multi-dimensional system incorporating different types of sensor platforms-surface, aerial and orbital - but linked together as part of a single network.

Simulation: An operating imitation of a real process. It refers to the construction and manipulation of a model capable of depicting a particular situation or condition and manipulating its variables and interrelationships. Thus, a simulation is mainly concerned with developing a model that represents or approaches reality.

Software: Anyone or the totality of programs and routines uses to extend the capabilities of computers.

Strategy: A method, plan, or series of plans for obtaining a specific goal or set of goals.

Structure: The arrangement of organic or artificial units or parts in a whole; the arrangement of constituent parts; the manner of organization.

System: A regular or orderly arrangement of components or parts in a connected and interrelated series or a whole; a series or group of components necessary to some operation.

Subsystem: A series or group of components that perform one or more well-defined operations of a more complex system.

Transducer-active: A sensor whose output waves depends on one or more sources of power apart from those supplied by any of the activating waves, which power is controlled by one or more of the input waves.

Transducer-passive: A sensor whose input waves are independent of any sources of power, controlled by the actuating wave.

User Agency: An agency that uses the data and its interpretation in direct support of its specific area of responsibility.

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