Water Research Progress at OSU

Seminar Conducted by

WATER RESOURCES RESEARCH INSTITUTE

Oregon State University

Fall Quarter 1978

January 1979

Preface

Water-related research has been conducted on the campus of Oregon State University over a period of many decades. Attention has been directed at a broad spectrum of problems, many of them multi-disciplinary in nature. Both faculty members and students have been involved in the projects -- quite often in collaboration with federal and state agencies. The three major state industries (forest products, agriculture, and recreation/tourism), and their support settings (urban areas, concentrated and dispersed industries), have been addressed in the context of water-related problems.

It seems appropriate to step back periodically to consider some of the results obtained and to examine likely directions for future research. This seminar series attempted to do just that. Speakers were asked to identify the state of knowledge in significant subject areas and to indicate the role that research has played. It would be impossible to cover all facets of research or to document fully the state-of-the-art for those areas under scrutiny. However, we present a summary and synthesis of important findings and some ideas regarding tomorrow's objectives.

The weekly presentations were open to faculty, undergraduate and graduate students, and the general public.

Peter C. Klingeman
Director

Corvallis, Oregon
January 1979

Funds for this publication were provided by the office of Water Research and Technology, U.S. Department of the Interior, under the provisions of the Water Research and Development Act of 1978.

The Institute

The Water Resources Research Institute, located on the Oregon State University Campus, serves the State of Oregon. The Institute fosters, encourages and facilitates water resources research and education involving all aspects of the quality and quantity of water available for beneficial use. The Institute administers and coordinates statewide and regional programs of multidisciplinary research in water and related land resources. The Institute provides a necessary communications and coordination link between the agencies of local, state and federal government, as well as the private sector, and the broad research community at universities in the state on matters of water-related research. The Institute also administers and coordinates the interdisciplinary graduate education in water resources of Oregon State University.

This seminar series is one of the activities regularly undertaken by the Institute to bring together the research community, the practicing water resource specialists, students of all ages and interests, and the general public, in order to focus attention upon current issues facing our state.

Contents

Presented September 28, 1978 by PETER C. KLINGEMAN, Director, Water Resources Research Institute.

The Scope of Water Research

The purpose of the seminar series is to present a summary and synthesis of campus research progress for water-related resources. The summarized research was primarily conducted over the past decade. Some earlier research will also be summarized, as it often was instrumental in the development of the research staffs and of focal points for the research emphasis of various campus departmental units. Related non-university research by federal agencies located on the Oregon State University campus will be described, in part, to show the interplay of federally-conducted and university-conducted research. However, no attempt will be made to cover the full scope of non-university research.

The purpose of individual seminars is to address a relatively narrow subject area of water research. Speakers familiar with each subject area will present a summary and synthesis of research focusing on some unifying topic, such as watershed hydrology of erosion from agricultural lands. The speakers themselves will have conducted part of the research being conducted.

The seminars are not meant to be merely a recitation of projects and of their findings. Instead, the speakers will synthesize the past research. They will identify the past and present state of knowledge in each focal area. They will identify ways in which campus research has contributed to the advancement of the state of knowledge. The seminars will not be restricted to projects funded by the Water Resources Research Institute; instead, they will attempt to synthesize all pertinent research conducted on the campus over the past decade or longer.

The synthesis of research progress will generally emphasize concepts and conclusions, rather than data. However, some data will undoubtedly be included to show phenomena or system functioning and the impacts of various activities on these. Speakers will try, where possible, to show some of the important linkages among hydrologic, biologic and socio-economic aspects of the problems researched.

The Beginnings of Campus Water Research

The earliest water research on the OSU campus occurred as part of the agricultural research that was basic to the role of a land grant college. Much of the early work involved water in only an "incidental" manner, rather than as a focal point for investigation. Yet with scientific inquiry into plant growth and with the need to irrigate crops efficiently, water research was a significant by-product. Today, the agricultural sector is responsible for about 80 percent of the total water use in Oregon.

The Agricultural Experiment Station has acted as the administrative unit for most of the agriculture-related water research since its inception in 1888. A growing amount of research specializing in forest lands, having its beginning in the 1920's, led to the separation of that activity from the Agricultural Experiment Station and from the Oregon Forest Research Center by establishment of the Forest Research Laboratory in 1961.

The land grant colleges were also charged with the "mechanical arts". An Engineering Experiment Station was established on campus in 1927. Water research there tended to involve pumps and turbines or dams and similar hydraulic structures. But one of the most significant investigations affecting Oregonians was that undertaken to document the pollution of the Willamette River, contributing vital data to pinpoint early efforts in the river's restoration.

Formation of the Water Resources Research Institute

During the 1950's it became increasingly evident that many interdisciplinary aspects of water required investigation. Thus, in 1959, Professors Burgess, Castle, Krygier, Warren, and others, organized the Water Resources Research Institute (WRRI) under the Agricultural and Engineering Experiment Stations. The purposes of WRRI were (1) to coordinate the multi-disciplinary efforts necessary for solution of critical water problems and (2) to participate with state, federal and local agencies in the study of water development projects so that the scientific and engineering expertise of the University might be focused on research activities necessary to provide a sound basis for resolution of water problems.

The establishment of WRRI at Oregon State University was authorized by the Oregon State Board of Higher Education in September 1960. Financial support was provided from Board funds.

An Enlarged WRRI Role

The U. S. Congress passed the Water Resources Research Act of 1964 (Public law 88-379) and established a federal water resources research program in each state. These programs were to be administered at university-based water resource research institutes -- generally to be located at land grant colleges. Since OSU had already established such an institute five years earlier, to meet different needs, Governor Hatfield designated the WRRI at OSU as the eligible institution for participation and so notified U.S. Secretary of the Interior Udall in August 1964. The "parent" federal agency established to administer this act was the Office of Water Resources Research (OWRR), since restructured as the Office of Water Research and Technology (OWRT).

The Water Resources Research Act of 1964 greatly enlarged the WRRI scope of responsibilities. Under federal law, WRRI was the water resources research institute for the entire State of Oregon, with state-wide responsibilities. The federal act provided federal funds for the Institute's financial support; state support was reduced. However, during the 1969-71 biennium the Oregon State Legislature did appropriate some funds for the administrative support of WRRI.

The enlarged role of WRRI is well reflected by the objectives of the Institute. These are:

1. to provide a means for appraising special needs for water resources research and education;

2. to promote scientific endeavor wherever there are pressing needs for water resources research;

3. to encourage and facilitate the entry of qualified scientists into water resources research;

4. to coordinate, integrate and facilitate the efforts of scientists and organizations conducting water resources research;

5. to provide visible evidence of the capabilities available on campus to conduct outstanding research in both broad and specific areas of water resources and to provide means of contact between the scientists doing this research and organizations supporting such research;

6. to disseminate information giving the results of research on water and related land resources to all interested agencies and individuals;

7. to promote and support an interdisciplinary graduate education program in water resources at Oregon State University.

WRRI Membership and Administration

WRRI membership is open to all faculty members in any university or college in Oregon who are actively engaged in water-related research and education or who wish to keep themselves involved and informed regarding such activities.

Institute administration has slowly evolved since 1960. It is presently administered by a Director and a Governing Board, together with a staff including the Executive Secretary, a secretary and a clerical secretary. The 10-member Governing Board consists of the Institute Director, the Deans of the Schools of Forestry and Engineering, the Director of the Agricultural Experiment Station and six faculty members from Oregon's University system who are actively engaged in water-related research.

Overview of WRRI-supported Research

The basis for WRRI research support through OWRR/OWRT programs that has been applied by the Institute Governing Boards over the years is five-fold:

1. to produce relevant research findings that can be applied to solve pressing specific problems of state, regional or national scope;

2. to produce relevant research findings that are urgently needed to solve a pressing local problem;

3. to fill significant missing gaps in the broader understanding of an important problem;

4. to provide "seed money" to explore a promising concept or technique and to develop it to the point where more substantial funding might be sought from other sources, including OWRR/OWRT programs;

5. to provide a means for encouraging competent, qualified investigators to enter some field of water research where ongoing research is insufficient to adequately address pressing problems; and

6. to acquire baseline information for resource characterization needed for subsequent research or decisions.

Since May 1965, WRRI has funded 76 research projects through OWRR/OWRT programs involving 55 principal investigators from 24 academic units of 4 state institutions of higher education. Through other federal support, WRRI has facilitated the research of 22 principal investigators from 13 OSU academic units on 13 projects. Additionally, in-state support has involved 6 principal investigators from 4 OSU academic units on 5 projects. Combined, the 94 projects have involved 72 principal investigators from 29 academic units at 4 state institutions.

During the period FY 1966 - FY 1978, the OWRR/OWRT research program has brought 2 million dollars of federal support into Oregon, matched by about 1.5 million dollars of state contributions (indirect costs, etc.). These funds have been applied to solving a broad front of water-related problems. A substantial portion of the WRRI research program has been directed to water problems involving forested lands and timber harvesting. Another sizeable portion has been devoted to a broad range of agriculture and irrigation water problems. Other important areas of research funding, less cohesively identifiable, have dealt with industrial wastes, problems of urbanizing areas and recreation. Thus, the three major state industries (forest products, agriculture and recreation/tourism) and their support settings (urban areas and concentrated or dispersed industries) have been addressed in the context of water-related problems.

Many different types of matrices have been used in describing water-related research. To show the involvement of different research disciplines in Oregon in solving problems through WRRI in particular subject areas, a table has been prepared. The choices of research subject areas, while somewhat arbitrary, identify areas of major statewide concern.

WATER RESEARCH SUBJECTS AND ACADEMIC DISCIPLINES
SUPPORTED UNDER WRRI WITH OWRR/OWRT FUNDS, FY 1966-FY 1978

Research Subject Area	Research Disciplines Actively Involved																		
	Ag. & Res. Ec.	Ag. Engr.	Anthro.	Biol.	Botany	Bus. & Tech.	Chem.	Civil/oc. Eng.	Engrg/Gen.& Ind. Engr.	F&WL	Food Sci.	Forest Engrg. & Mgmt.	Geog.	Geol.	Law	Microbiol.	Polit. Sci.	Rangeland Res.	Soil Sci.
I. Forest & Rangeland Hydrology, Water Quality and Mgmt.		X			X			X	X	X		X				X		X	X
II. Irrigation & Agriculture Water Use, Conservation, Land & Animal Pollution, Water-Energy Relations, Water Pricing, Water Allocation	X	X									X								X
III. Industrial & Municipal Wastes Food Processing, M&I Effluents, Forest Products, Techniques							X	X	X	X	X					X			
IV. Problems of Urbanizing Areas Floodplains, water supply & quality, land instability, wastes, river impacts				X			X	X	X				X	X		X			
V. Recreation Federal role, Greenway, water supplies			X										X			X			
VI. Aquatic Ecosystems Benthic zones, microorganisims, plants, fisheries, linked systems	X				X		X	X		X		X				X			
VII. Ground Water Availability, contamination														X		X			
VIII. Resource Characterization Lakes, streams, marshes, estuaries soils, reservoirs		X					X	X		X		X		X					X
IX. Broad Planning, Mgmt., Institutions								X							X				
X. Broad Socio-Politico-Economic-Legal	X		X			X									X		X		

Disseminating Research Findings

An essential element of all research is the dissemination of findings to all those having potential interest in or use of the results. Several means of research information dissemination are used by WRRI.

Project reports form the backbone of WRRI information dissemination activities. These are prepared for the sponsor agency. When the research involves OWRT funds, reports are also sent to the WRRI's in all other states for their use and dissemination of findings. The principal investigator also furnishes WRRI with a list of people or agencies to whom the report should be sent. Finally, extra reports are kept at WRRI and listed on the Publications List that is sent out periodically, so that interested individuals can also obtain copies.

A newsletter, "Oregon's Environment", is prepared bi-monthly and is circulated to some 2000 readers, most of them in Oregon. The readers come from all areas of society, ranging from political leaders to farmers or ranchers. The newsletters present capsule summaries fo research applicable to Oregon water problems. The summarized information comes not only from WRRI research but also from reports of research conducted in all parts of the nation.

Seminars offer a third important vehicle for disseminating research results. Approximately 20 seminars each year are held by WRRI on the OSU campus as part of the graduate education program. These are organized about some central theme each academic term, such as "Energy and Water Resources" or "Toxic Materials in the Aquatic Environment", so as to provide a measure of unity and cohesiveness. Seminar attendees include students, faculty, agency staff members, and the general public.

Periodically, special programs are offered to disseminate information to particular groups. Recent examples include a Wetlands Workshop for federal agency people involved with permit reviews and a conference on Non-federal Financing of Water Resources Development for state decision-makers in the Pacific Northwest states (a joint effort of the Oregon, Idaho and Washington Institutes).

Organization of such conferences by universities is a necessary endeavor to augment the efforts of the many national and international organizations which hold meetings. The reason for universities to do so is to offer a platform at which the questions can be discussed without the limitations often imposed at other conferences.

A polarization may be occurring between knowledge producers and knowledge users at present. Research that is often generously funded is not sufficiently fast or not at all translated into practice. The reasons for this lag of time in knowledge transfer are worth discussing on another occasion. An embryo of confrontation in the water resources field may be in the offing between the developing and developed regions of the world. Needs have been proven for the new knowledge and its transfer in disciplines related to water resources. Regardless of many efforts, water resources technology still is not very advanced. When the Viking space probe landed on Mars, it could have met many hypothetical atmospheric conditions on that planet and performed well for these various atmospheric conditions. However, one cannot yet tell what is the probability for a dam to collapse next year under given conditions of soils, rocks, and materials involved in the construction of large dams. The classical water resources technology is not being adjusted and developed sufficiently fast to meet new conditions and needs. Society is proud of the space technology, but also is ready to test and produce, as well, the new technologies of the same quality for the objectives on the earth. Water resources technology belongs to these needed improvements.

It is estimated that the developing countries need to produce about 32,000 new water resources specialists each year. New vocational schools and universities are needed to meet the demand. The transfer of water resources knowledge to developing regions of the world is a challenging task for all the existing organizations in both the developed and developing regions. Several lines of transfer of this knowledge are feasible, either individually or jointly by the international, governmental, commercial, and university organizations. Universities of the world can and should play a large role in this knowledge transfer, particularly by using the approach of continuing education of professionals. For particular areas of technology, the specific features of knowledge transfer may not be applicable identically in all disciplines.

The total management of water resources is an activity of considerable scale in any national economy. In the United States, it requires approximately $50 billion dollars per year, including water for cities, industry, energy, and agriculture. If this figure is extrapolated to the world population, it would reach several hundreds of billions of dollars. Yet the water industry in most countries is not organized to carry out its own research and development or to deliver scientific knowledge to the point of application. For this reason, a diverse group of transfer agents serve the needs. These include the universities, government agencies at all levels, libraries, scientific and technical associations, extension services, non-profit and profit institutions. Little has been written about the effectiveness of these diverse groups and, although a great deal is known about water resources, little is known about the most effective ways to transfer water knowledge.

Presented October 5, 1978 by GEORGE W. BROWN, Head, Department of Forest Engineering, Oregon State University.

Advances in Watershed Hydrology

Oregon's 23 million acres of forest land provide a variety of goods and services for our citizens and the nation. Attention often focuses on the 9 billion board feet of timber harvested each year in our state. And certainly with some justification; this valuable resource provides the backbone of Oregon's economy.

There is, however, another important resource that is produced from Oregon's forest land--high quality water. Most of our state's river systems begin in forested watersheds. Understanding how these forested watersheds function and how man's activities affect this functioning is an important key in making wise decisions about management of both timber and water. Recent legislation by the federal government and by our state through the Forest Practices Act lends the force of law to our desire to better understand the interaction between forestry activities and Oregon's water resources.

During the 12 years our Institute has been financed by OWRT, a major emphasis of our research has focused upon the hydrology of forested watersheds. In addition, the Forest Service has a major research program on water resources in managed forest watersheds. Their program is located on the OSU campus at the Forestry Sciences Laboratory. Together, these programs form one of the most concentrated watershed management research efforts in the United States. I wish to describe the work we have done together in three major areas: predicting water yield from forest lands and the effect of timber harvesting on that yield; modeling runoff processes; predicting water quality in forest streams and the effect of man's cultural activities on quality.

PREDICTING WATER YIELDS FROM FOREST LANDS

The presence of trees in our state's most important watersheds is by no means an ecological coincidence. Trees require large volumes of water for their establishment and growth. Those portions of Oregon which receive large amounts of precipitation and produce high runoff are ideally suited for trees. The water used by trees, called transpiration, is returned to the atmosphere as vapor. Without transpiration, most of this water would find its way into streams as runoff.

Some of the earliest watershed research in our country was begun to determine the amount of water trees used. When this work began in Oregon, several water supply issues were at stake:

- increased water for domestic use from forested, municipal watersheds

- increased water for irrigation

- interstate export of Oregon's water

Manipulating the forest, a heavy user of water, was posed as an alternative for increasing water yield.

Several sets of studies were completed by OSU and Forest Service hydrologists. The Forest Service established several experimental watershed studies in the northern, central and southern Cascades of Oregon. The University began a watershed study in cooperation with several agencies and timber companies in the Coast Range. All of these watershed studies followed a similar design. In each study, two or more watersheds were scheduled to be treated following a 7-10 year period of calibration. At least one additional watershed was designated as a control and remained untreated throughout the study. Following calibration, the designated watersheds were treated in some manner (road construction, harvesting, etc.) and the response compared to the pretreatment relationship with the control watershed.

Scientists also began some very sophisticated studies on evapotranspiration processes in forest lands. In this research, energy exchange between the forest canopy and the atmosphere was used as the variable for predicting water use.

This hydrology and evapotranspiration research produced several interesting findings:

1. On an annual basis, about 30-40 percent of the precipitation that falls in western Oregon is transpired (Rothacher, et. al., 1967).

2. Harvesting timber by clearcutting can be expected to increase streamflow by this same amount, with the increase in volume occurring primarily during the winter months. In absolute volume, clearcut harvesting in the Coast Range increased annual streamflow by about 24 inches or two acre-feet/acre the first year following harvest. In the Cascades streamflow was increased by 18 inches or one and one-half acre feet/acre the first year following harvest (Harr, 1976; Rothacher, 1970).

3. Summer streamflow generally triples the first year following clearcutting. While this is a large percentage difference, it represents a small difference in volume since this is the period of lowest flow (Harr, 1976; Rothacher, 1970; Harr and Krygier, 1972).

4. Partial cutting in a watershed produces smaller increases in streamflow; if less than about 25% of the watershed is logged, increases are not readily detectable (Rothacher, 1970).

5. Clearcutting increases the small peak flows from fall and spring storms. Greatest increases are in the fall prior to soil moisture recharge. There is little or no effect on large, mid-winter peak flows which occur after soil moisture recharge is complete (Rothacher, 1973).

6. Increased water yield declines with time as trees and other vegetation become reestablished following clearcutting. The rate of return to preharvest levels varies with site conditions, but is generally a negative exponential function.

In my opinion, the results of this research have been very useful for those concerned with the management of forest lands and their aquatic resources. First, it has shown that timber harvesting may produce an increase in water yield; in fact, streams do not dry up following harvest. But it is also very clear that opportunities for substantially increasing water yield will require a rather drastic manipulation of a large part of Oregon's forest watersheds. And given present concerns and policies for forest management, it is unlikely that we will be able to implement large-scale water yield improvement projects on our forest lands.

MODELING RUNOFF PROCESSES

It is important for resource managers to understand the impact of management on the pattern or timing of runoff as well as the changes in volume. Three types of studies have been conducted to answer these questions. The first type is the empirical measurement of changes following treatment of a watershed. The watershed studies described above were also designed to monitor changes in individual storm events as well as total water yield. As a result, we have good general information about hydrograph response in both Cascade and Coast Range streams.

The second type of study focuses on definition of the individual hydrologic processses responsible for the changes in streamflow observed on watersheds. Such studies are essential for developing explanations of the changes observed from empirical monitoring and to provide the basis for extrapolation of results to other watersheds with different characteristics. Unless these process oriented studies occur concurrently with empirical watershed research, accurately predicting outcomes of alternative management strategies is all but impossible. The principal process work done at OSU on forest watersheds has been the definition of subsurface flow processes in sloping forest soils and water use by vegetation. This work has been a major contribution to our understanding of how rainfall reaches streams in our steeply sloping, highly pervious soils on forested lands.

The third type of research utilizes the empirical data obtained from both process and watershed studies, but seeks to develop a more general solution through mathematical modeling or simulation. The objective of the simulation studies is to predict the changes in streamflow that would occur over a range of precipitation events from alternative management activities. This research at OSU has been done almost exclusively by those scientists working in the Coniferous Forest Research Program.

The results of this research effort have also provided useful information for resource managers on the behavior of forest streams and their response to management. Some important findings are that:

1. Peak flows from small, headwater streams are "lost" downstream as a result of "dampening" processes in the channel. This illustrates the difficult and complex problem of routing flood peaks from treated watersheds.

2. Surface runoff, or overland flow, on undisturbed forest soils seldom occurs in Northwest Oregon. Water travels from upper slopes to stream channels via subsurface or underground routes. We also know that forest soils are seldom saturated in the classical sense (Harr, 1977).

3. The patterns of water use by forest vegetation have been well established and can now be predicted with some accuracy (Waring et. al., in press).

4. Computer models are useful for simulating runoff processes runoff from forest land. For example, a model has been tested with data sets from Oregon, Arizona, and North Carolina and works very well for annual runoff (Waring, et. al., in press).

The information developed from these studies and the water yield studies has been used in a variety of ways. First, it tells forest managers, water resources managers, and the public that major flooding events are not influenced by timber harvesting. Not only are the large peak events unaffected by harvesting, the smaller ones get lost downstream. This means that resources and efforts for flood control activities can be focused on other problems. Peaks from headwater areas are not necessarily translated into flooding downstream riparian zones.

Finally, the research has raised important questions about the translocation of water on forested slopes. It has demonstrated that the classic overland flow or surface runoff concept of runoff generation is not valid. Neither is the concept that forest soils must be raised to moisture levels near saturation before streams begin to rise. Also, this research has helped us better understand how chemicals, both naturally-derived and those applied by man, are transported along with water through the forest soil matrix. This has significant implications for the water quality issues we will discuss next.

WATER QUALITY IN FOREST STREAMS

Some of the most exciting work in forest hydrology at Oregon State deals with the water quality of forest streams and man's impact on that quality as a result of management. I believe it is safe to say that no other university has been so deeply involved in this topic. While I will confine my remarks to the hydrologic or physical aspects of water quality, it is important to understand that these several studies all have a biological focus or ultimate objective. They have been conducted in cooperation with fisheries and aquatic biologists with the goal of relating treatment of the forest to changes in water quality and, in turn, biological response. The major political issue that these studies were designed to resolve was the question of harvesting impacts on the useability of water for domestic consumption and fish production.

Two types of water quality studies have been conducted at OSU. The first type of study is the classical experimental watershed study described earlier in the section on water yield. Water quality measurements were overlayed on the water yield experiments and included measurements of sediment, temperature, and various chemical constituents of water. The objective of these water quality studies was to obtain gross estimates of changes produced by a given treatment. As with any watershed study which focuses on output, major problems or changes can be easily identified, but it is difficult to develop generalized models capable of predicting outcomes of varying treatments over varying sets of conditions. A second type of study was conducted to overcome this shortcoming. These studies can be classified generally as process studies and focus on developing functional relationships between driving or controlling variables and the observed change in water quality. These studies are generally designed to provide predictive relationships capable of fairly broad extrapolation.

Watershed Studies

Watershed studies on water quality impacts of harvesting have been conducted by Forest Service and University scientists in the forests of the Cascade and Coast Ranges in conjunction with water yield studies described earlier. The general design of these studies was to monitor water quality of 3 to 4 watersheds for a period of time to develop comparative relationships while the watersheds were in an unaltered state. Following this "calibration" period, two or more of the watersheds were treated (road construction, harvesting, etc.) and one left unaltered to serve as a control.

Suspended sediment and samples for dissolved chemical constituents were collected at the bottom of each watershed. In some cases, samples were collected by a pumping device which sampled a fixed proportion of the streamflow. In other cases, these samples were collected by hand. Depending upon the measurement technique, estimates were made for changes in annual yield or changes in concentration of the water quality parameters. A variety of physical and chemical water quality characteristics have been studied including suspended sediment, temperature, turbidity, total dissolved solids, dissolved oxygen and a wide range of ion concentrations including calcium, magnesium, potassium, nitrate and bicarbonate.

The results of the water quality studies have provided useful information to forest managers, fisheries managers, and pollution control specialists. The results have been incorporated into rules, regulations, and guidelines for controlling nonpoint source pollution from silviculture on federal, state, and private forest lands in Oregon and other states as well. Some of the most important findings are these:

1. Sediment is the nonpoint source pollutant of greatest concern. It also has the greatest natural or background variation (Brown and Krygier, 1971).

2. Sediment carried by a stream varies in concentration with the volume of streamflow, season of the year, and with stage condition (rising or falling). The pattern and level of sediment yield may be significantly altered by major flood events. Variation between watersheds, even those adjacent to each other, is also quite large (Brown and Krygier, 1971).

3. Timber harvest operations increase the amount and variation of sediment transported in streams. The level of increase is related to the degree of soil disturbance. Road construction in mountainous terrain produces the greatest volume of sediment, often as a result of landslides. Slash burning, which exposes mineral soil to winter rains, is the next largest source. Timber falling and yarding with cable systems produces very little soil disturbance and no significant increase in sediment (Brown and Krygier, 1971; Fredriksen, 1965).

4. The increases observed in sediment yield following harvest operations tends to be highest the first year and declines during following winter seasons. The rate of decline is proportional to the rate of revegetation (Brown and Krygier, 1971; Fredriksen, 1965).

5. In western Oregon, mass wasting is the dominant form of erosion in the mountainous terrain of the region. Timber harvesting, and especially road construction, increases the frequency of these events. Road-related mass failures are most frequent immediately following construction, but may continue long afterwards especially after large winter storms. One survey of 21 undisturbed watersheds and 13 clearcuts in the Coast Range showed one failure per 19 acres in clearcuts and one in 17 acres in undisturbed areas. The rate of erosion from mass wasting on clearcuts was 3.5 times that from undisturbed watersheds. The rate of erosion from road-related mass wasting is generally several times that amount (Brown and Krygier, 1971; Fredriksen, 1965; Ketcheson and Froehlich, 1978; Swanston and Dyrness, 1973).

6. Stream temperatures can change significantly following clearcutting if the stream is exposed to direct solar radiation. Changes in the maximum daily temperature from 60 to 85^{o}F were observed on two small streams following through clearcut units (Brown and Krygier, 1970).

7. Shade from riparian trees and brush can prevent temperature changes in the stream even though the adjacent forest has been clearcut (Brazier and Brown, 1972; Brown, 1969).

8. Logging residue, if allowed to accumulate in the channels of small streams, can depress dissolved oxygen concentrations from saturation to near-zero levels (Ponce and Brown, 1974; Berry, 1974).

9. The concentration of nutrients such as nitrogen or bicarbonate increases in streams following clearcutting and slash burning. First year increases in NO_3-N vary from 3 (Coast Range) to 130 (Southern Cascades) times the concentration prior to cutting. In no case, were these concentrations above levels considered hazardous to humans or fish. For example, in the southern Cascades, where the largest percentage change occurred following clearcutting, NO_3-N increased from 0.002 mg/l to only 0.275 mg/l. The highest concentration observed following clearcutting was in the Coast Range where concentrations reached 2.10 mg/l, a level below the background concentration on a nearby control watershed dominated by alder, a nitrogen fixing species (Brown, et. al., 1973; Fredriksen, et. al., 1975).

Process Studies

Studies designed to develop functional relationships between several independent variables and water quality changes produced by harvesting were conducted to improve our ability to predict management impacts. Many of these studies were designed to answer important questions raised by watershed studies. Many were conducted on the experimental watersheds or used basic data from these early experiments. The approach of the process studies, however, was to measure many variables very intensively over a short period of time rather than a few variables over a long period of time. Also, the focus was on defining the relationship between several independent variables and one dependent variable rather than the converse.

The range of process studies undertaken at Oregon State by university and Forest Service scientists has been quite large. These include studies of sediment transport, organic residue accumulation in streams, the biochemical oxygen demand of logging debris, reaeration in turbulent streams, temperature change processes, buffer strip stability, and the fate of applied chemicals in the forest environment. The results of many of these studies have already been incorporated into rules and guidelines for regulating forest operations. Others have provided important fundamental information that will form the basis for eventual drafting of rules. Some of the most important findings are these:

1. Precise measurements of suspended sediment show a regular pattern of changing concentration during a storm event. The pattern is like a hysteresis loop with sediment concentrations highest on rising stages and rapidly declining on falling stages. Early fall storms have the highest concentrations of suspended sediment. Later storms produce less sediment, indicating a pronounced seasonal flushing of sediment from the stream system. This means that "background" values for water quality monitoring are likely to be highly variable on small streams (Beschta, in press).

2. In Oregon Coast Range streams, the amount of sediment being transported as bedload becomes an increasingly important part of the total load when flows exceed approximately 15 ft^3-sec^{-1}-mi^{-2}. However, during small peak flows (less than a 5-year return period) the bedload transport may comprise only 10 to 20% of the material being carried as suspended load. A general transport of bed material does not occur when flows are below 15 ft^3-sec^{-1}-mi^{-2} (Beschta, personal communication).

3. Bed material moves through a stream channel in waves or pulses, probably as a result of periodic destruction of the armor layer of the channel. This phenomenon also produces fluctuations in the concentration of suspended sediment because large quantities of fine material are stored in the bed of streams (Paustian and Beschta, in press; Milhous and Klingeman, 1973).

4. Organic residue is an important natural component of stream channels in the Pacific Northwest. In undisturbed watersheds covered with old-growth forests, the quantity of residue may be greater than 20 tons per 100 feet of channel. This residue acts as a barrier to movement of bed material, may serve as a stabilizing element for stream banks, and may serve as an energy source for important aquatic organisms (Froehlich, 1973).

5. The quantity of organic residue may be markedly increased by clearcutting if no special measures are taken. In steep channels, residue loading may combine with mass wasting to produce damaging debris avalanches. Directing the fall of timber away from streams by pulling jacking trees or using buffer strips to prevent felled timber from rolling into the stream channel can keep most of the residue from entering channels during timber harvest (Froehlich, 1973).

6. Green needles, leaves, twigs, and other finely divided organic residue have an extremely high biochemical oxygen demand. In small streams, the demand is exerted very quickly because the simple sugars present in fresh vegetation are rapidly backed into the water. This explains the reduction in dissolved oxygen observed in the watershed experiments and focuses attention on the need to control the amount of fine residue entering streams during timber harvest (Berry, 1974; Ponce and Brown, 1974).

7. The rate of reaeration following oxygen depletion is generally quite rapid in the turbulent, small streams typical of forested watersheds. Where streams are free-flowing oxygen concentrations can increase from less than 1.0 mg/l to 6 mg/l in less than 300 feet. We now have a method for predicting reaeration potential of a channel suitable for use by forestry field personnel (Ice, 1978).

8. Direct solar radiation is the dominant source of heat for raising the temperature of small streams. Streams do not readily cool through evaporation or convection once warmed by the sun. Temperature increases resulting from exposure of the water following clearcutting can be accurately predicted with a model suitable for use by field personnel (Brown, 1969; 1970).

9. Proper design of buffer strips is essential if streams, and water quality, are to be protected following timber harvest. Blowdown is a common occurrence in buffer strips and can significantly degrade the aquatic environment. Guidelines for buffer strip design are presently being formulated with basic data collected from a survey of over 80 buffer strips (Steinblums, 1978).

10. Chemicals applied to forest vegetation or forest soil follow the same pathway to streams as does water, the principal carrier of these chemicals. This pathway is controlled by the rapid infiltration of surface soil and the dominance of subsurface, rather than overland, flow. Chemicals applied to vegetation and soil surfaces are generally transported into the soil matrix where adsorption and biochemical weathering significantly reduce the movement. This explains the very low concentration of chemicals usually observed in stream water after application. For a more thorough review of this complex issue see Norris (1976).

NEW DIRECTIONS

Watershed research on Oregon's forest lands continues to be an exciting and interesting area in which to work. The need for information by those who manage forest land, fisheries, or water resources and by the general public has never been greater. This need will continue to grow as resources become more scarce and the conflicts between competing resource uses become more clearly defined. Water resource issues have always been of high public interest in Oregon and that interest is not likely to subside.

Research in forest hydrology or watershed management will be influenced by several key issues during the next ten years. These issues include:

- Increasing regulatory activity to control non-point source pollution from forest lands.
- Increasing pressure for intensive management of Oregon's forest lands including:
    - increased wood production from present forest land base
    - extension of management activities into more inaccessible areas
    - rehabilitation of nonproductive forest land
    - greater utilization of wood residue for energy production.

These issues set the stage for the information we must develop through research so that decision-makers, including the general public, will be able to make rational, informed judgements about our natural resources. I believe the research will be characterized in the following way:

Development of Predictive Models. The research will shift to include an even greater proportion of process-type studies. We'll continue to use watershed studies, but probably in a new way. And that is to use them to test hypotheses rather than to formulate them. The need to predict the outcomes of management activities across a broader range of conditions and to compare alternative management strategies precludes, I believe, our reliance on the traditional watershed approach.

Focus on Sediment and Chemicals. The two major classes of nonpoint source pollution of greatest concern are probably going to be sediment and chemicals applied to increase the productivity of forest land. Sediment is certainly the most common pollutant and probably the one of greatest significance to the management of aquatic resources. Yet we know very little about its production or predicting this production, especially from landslide processes. Nor can we predict with any accuracy the influence of road construction on landslide occurrence. Neither do we understand, in any predictable way, how sediment materials are transported or deposited in our stream-river-estuary continuum and the variation in response of the aquatic ecosystem to this sediment. With more steep forest land to be intensively managed, more roads to be constructed, more material removed from the land, the sediment problem is likely to occupy a substantial portion of researchers' time.

The present concern about chemicals in the environment is likely to accelerate. As we are faced with more difficult decisions about the trade-offs between the use of chemicals and the growing of trees, the need for clearly articulated information about the fate of these chemicals in our environment increases. The problem is not one that is just for chemists. Since water is the common carrier, the need for better information about water movement in the forest is no longer an academic issue.

Greater Involvement In Watershed Research. As the complexity and political sensitivity of these forest management-water resource issues grows, we will begin to see a greater number of agencies, organizations, and disciplines represented in the research effort. EPA's Environmental Research Lab here on campus has just recently begun a nonpoint source pollution research effort. We can expect more forest industries to become involved in watershed research. Weyerhaeuser has been actively involved in watershed research since about 1973; in the past year Georgia Pacific and Potlatch have hired hydrologists to work on nonpoint source pollution problems. It is also apparent that the interdisiplinary research that began with the Alsea Studies will become the rule rather than the exception. Complex watershed problems will not be solved any other way.

Better Interpretation of Research Results. I also believe that our research will be structured in a way that will lend itself to better interpretation of research results. The pressure to incorporate research results immediately into regulatory programs will put additional pressure on researchers to structure research projects that provide information more directly useable by managers. This means research designed from the outset to link with other information that leads to a management solution. In its simplest form, it is a consistency of units of measurement. But we must also design research that will lead to application in the field. Too often in the past, we have given managers tools to use that were far too complex for their use. Complicated simulation models, for example, that utilize data inputs managers can never hope to obtain.

I believe the next ten years will be extremely exciting ones for those of us working on forest watershed problems. The heat is on to provide information to help solve some critical management issues. And that is just where we ought to be.

BIBLIOGRAPHY

Berry, John D. Modeling the impact of logging debris on the dissolved oxygen balance of small mountain streams. M.S. Thesis. Oregon State University, Corvallis. 163 pp. 1974.

Beschta, Robert L. Long term patterns of sediment production following road construction and logging in the Oregon Coast Range. Water Resources Research (in press). 18 pp.

Brazier, John R., and George W. Brown. Buffer strips for stream temperature control. Oregon State University Res. Pap. No. 15. 12 pp. 1972.

Brown, G.W. Predicting temperatures of small streams. Water Resources Res. 5(1):68-75. 1969.

Brown, G.W. Predicting the effect of clearcutting on stream temperature. J. Soil and Water Cons. 25(1):11-13. 1970.

Brown, G.W. The impact of timber harvest on soil and water resources. Oreg. State Univ. Ext. Bull. 827. 17 pp. 1973.

Brown, G.W., A. Gahler, and R. Marston. Nutrient losses after clearcut logging and slash burning in the Oregon Coast Range. Water Resources Res. 9(5):1450-1453. 1973.

Brown, G.W. and J.T. Krygier. Clearcut logging and sediment production in the Oregon Coast Range. Water Resources Res. 7(5):1180-1198. 1971.

Brown, G.W. and J.T. Krygier. Effect of clearcutting on stream temperature. Water Resources Res. 6(4):1133-1139. 1970.

Dyrness, C.T. Mass soil movements in the H.J. Andrews Experimental Forest. U.S. Dept. Agr., Forest Serv., Pac. Northwest Forest and Range Exp. Sta., Res. Paper PNW-42. 12 pp. 1967.

Dyrness, C.T. Hydrologic properties of soils on three small watersheds in the western Cascades of Oregon. USDA For. Serv. Res. Note PNW-111. 17 pp. 1969.

Fredriksen, R.L. Sedimentation after logging road construction in a small western Oregon watershed, In: Proc. Fed. Interagency Sedimentation Conf., 1963. U.S. Dept. Agr., Misc. Pub. No. 970. pp. 56-59. 1965.

Fredriksen, R.L. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small western Oregon watersheds. USDA For. Serv. Res. Pap. PNW-104. 15 pp. 1970.

Fredriksen, R.L., D.G. Moore, and L.A. Norris. Impact of timber harvest, fertilization, and herbicide treatment. Proc. 4th North Am. Forest Soils Conf. pp. 283-313. 1975.

Froehlich, H.A. Natural and man-caused slash in headwater streams. Loggers Handbook 33:15-17. 1973.

Hall, James D., and Richard L. Lantz. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. In: T.G. Northcote (ed.). Proc. of a symmposium-salmon and trout in streams, Univ. of British Columbia, Vancouver. pp. 355-375. 1969.

Harr, R.D. Forest practices and streamflow in western Oregon. USDA For. Serv. Gen. Tech. Rep. PNW-49. 18 pp. 1976.

Harr, R.D. Hydrology of small forest streams in western Oregon. USDA Forest Service Tech. Rep. PNW-55. 15 pp. 1976.

Harr, R.D. Water flux in soil and subsoil on a steep forested slope. J. Hydrol. 1977.

Harr, R.D., W.C. Harper, J.T. Krygier, and F.S. Hsieh. Changes in storm hydrographs after roadbuilding and clearcutting in the Oregon Coast Range. Water Resources Res. 11(3):436-444. 1975.

Harr, R.D., and J.T. Krygier. Clearcut logging and low flows in Oregon coastal watersheds. Oreg. State Univ., Sch. For., For. Res. Lab. Res. Note 54. 3 pp. 1972.

Harris, D.D. Hydrologic changes after clearcut logging in a small Oregon coastal watershed. J. Res. U.S. Geol. Surv. 1:487-491. 1973.

Ice, George G. Reaeration in a turbulent stream system. Ph.D. Thesis. Oregon State University. 174 pp. 1978.

Ketcheson, G., and H.A. Froehlich. Hydrologic factors and environmental impacts of mass soil movements in the Oregon Coast Range. Water Res. Research Inst. Oregon State Univ., Report WRRI-56. 1978.

Levno, A., and J. Rothacher. Increases in maximum stream temperature after logging in old growth Douglas-fir watersheds. USDA Forest Serv. Res. Note PNW-65. 1967.

Milhous, R.T., and P.C. Klingeman. Sediment Transport in a Gravel-Bottomed Stream. In: Hydraulic engineering and the environment. Proceedings of th 21st Annual Hydraulics Division Specialty Conference, ASCE, Bozeman, Montana, August 15-17, 1973.

Norris, Logan A. Forests and rangelands as sources of chemical pollutants. In: Non-point sources of water pollution. Water Resources Res. Inst. Seminar Proc. pp. 17-36. 1976.

Paustian, Steven J., and Robert L. Beschta. The suspended sediment regime of an Oregon Coast Range stream. Water Resources Bull. (in press).

Ponce, Stanley L., and George W. Brown. Demand for dissolved oxygen exerted by finely divided logging debris in streams. Oregon State University Forest Research Lab. Res. Pap. 19. 10 pp. 1974.

Rothacher, J. Increases in water yield following clear-cut logging in the Pacific Northwest. Water Resources Res. 6:653-658. 1970.

Rothacher, J. Does harvest in west slope Douglas-fir increase peak flow in small forest streams? USDA For. Serv. Res. Pap. PNW-163. 13 pp. 1973.

Rothacher, J., C.T. Dyrness, and R.L. Fredriksen. Hydrologic and related characteristics of three small watersheds in the Oregon Cascades. USDA For. Serv. 1967.

Rothacher, Jack S., and Thomas B. Glazebrook. Flood damage in the National Forests of Region 6. USDA Forest Serv., PNW Misc. Pap. 20 pp. 1968.

Steinblums, Ivars J. Streamside buffer strips: survival, effectiveness, and design. MS Thesis, Oregon State Univ. 181 pp. 1978.

Swanston, Douglas N. Debris avalanching in thin soils derived from bedrock. USDA Forest Serv. Res. Note PNW-64. 7 pp. 1967.

Swanston, Douglas N., and C.T. Dyrness. Managing steep land. J. of Forestry 71(5):264-269. 1973.

Swanston, Douglas N. and Frederick J. Swanson. Timber harvesting. Mass erosion and steepland forest geomorphology in the Pacific Northwest. In: Geomorphology and engineering. D.R. Coates (ed.), Downden, Hutchinson and Ross, Inc., Strandsburg, PA. pp. 199-221. 1976.

Waring, R.H., James J. Rogers, and W.T. Swank. Water relations and hydrologic cycles. In: Woodlands Synthesis Volume, International Biological Program. D. Reichle (ed.), (in press).

Presented October 12, 1979 by RICHARD A. TUBB, Head, Department of Fisheries and Wildlife, OSU.

Some Developments in Fisheries Research

Fifty years ago the United States and other countries offered prizes to scientists, inventors, and adventurers if they could accomplish a significant technological feat. Lindbergh's flight to Paris was in response to a prize offered for a non-stop flight across the Atlantic. Since that time, governments have refined their approach to encouraging achievements in science and technology. Congress simply passes an Act declaring the establishment of a new management practice or setting a particularly desirable management goal. The most successful legislation of this type was the flight to the moon by the United States in 1969. Recently Congress has launched programs that were based upon desirable goals for the management of natural resources. Two of these programs directly concern fishery resources and the management of the aquatic environments. Both acts will affect a major portion of the fishery research efforts in the decade and have mandated more sophisticated management techniques.

The first Act, called the Toxic Substances Control Act of 1976 (PL 94-469) requires manufacturers to provide adequate data on the effects of chemical substances and mixtures added to the waterways. As an afterthought, the Act states that the control authority "should not be exercised in a manner as to impede unduly or create unnecessary barriers to technological innovations". What the Act failed to take into account, was that the technology needed to implement the Act has not been developed by the scientific community. Fish toxicologists have not been able to develop a simple, short-term test that manufacturers could use to clear chemical substances for production.

There are two bioassays available for clearing a chemical substance or chemical mixture: The 96-hour bioassay and a 12-month bioassay (MATC). The 96-hour bioassay estimates the LC-50 or the concentration that will kill 50% of the fish. An application factor was arbitrarily set at 10% of the LC-50. The MATC test is an estimate of the maximum concentration which causes no significant effects on growth, survival, or reproduction of a species. Expecting manufacturers to clear about 1500 chemicals last year by means of 12-month tests with the necessary replications is not a realistic view of the legislative mandate of the Congress. Hence, a great deal of effort has been devoted to finding a relationship between the MATC and the 96-hour bioassay.

Mount (1977) showed that no consistent relationship existed between the MATC tests and the 96-hour bioassay. The MATC test is obviously a more sensitive test than the 96-hour bioassay but the MATC results are variable. There is an urgent need to establish an experimentally determined safety factor that can be applied to the LC-50. Given our present state of knowledge of fish physiology and fish toxicology, an accurate safety factor for the LC-50 probably cannot be set from a completely objective viewpoint.

The real need is to understand the basis for the toxic responses measured in the short and long term bioassays. The ability to extrapolate the effects of a chemical substance to all fish from a MATC bioassay of a single species of fish must rest on an understanding of basic physiological processes and responses. Additionally, the effects of mixing two or more toxic substances can be additive, subtractive, or superadditive and the means for predicting these actions has not been developed by toxicologists. A much stronger theoretical base is needed to make the kind of predictions required by PL 94-469. Much time has already been wasted trying to find short cuts for implementing the Act. The purposes of the Act are necessary and desirable and the fish toxicologists should be encouraged to find theoretical explanations for the toxic responses of fish.

DEMANDS ON RESEARCH COMMUNITY

A second Congressional Act in 1976 (PL 94-265), is affecting the national and international management of marine fish resources and making new demands on the research community. The Fishery Conservation zones established by the Act extended national jurisdiction to 200 nautical miles beyond the coastline of a country. Several South American countries (e.g., Peru, Chile, and Brazil) established the principle of extended jurisdiction over fish resources, but after passage of PL 94-265, virtually every country established fishery conservation zones of 200 nautical miles. The fishery conservation zones for the United States encompass an area nearly the size of the contiguous 48 states. The control and protection of fish resources was only one part of a complex act. The Act commits the United States to managing the fishery resources on the basis of an optimum yield concept. Management must be based on the best available scientific information. The concept of optimum yield is still not clearly defined but essentially it permits a safety factor in setting a quota for a fishery and decreases the probability of overfishing.

The most objective means for implementing the Act appear to be the development of models for each fishery. Theoretically, models can incorporate the mass of data available from the commercial catches of fish and provide a means of refining techniques used to set fishing quotas. The most successful fishery models have been deterministic models, but there is an increasing need for stochastically based models. It is certain that the more intensive management required under PL 94-265 will not permit management based upon historical trends.

Trends may be important but the processes causing the trends must be defined and quantified. Hayman (1978) demonstrated that the use of trend data to develop quotas for the Dover sole (*Microstomus pacificus*) would result in the demise of that fishery. Productivity of the fishery was strongly correlated with the rate of upwelling off of the Oregon and Washington coasts. In order to harvest the maximum tonnage of Dover sole, a variable quota based upon updwelling must be set by the fish managers. Variable quotas do not, however, fit into most economic models. A stable source of supply is required to maximize profits in the market place. This conflict between biological production and fish economists means that teams of scientists will be required to develop fishery management models.

One final result of the Act is that the United States cannot try to stockpile their fish resources. The fishery resource in the zone will be managed for exploitation by the United States fishing fleet and foreign fishing fleets. The management needs will clearly dictate the direction of marine fishery research for the next two decades, but we still must have a better understanding of the ecosystems producing the fish and other products of importance.

More thought needs to go into designing experiments that help us to define the limits and productive capacities of natural ecosystems. Warren and Liss (1977) have proposed a tentative basis for designing ecological studies in aquatic ecosystems and more basic research on this ecosystem is needed before developing research projects that do not adequately describe natural ecosystems. Fish are only a small part of the organic products produced by aquatic ecosystems. Forbes' (1925) observation, that one learns very little about fish unless the entire ecosystem is studied, is still true today. Our research will be dictated to a large extent by research funds supplying the needs of fish managers. Management cannot be extended much further without a better understanding of the forces driving ecosystems. Forbes' (1925) observations on the need to study the entire aquatic ecosystem are still appropriate. Fishery research may be dictated by management needs but real advances can only come from an increased understanding of the dynamics of an ecosystem.

LITERATURE CITED

Forbes, Stephen A., 1925. The lake as a microcosm. Illinois Natural History Survey Bulletin. 15:537-550.

Hayman, Robert August. 1978. Environmental fluctuation and cohort strength of Dover sole (Microstomus pacificus) and English sole (paraphrys vetulus) in an area off the Columbia River. M.S. Thesis. Oregon State University, 78 p.

Mount, D. I., 1977. An assessment of application factors in aquatic toxicology in: Symposium on Recent Advances in Fish Toxicology. U. S. Environmental Protection Agency. Ecological Series. EPA 600/3-77-085. 183-190 p.

Warren, Charles E. and William J. Liss. 1977. Design and evaluation of laboratory ecological system studies. U. S. Environmental Protection Agency. Ecological Series. EPA - 600/3-77-022. 115 pp.

Presented October 19, 1978 by MOYLE E. HARWARD, Department of Soil Science, Oregon State University.

Erosion and Sedimentation on Agricultural Lands

SCOPE OF SEMINAR

Primary emphasis in this discussion is on erosion and sediments from agricultural lands. Specifically, we will be talking about the situation in the high lands winter rainfall zone of the Pacific Northwest (area west of the Cascades). However, one of the purposes of this seminar series is to focus on unifying topics and to present some general concepts. In the broad sense, we are dealing with soil-water relationships to non-point sources of pollution. There are some processes common to erosion, septic tank effluents, and mass movement (landscape stability) and these will be illustrated.

BACKGROUND ON EROSION STUDIES

Present Status:

A few decades ago there was considerable interest in agricultural practices in relation to wind and water erosion where emphasis was on conservation of the resource. Present concern is on water quality as evidenced by PL92-500 and section 208 dealing with non-point sources of pollution (NPSP). This has resulted in renewed interest in erosion. However, a new dimension has been added in that the bottom line is water quality. Erosion studies per se are not enough; we have to relate this to sediment transport.

Most of the research on erosion has been in the Midwest and eastern U.S. Much less has been done on agricultural lands in the northwest. There has been some work in the Palouse Country of Washington, but little or no attention in Oregon. Until recently it was not recognized as a major or priority problem. However, arguments about the magnitude of problems here relative to other areas is a mute question. All states are concerned with section 208, PL92-500 dealing with NPSP

There is ample evidence that we do have erosion problems in this region. It is possible that we may be seeing increased rates of erosion as a result of changes in land use and management practices. Regulation of grass field burning has resulted in some shift from grass to grain on the hill soils surrounding the valley. In an effort to solve an air quality problem, we may have increased the problem of sediments and water quality. The questions arises as to whether or not this is an acceptable trade-off. Effects of sediments and decreased water quality may be longer lasting and more difficult to control than temporary problems of air pollution. Nevertheless, it is clear that we have erosion-sediment problems which need attention.

Increased awareness and concern by farmers working through commodity groups and resource organizations, such as the Wheat League, and Soil and Water Conservation Districts, resulted in a regional research effort on erosion. They provided the stimulus and, importantly, were successful in securing funds to develop the program. The total program known as STEEP (Solutions to Environmental and Economic Problems) is broad and includes all factors which affect erosion. The 5 major areas include; (1) tillage and management, (2) plant design, (3) erosion and runoff prediction, (4) pest management, and (5) economics. The Oregon responsibilities specifically are on erosion and runoff prediction for the high winter rainfall zone of the Pacific Northwest (west of Cascades). This seminar will focus on investigations of erosion and sediment transport in an agricultural watershed on the hill soils which surround the Willamette Valley.

USLE: Use and Limitations

The Universal Soil Loss Equation (USLE) is often taken as a starting or focal point in erosion studies (Wischmeier et al., 1971). The equation has the form

$$A = RKLSCP$$

where:
A is predicted soil loss (T/A),
R is a rainfall factor,
K is a soil erodibility factor,
L is slope length,
S is steepness,
C is the cover or cropping factor, and
P is the erosion control practice factor.

The equation was derived and calibrated using a large amount of data, largely from the Midwest and eastern U.S. The USLE provides a means for evaluating the effect of cultural practices on erosion. Accordingly, it is a tool used by the U.S. Soil Conservation Service to aid decisions on the need and design for specific management practices (SCS, 1976). Properly calibrated and used, it serves a useful purpose. Unfortunately, its limitations are not always understood and it is sometimes misused (Wischmeier, 1976).

Some of the limitations of the USLE are important because of the conditions we have in our area.

1. The equation has not been adequately calibrated for our area.

2. The R factor deals with intensities or energies of rainfall. This is important in the Midwest and East which have rainfall more evenly distributed over the year and where convective type storms are important. Our area is characterized by prolonged winter rainfall periods with gentle or moderate intensities with some more intense storms. The R factor does not take into account the antecedent moisture, i.e., the prior rainfall and levels of soil moisture at the onset of a given storm.

3. The K factor on soil erodibility is measured with standard plots under a specified set of conditions. More often it is estimated on the basis of % clay, % organic matter, structure class, and permeability class. Particularly important, the K factor applies to the surface soil and does not take into account the presence or influence of subsurface restrictive layers.

4. The equation assumes a uniform slope. It does not take topographic position into account.

5. The equation relates only to detachment and is not intended to provide information on amounts which get into streams. It should be emphasized that equating erosion estimates from the USLE to stream sediments is not justified.

Unfortunately, some of the limitations of the USLE involve the very systems with which we have to work. The soils of western Oregon tend to be fine textured and frequently have restrictive layers of clay or rock. The Pacific Northwest is the only region in the U.S. with high winter rainfall and dry summers. Much of the rainfall is slow to moderate in intensity and storms with higher intensities tend to occur after periods of moderate rainfall rates. As a result of this soil-weather interaction, perched water tables develop even on hill slopes. Lateral downslope subsurface flow occurs at fairly high rates. This water tends to surface in downslope positions. These properties and processes are expected to have an influence on erosion and on transport of pollutants.

INVESTIGATIONS ON AN AGRICULTURAL WATERSHED

Objectives:

In view of the background outlined above, three objectives were selected. The first problem was to identify the factors which predominately affect overland flow and, therefore, erosion. This essentially involves identification and quantification of interactions of soil properties and weather. The second question is, once overland flow and erosion occur, how much sediment gets into the stream. This involves elucidation of the factors and processes involving sediment transport through the hydrologic system. The third objective deals with applications to management practices once the factors and processes are understood.

Study Area and Procedures:

The watershed selected for major emphasis in the study is typical of the hill soils surrounding the Willamette Valley. It is in private ownership and much of it is in annual cropping to grass seed or grain. The investigations are designed to fit existing and usual practices of the operator. Seedbed preparation, fertilizing, seeding, and harvesting are done by the farmer and we have enjoyed excellent cooperation with them. Equipment for monitoring and sampling runoff and sediments are installed in the fall after seeding and prior to initiation of fall or winter rains. All equipment is removed in the summer prior to harvest. The information obtained in this manner represents "real world" situations and reflects current practices in the region.

The total watershed is approximately 260 ha in size. A nested watershed approach is being utilized. Gross erosion is being evaluated from measurement of runoff volumes and sediment concentrations from erosions plots installed on different soils and topographic positions. Net erosion is obtained from flow volumes and sediments passing through flumes on subwatersheds and a culvert at the main outlet.

Other data being obtained include geomorphic maps, detailed soil maps, topographic maps at 5 ft. contour intervals, moisture contents as a function of depth by use of tensiometers and a neutron probe, depths to perched water tables and piezometric pressures, in situ and laboratory determinations of saturated and unsaturated hydraulic conductivities, infiltration, density of soil horizons, and continuous record of rainfall in 0.01 inch increments. This information is intended to provide a measure of both subsurface flow (interflow) and overland flow in response to soil properties and weather, including antecedent moisture. The observed phenomena will then be related to amount of erosion and movement of sediments through the hydrologic system.

Factors Affecting Runoff and Erosion:

Nature of Soils

Geomorphic studies revealed discontinuities in soil profiles on the watershed (Glasmann, 1979). Younger silty materials overlie paleosols developed on sedimentary rock. Textures of the underlying Spencer Formation and its associated soils range from sandy loam to clay. The overlying younger sediments are almost uniformly silt loam. The silt cap exists up to elevations of about 122 m (400 ft). Above this, the surface soils are developed from the Spencer Formation or other local parent materials.

This presence of multilayered soils on the watershed affects erosion and sediment yields in two ways. Differences in hydraulic properties between the younger sediments and the more highly weathered components in lower horizons influence the build-up of perched water tables. As the perched water table and the associated "capillary fringe" approach the soil surface, runoff increases. It will be shown later that the saturated zones tend to be greater and persist longer in lower slope positions than in upper slope positions. The second effect is the nature of the surface materials themselves. These silty materials do not have large cohesive forces to hold the particles together and they tend to have poor structure, exhibit crusting and are susceptible to erosion.

Effect of Soils and Landscapes Position on Gross Erosion and Runoff

The amount of erosion per unit area varies with the soil, the landscape position, and rainfall (Table 1). Of particular interest are the relationships between these factors. By far, the greatest amount of erosion occurred with the most intense storm during the period December 12 to 16. The most striking aspect of the data is the difference between upper and lower slope positions. In all cases, the plots in lower positions exhibited greater erosion than plots in upper slope positions. Slope lengths were the same in all plots with borders installed so that the runoff area was constant. For watershed E1, the slope of the lower plot was only 0.2% greater than the upper one. For watershed E4, the slope of the upper plot was slightly (0.6%) greater than the lower one. Therefore, differences in erosion cannot be accounted for by differences in slope. There are differences in the soils on watershed E1. The Dupee soil of the lower plot is less well drained than the upper Willakenzie soil. However, the soil series for the plots on watershed E4 were the same. Clearly, the differences in erosion relate primarily to position on the landscape.

Differences between soils and landscape position are also reflected in the total volume of runoff (Table 2). In all cases except one, the runoff from plots in lower landscape positions was greater than that from upper landscape positions. For each watershed, the total runoff from the upper plot was approximately 40% of that for the lower plot. This is approximately the same order of magnitude for difference in gross erosion (Table 1). There is one other aspect of the data which is of interest. Erosion and runoff roughly correlate with each other, especially during the more intense storms. However, the correlation is not always direct or complete. For the lower plot (M2) on watershed E1, the storm of December 12-16 resulted in a sediment yield of 3,000 kg/ha. For the storm period of December 16-January 6, the sediment yield decreased to 640 kg/ha. The earlier storm period had higher intensities and greater total rainfall. The volumes of runoff, however, for these two storm periods were of the same orders of magnitude. Plot E1M2 maintains a high base flow. This is due to the nature of the soil and the landscape position. Plot E1M2 is on the Dupee soil which occurs near the base of the slopes and the drainage channels. Water tends to surface in these topographic positions and this is reflected in the volumes of runoff.

Perched Water Tables

Previous work on suitability of soils for septic tank drainfields demonstrated the importance of perched water tables on hill soils (Hammermeister, 1978; Rahe et al., 1978). The data presented above suggest that perched water tables on agicultural hill soils also affect erosion and runoff. The development and occurrence of perched water tables is illustrated by piezometric pressures on subwatershed E4 during the storm period of December 12-16 (Table 3). At the beginning of this storm period, water tables already existed on the hill slopes due to the influence of previous rainfall. For the upper slope position, the piezometric pressures were 0 for the piezometer installed at the 140 cm depth, while they were positive for the 72 cm depth. Therefore, the restrictive layer occurs between 72 and 140 cm. The restrictive layer is closer to the surface at the lower slope position and occurs between 51 and 86 cm.

For the upper slope, the piezometric pressures in the 2 upper horizons fluctuate in response to rainfall. The pressures gradually increase with time for the 72 cm depth which indicates a build-up of the perched water table. In the case of the lower slope positions, the piezometric pressures at the 18 and 51 cm depths are sufficient to bring the water table to the soil surface. The data clearly suggest the build-up of perched water tables and subsurface movement of water. There is some movement down through the profile plus downslope movement above the restrictive layer. The saturation of the profile in the lower slope position is due to both subsurface movement from upslope plus a decrease in depth to the restrictive layer. These in turn result in greater runoff and erosion from lower slope positions as previously shown.

Prior Storm Patterns and Water Discharge

Runoff and sediment passing through flumes provides a measure of "net erosion". The occurrence and nature of the hydrographs depends not only on the nature of the watershed (soil and landscapes) and storm intensities, but also on the antecedent moisture. This also is related to saturation of the profile and development of perched water tables. A storm on November 23, 1977 resulted in 23 mm of precipitation during a 5 hour period. Maximum intensities of 3 mm/15 minutes were observed (Figure 1). This storm produced no runoff from one of the subwatersheds. Yet, on this same watershed, comparable sized storms with slightly less intensities (2mm/15min.) on December 11, 1977 and on January 5, 1978 both resulted in runoff and transport of sediment (Figures 3 and 5).

Two relationships are of interest. Once conditions are favorable for runoff, the hydrographs show a very rapid response. Precipitation, flow (Q in l/sec) and sediment load (G in gm/sec) closely superimpose. Once rainfall decreases or stops, the flow quickly drops off. The advent of another shower shows an almost instantaneous response in flow. The other relationship involves the prior storm patterns and their effect on saturation of the profile and development of perched water tables. For the storm on November 23 when no runoff occurred, the amount of perching was low (Figure 2). For the later storms on December 11 and January 5, the levels of perched water tables were at or near the surface (Figures 4 and 6). This is especially true for the lower topographic positions. These data illustrate the nature of the soil-weather interactions which are important to this region. The effect of antecedent moisture on runoff and erosion is one of the major differences between the high winter rainfall zone of the Pacific Northwest and the Midwest which is characterized by summer convective storms.

Changes with Time

The behavior of the watershed changes with time during the rainfall season. Whereas the early runoff events tend to coincide with saturation of the profile, runoff in later storms may occur when saturated zones are not at the surface. The 0.4 ha watershed exhibited runoff during the storm of January 5 even though the perched water tables were not at the surface (Figures 7 and 8). This may be compared to the 1.4 ha watershed in this same data (Figures 5 and 6). It is possible that in the 0.4 ha watershed the "capillary fringe" was close to the surface in the lower landscape position. However, it was observed during the storm that some runoff was occuring on all parts of this watershed. This, along with observations on the nature of the soil surface, suggests the increasing importance of compaction and crusting as the season progresses.

As the soil settles and aggregates are dispersed by raindrop impact, infiltration may become a limiting factor. Consequently, infiltration studies are being made during the current (1978-79) winter season. The preliminary data indicate that, indeed infiltration does increase with time (Figure 9) on these soils. Water from the infiltrometer was added at a fairly high rate of about 7.2 cm/hr. This is in excess of the storm intensities normally observed in this area. For the test on October 18, the soil accepted the added water at the rate applied for 18 minutes. Although there was a slight decrease in the rate of infiltration after that time, continued infiltration was still high. For tests in November and December, the rates of infiltration were lower than previously. This was manifested in the amount of time before infiltration started to drop as well as the decreasing rate of infiltration.

Present Concepts of the Erosion Process

Agricultural watersheds on the foothills surrounding the Willamette Valley are dynamic; their behavior changes with time. Following cultivation and seeding in the fall, the surface soils are well structured, porous and friable. Infiltration capacity is not limiting. There is a strong effect of antecedent moisture. The effect of early sotrms is in saturation of the profile. Initiation of runoff tends to coincide with development of perched water tables where the "capillary fringe" is at or near the surface.

There is a significant amount of lateral downslope subsurface flow. This water tends to surface in lower landscape positions. Runoff and erosion are greater in toeslope positions than in upper topographic positions. As the winter season progresses, the more intense storms tend to settle the soil and disperse the aggregates due to raindrop impact. The increase in compaction and crusting result in a decrease in infiltration. Thus infiltration becomes increasingly important as the season progresses.

Implications to Management:

We are well along to understanding some of the factors which influence erosion and sediment transport under our regional soil-weather conditions. Because of differences in weather patterns from one year to the next, we need additional data which will permit us to separate the effects of average from unusually large storm events. In the meantime, our research suggests a number of alternatives in management practices which need to be evaluated. These include:

1. Tiling to reduce the influence of perched water tables on runoff and erosion. Consider tiling from the standpoint of water quality rather than just an effect on crop production.

2. Buffer strips to act as sediment traps.

3. Grass waterways.

4. Drop structures in stream channels.

5. Sediment basins in streams or at the end of drainage channels.

By integrating our information on the nature of soils and landscape positions with work done elsewhere, the effects of the last four can be reasonably anticipated. The first alternative on tiling is more distinctive for our regional soil-weather conditions and should receive priority for future research.

RELATION OF PERCHED WATER TABLES TO OTHER ENVIRONMENTAL PROBLEMS

There are some common denominators between erosion, movement of pollutants from septic tank drainfields, and processes of mass movement on unstable landscapes. In all three cases, we are dealing with interactions of profile morphology and weather with respect to perched water tables and subsurface flow of water.

Recent studies on suitability of soils for installation of septic tank drainfields have demonstrated by the improtance of subsurface flow (Hammermeister, 1978; Rahe et al., 1978). The combination of restrictive layers in the soil profile and a high winter rainfall season results in the development of perched water tables. When the moisture content increases to the point where water enters the large pores and cracks, downslope movement becomes very rapid. Rates in excess of 15 meters/hr have been measured using tracer-salts and "tagged" coliform organisms. This water and any pollutants which it carries tend to surface in downslope positions.

The central portion of the Western Cascades in Oregon is characterized by landscape instability. Large slumps and earth flows are common, especially in a zone near the contact between the Little Butte Volcanic Series and the Sardine Formation. Examination of a large number of sites revealed common factors associated with mass movement (Taskey et al., 1979). Deposits of weathered basaltic colluvium and volcanic ash overlie highly weathered montmorillonite-rich tuffs and breccias. The montmorillonite layer is highly cohesive and supports a perched water table. Amorphous gels and hydrated halloysite exist above the montmorillonite and their presence helps to maintain saturated conditions due to their high water holding capacities. The amorphous gels and hydrated halloysite tend to release water upon disturbance and are associated with flowage-type failures.

In all three of the environmental problems involving non-point sources of pollution, perched water tables and subsurface flow of water are very important. These situations exist because of the interrelationships of soil properties and weather in our climatic zone. It is easy to appreciate the importance of soil morphology and soil physics to environmental problems.

REFERENCES

Glasmann, J. R. 1979. The geomorphology and stratigraphy of Elkins Road Watershed. M. S. Thesis, Oregon State University, Corvallis.

Hammermeister, D. 1978. Water and anion movement in selected soils of western Oregon. Ph.D. Thesis, Oregon State University, Corvallis.

Rahe, T. M., C. Hagedorn, E. L. McCoy, and G. F. Kling. 1978. Transport of antibiotic-resistant Escherichia coli through western Oregon hillslope soils. Jour. Envir. Qual. 7:487-494.

Soil Conservation Service. 1976. Universal Soil Lars Equation: Oregon. U. S. Dep. Agric., Soil Conservation Service, Portland, Oregon.

Taskey, R. D., M. E. Harward, and C. T. Youngberg. 1979. Relationship of clay mineralogy to landscape stability. In: Proceedings of Fifth North American Forest Soils Conference. Ft. Collins, Colorado. C. T. Youngberg, ed. (In press).

Wischmeier, W. H. 1976. Use and misuse of the Universal Soil Loss Equation. Jour. of Soil and Water Conser. 31:5-9.

Wischmeier, W. H., C. B. Johnson, and B. V. Cross. 1971. A soil erodibility monograph for farmland and construction sites. Jour. Soil and Water Conser. 26:___.

Table 1. Effect of soil* and landscape position on gross erosion from plots in 1977-78.

Storm period	Rainfall		Subwatershed E1		Subwatershed E4	
	Total for period	Maximum intensity	Upperslope M1	Lowerslope M2	Upperslope M1	Lowerslope M2
	mm	mm/15 min	- - - - - - -	- - kg/ha - -	- - - - - - -	- - - - - - -
Nov. 22-28, 1977	144	4.3	600	890	---	---
Nov. 28-Dec. 5	43	1.5	80	270	---	140
Dec. 5-12	66	2.8	---	880	270	510
Dec. 12-16	130	5.3	1,240	3,000	2,460	6,780
Dec. 16-Jan. 6, 1978	97	2.0	480	640	110	120
Jan. 6-19	96	1.3	60	320	10	90
Jan. 19-Feb. 3	61	3.0	70	290	90	100
Feb. 3-16	47	1.0	70	440	30	410

*Soils:

Subwatershed E1 -

Plot M1: Willakenzie silt loam, moderately well drained variant. Slope 6.3%.
Plot M2: Dupee silt loam, fine-silty variant. Slope 6.5%.

Subwatershed E4 -

Plots M1 and M2: Willakenzie silt loam, fine, moderately well drained variant. Slopes 8.3 and 7.7%, respectively.

Table 2. Effect of soil and landscape position on runoff from plots in 1977-78.

Storm period	Rainfall		Subwatershed E1		Subwatershed E4	
	Total for period	Maximum intensity	Upperslope M1	Lowerslope M2	Upperslope M1	Lowerslope M2
	mm	mm/15 min	- - - - - - -	- - - kl/ha	- - -	- - - - - - -
Nov. 22-28, 1977	144	4.3	215	368	---	---
Nov. 28-Dec. 5	43	1.5	78	267	---	---
Dec. 5-12	66	2.8	152	609	35	54
Dec. 12-16	130	5.3	313	772	286	507
Dec. 16-Jan. 6, 1978	97	2.0	358	830	30	62
Jan. 6-19	96	1.3	174	410	33	58
Jan. 19-Feb. 3	61	3.0	13	102	21	21
Feb. 3-16	47	1.0	21	291	73	379
			1,324	3,649	478	1,081

Table 3. Maximum piezometric pressure (cm) of perched water tables in relation to landscape position and rainfall for subwatershed E4.

Date	Rainfall	Depth of piezometers						
		Upperslope				Lowerslope		
		17	48	72	140	18	51	86
	mm	cm						
Dec. 11	34	9.5	37.0	52.0	0	18.0	53.0	0
Dec. 12	9	8.0	35.0	52.5	0	18.6	51.5	0
Dec. 13	44	11.0	39.5	57.0	0	18.0	54.0	0
Dec. 14	16	10.5	38.5	58.1	0	18.5	53.5	2.4
Dec. 15	59	11.5	38.5	61.0	0	18.5	54.0	3.5
Dec. 16	11	10.5	37.5	61.0	0	17.5	53.5	5.0

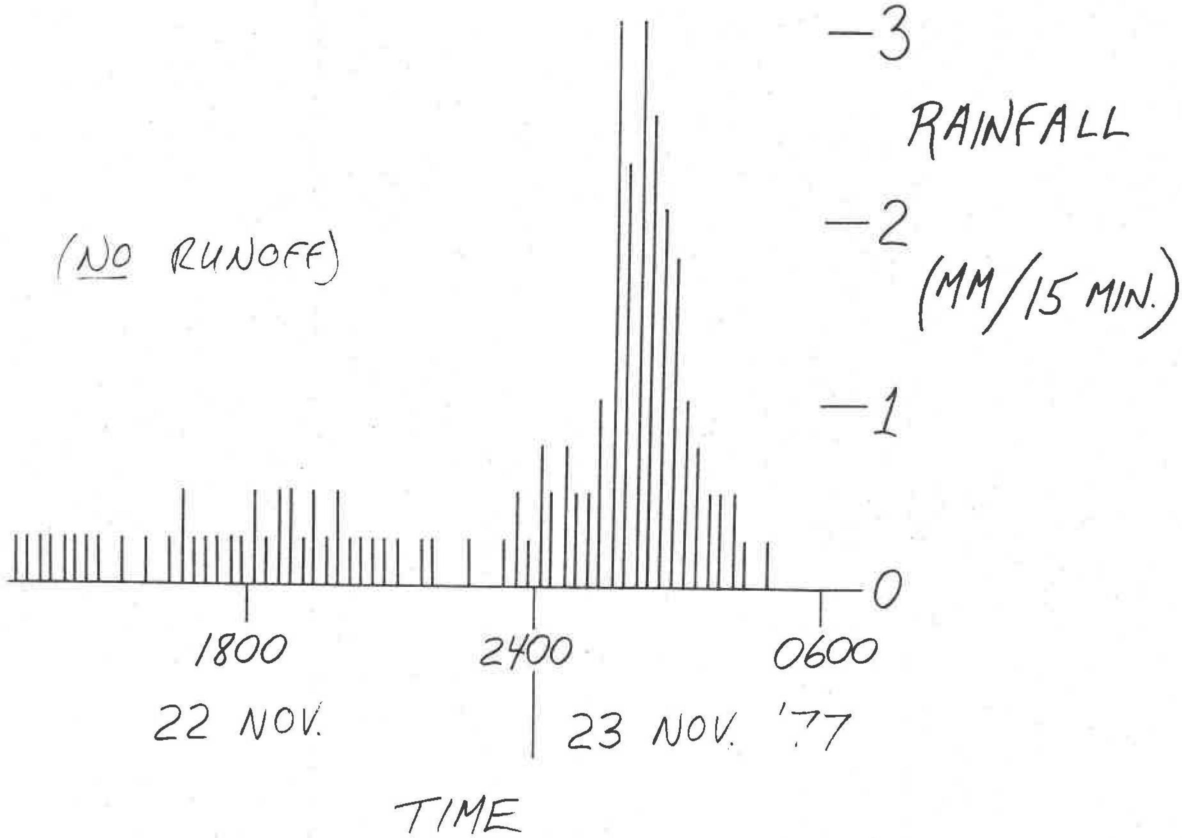


Figure 1. Rainfall at the Elkins Road watershed on November 23, 1977.

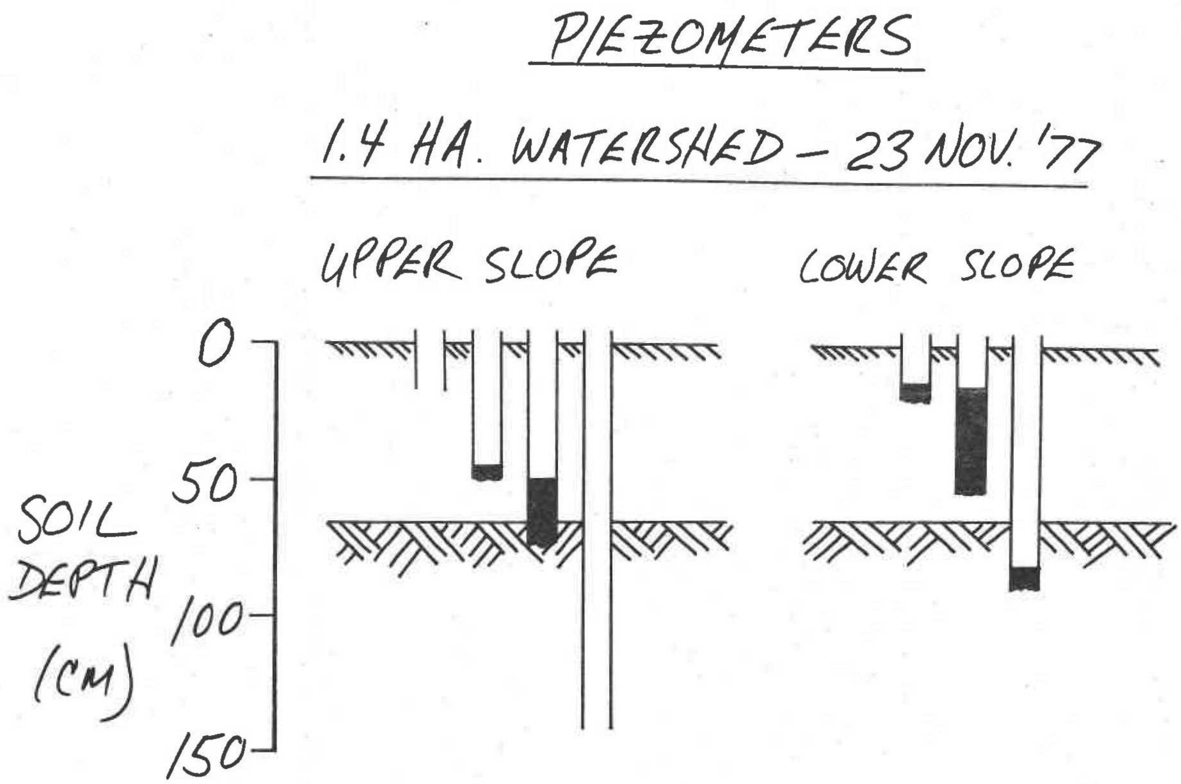


Figure 2. Status of perched water tables for the 1.4 ha watershed on November 23, 1977.

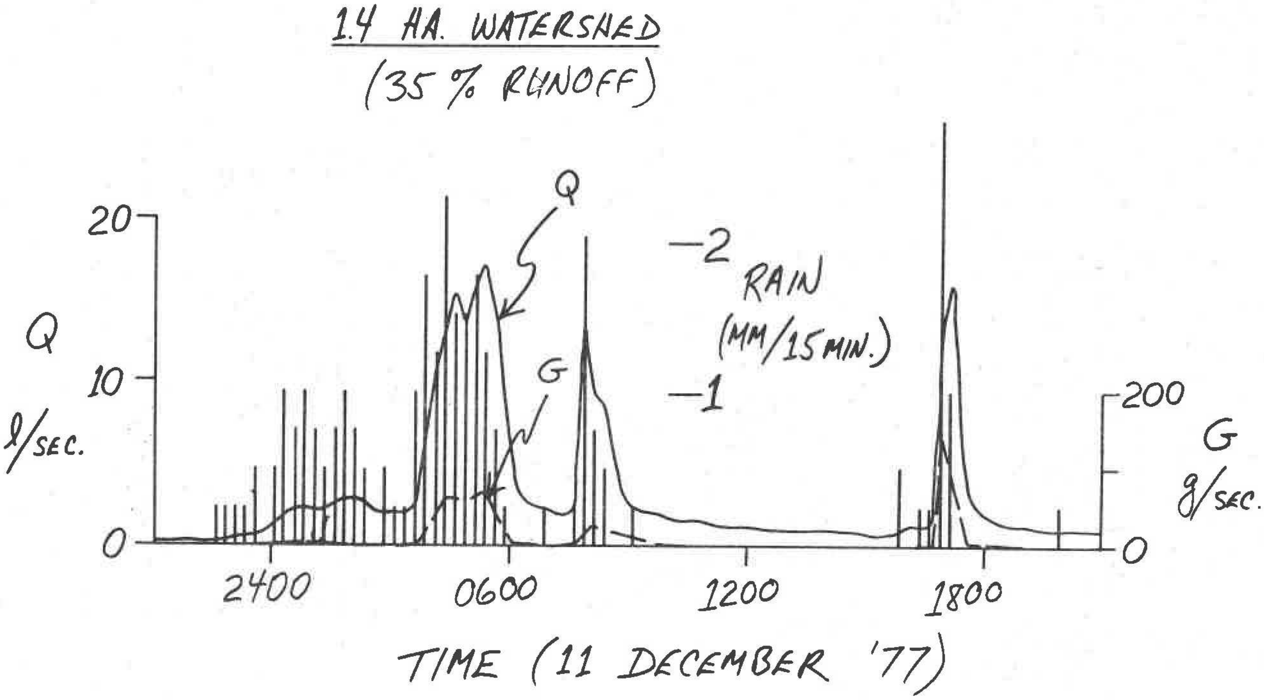


Figure 3. Hydrographs for 1.4 ha watershed in relation to rainfall for the storm on December 11, 1977.

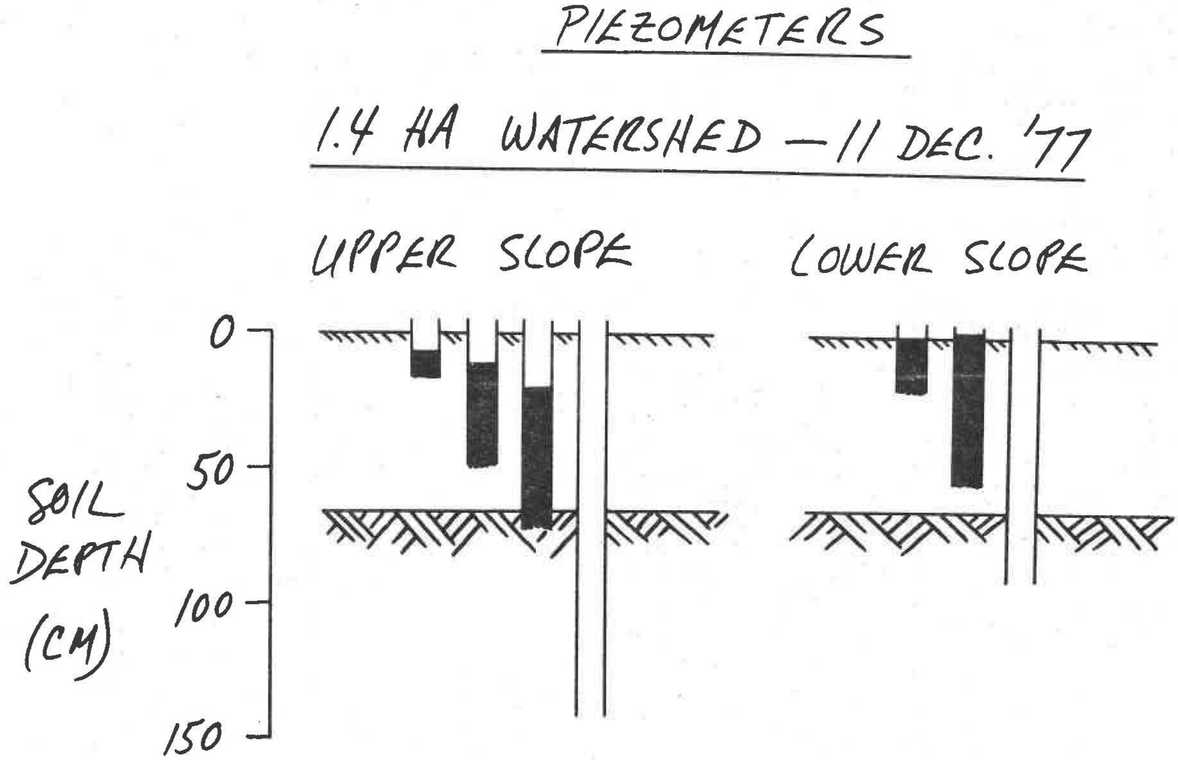


Figure 4. Status of perched water tables for 1.4 ha watershed on December 11, 1977.

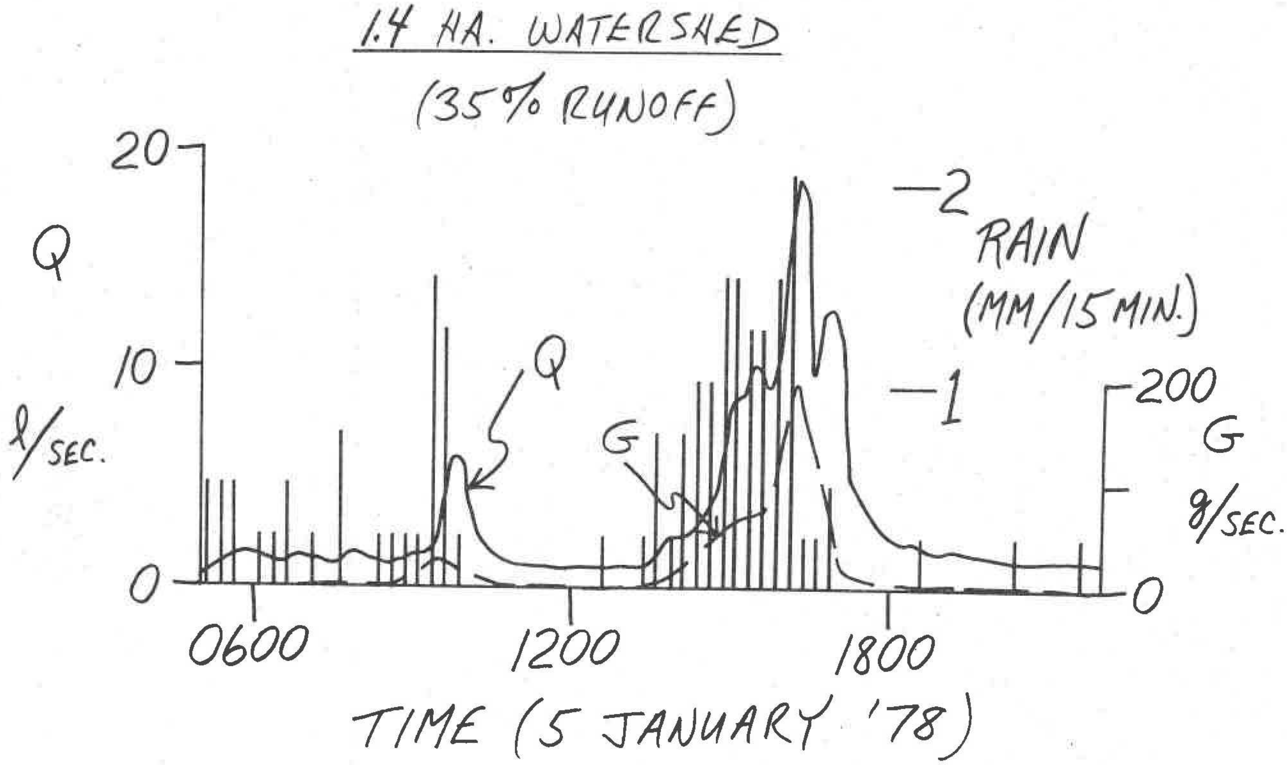


Figure 5. Hydrograph for 1.4 ha watershed in relation to rainfall for the storm on January 5, 1978.

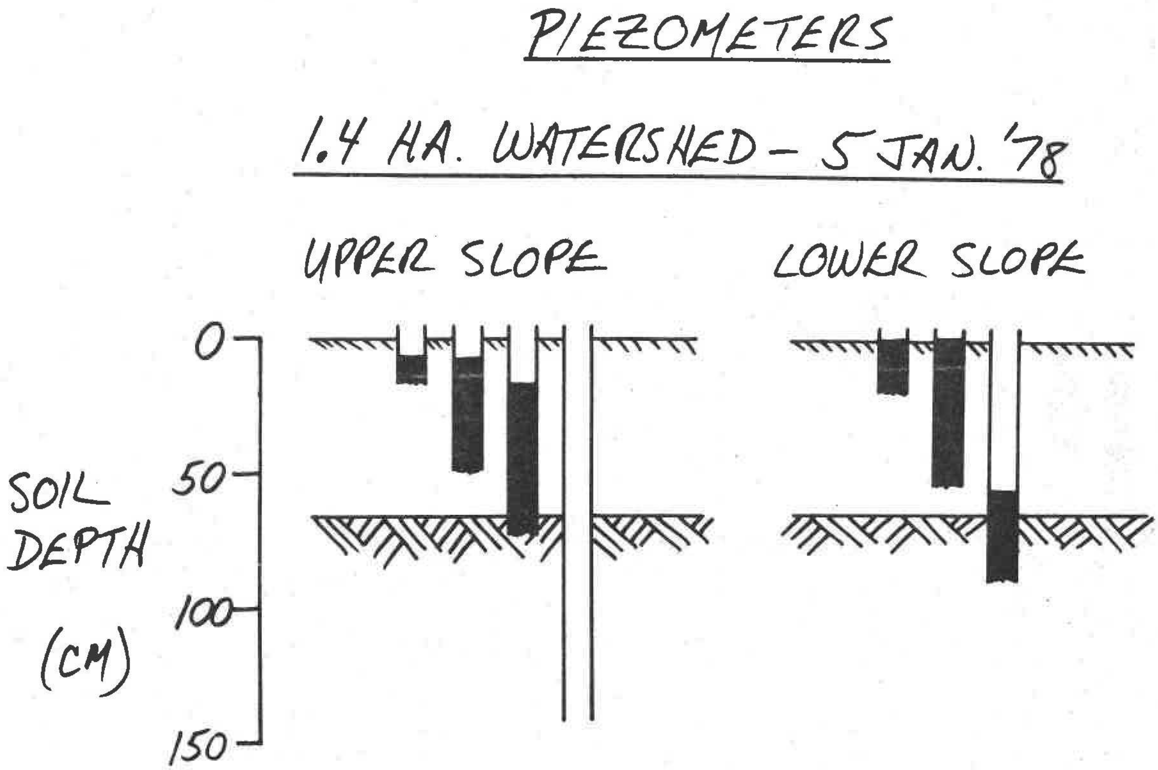


Figure 6. Status of perched water tables for 1.4 ha watershed on January 5, 1978.

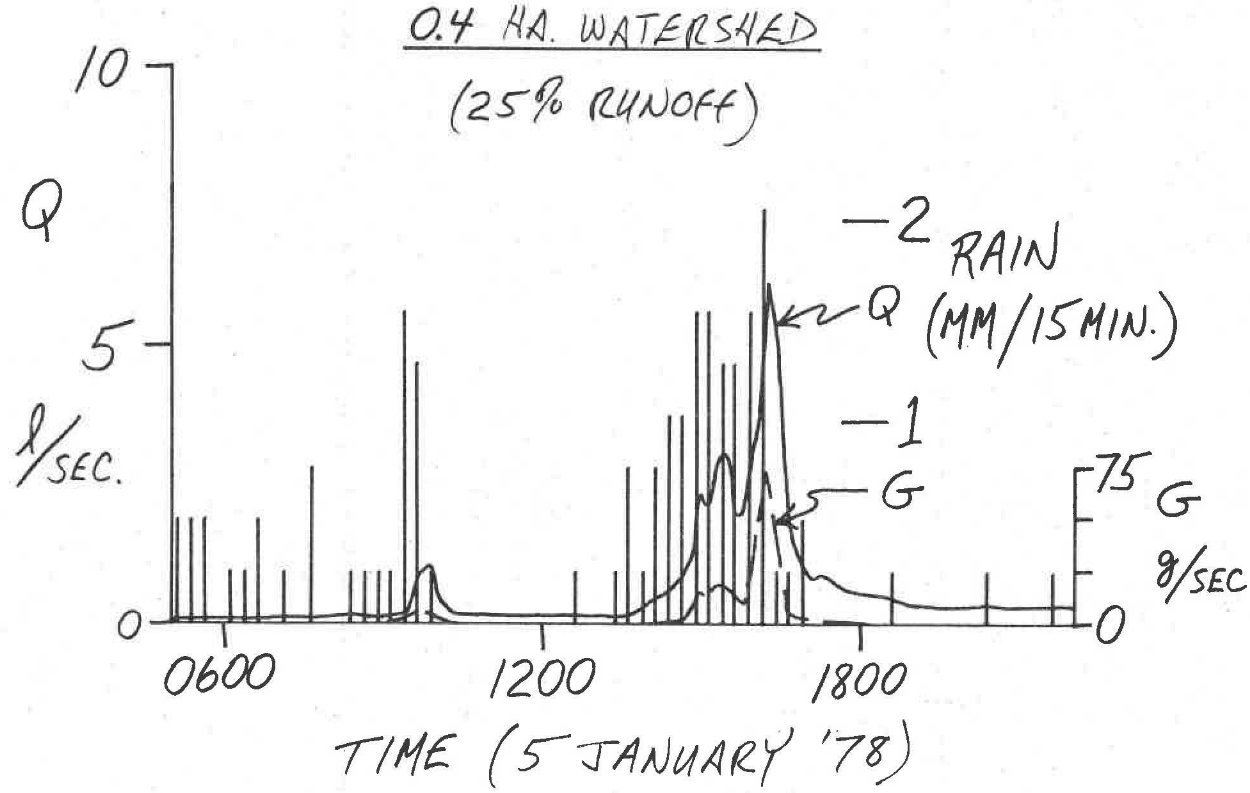


Figure 7. Hydrograph for 0.4 ha watershed in relation to rainfall for the storm on January 5, 1978.

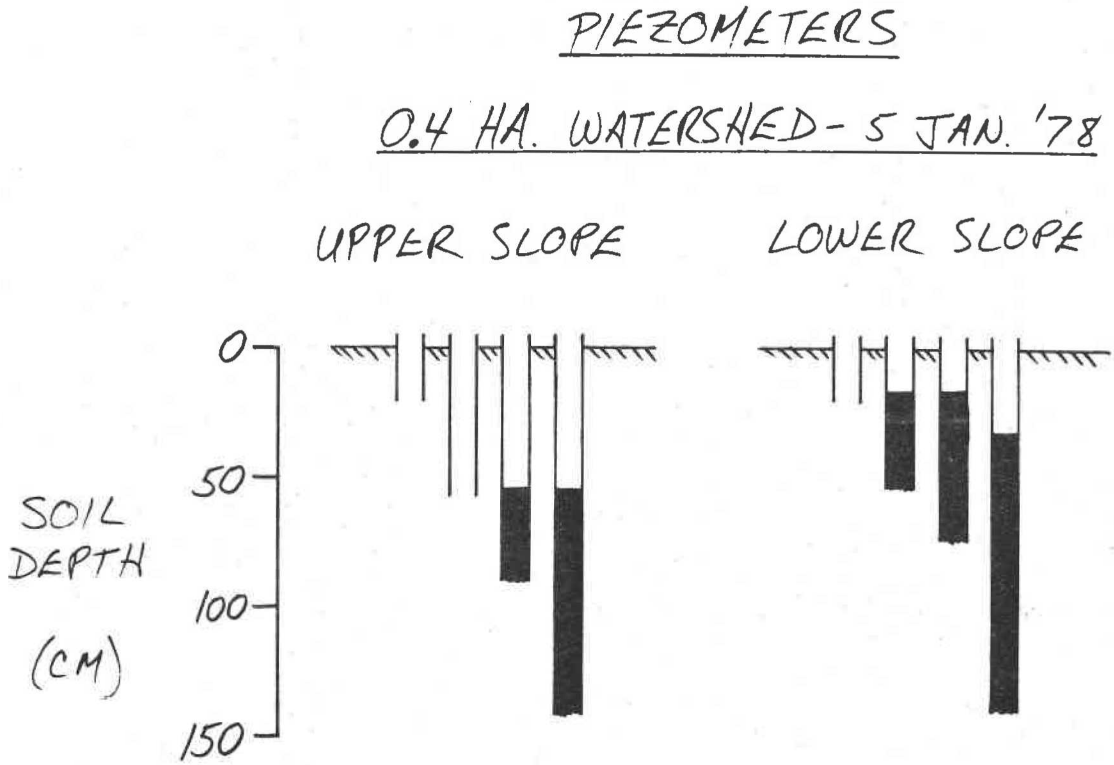


Figure 8. Status of perched water tables for 0.4 ha watershed on January 5, 1978.

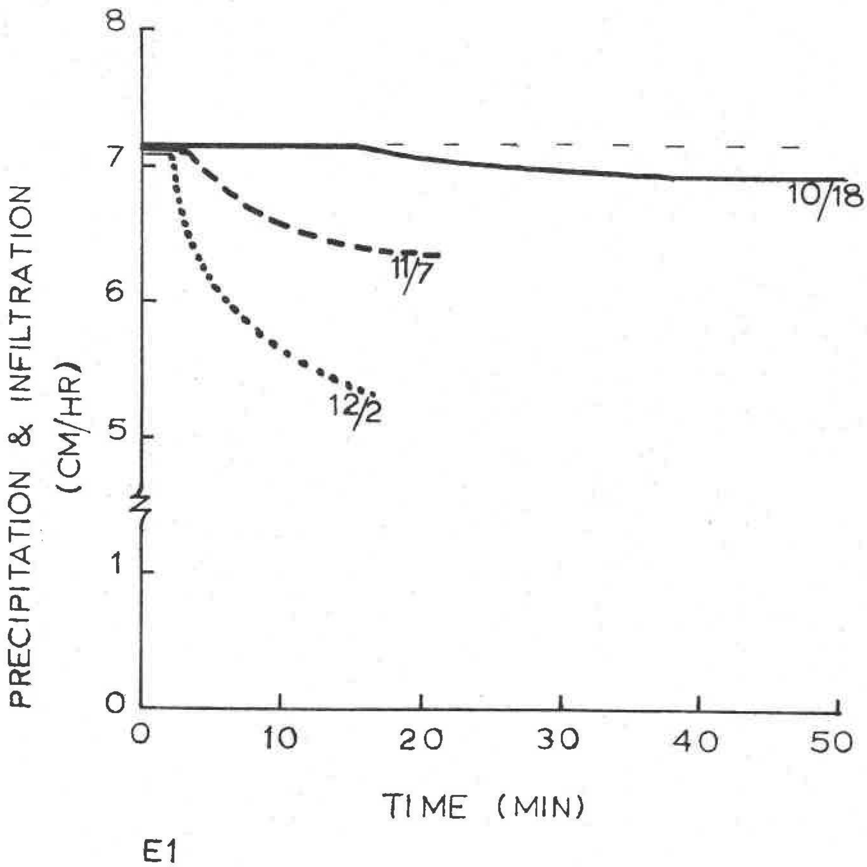


Figure 9. Changes in rate of infiltration with time.

Presented October 26, 1978 by MARVIN N. SHEARER, Department of Agricultural Engineering, Oregon State University.

Towards More Efficient Irrigation

Today's presentation is organized as a response to five questions:

(1) What are we really talking about when we talk about efficient irrigation?

(2) What is the effect of irrigation efficiency on the water supplies?

(3) Why should we be concerned about irrigation efficiency?

(4) What has Oregon State University been doing about it?

(5) What are our pressing problems?

By definition, irrigation efficiency is the ratio of the average depth of water applied to a field and stored, to the average depth of water applied multiplied by 100.

When water is applied to a field, four things can happen to it:

(1) It can be stored in the soil for crop use;

(2) It can be evaporated before it enters the soil;

(3) It can run off the surface of the field so that it never enters the soil;

(4) It can be lost to deep percolation by penetrating into the soil further than the root system of the crop being grown.

Let's look at the three "losses:" evaporation, runoff, and percolation, individually.

EVAPORATION

Two general classifications of irrigation methods are surface methods and sprinkler methods. Very little water is lost by evaporation with surface irrigation as there is little water surface in contact with the atmosphere outside the cropped area. On the other hand, with sprinkler systems, small droplets are sprayed through the atmosphere and evaporation may range from 0-35 percent of the water leaving the sprinkler nozzle. Usually, however, evaporation losses are about 10-15 percent for medium sized sprinklers. Many researchers feel that evaporation should not be treated entirely as a loss because it reduces crop consumptive use in the area that the evaporation occurs.

RUN-OFF

No water should be lost as runoff from sprinkler irrigation. Occasionally, however, we find that some will run off the surface of the land when sprinkler systems have been disigned to apply water faster than it can be absorbed by the soil. Surface irrigation systems, however, may have considerable runoff depending upon the management practices of the farmer, the system used, and the topography of the land which he is operating. Runoff from surface systems may vary from 0 to 80 percent.

In general, surface runoff can be limited to about 20 percent and with the addition of pumpback systems it can be reduced to zero. The larger runoff values are usually found in the high elevation wild meadow areas which receive only one irrigation per year and where production is limited by climate. Little expense can be justified for improving irrigation systems under those conditions.

But on the more productive farms, runoff water is reused many times before it finally leaves the farm boundary. It is picked up in ditches at lower elevations. The runoff or tailwater from these fields is picked up and applied to still lower fields, and in turn the tailwater from these fields is reapplied to yet lower fields, and so on through the farm.

If fields at the lowest elevations have pumpback systems they can return any remaining tailwater to the first ditch for reuse and no tailwater will leave the farm. This reuse pattern has been followed by many progressive farmers for many years.

This same use pattern occurs on irrigation projects and throughout river basins. The September-October 1978 issue of "Water Research in Action" makes this observation: "High on-farm or conveyance efficiencies may not always be a desirable objective. Efficient use of return flows and ground water contributions may result in better use of total water supply with less expenditure of other resources." In many river basin systems, inefficient individual and project irrigation systems are required if there is to be adequate water at lower points within the basin.

PERCOLATION

Percolation losses are affected largely by irrigation management practices. However, they are also affected by design of irrigation systems. Surface systems with excessively long runs have greater percolation losses than systems with runs of correct length. But, percolation losses from both surface and sprinkler systems are affected by the inability of the irrigator to uniformly place into the soil the exact amount of water lost through crop use since the last irrigation.

This loss generally ranges from 0-20 percent. The more uniformly the water is applied, the lower the loss. If a grower has a crop which can withstand deficit irrigation with only minor effect on production, percolation losses can be almost eliminated.

These three losses are frequently referred to by writers in popular magazines as wasted water, and contrary to public goals. The term "water loss" is really a misnomer, as both percolating and runoff water eventally finds its way back to streams or is stored as ground water where it can be re-used. It is not lost. The only real water loss that occurs during irrigation is due to evaporation which, as indicated previously, some researchers argue is not a loss.

If irrigation efficiency is a desirable goal, there must be some other reason for it than just to save water. If our primary goal is to save water for use during low flow periods to control minimum flows, we can have much more impact in achieving this goal through the construction of storage dams which can release water and supplement the flow during the dry season. There are many groups at this time, however, who are opposed to reservoir construction for various reasons, but if saving water is their objective, they must go to a reservoir construction to achieve it.

An example of how effective this can be is seen in Oregon's Willamette Valley. There are approximately 27 million acre feet of water flowing down the Willamette River annuallly. Of this amount, roughly 2 million acre feet can be stored in flood control reservoirs. The rest flows to the ocean. Slightly less than 25 percent of the minimum flow at Salem during the summer low flow period can be maintained by natural flow. The remainder comes from reservoir releases.

Then, why be concerned about irrigation efficiency? There are five principal reasons.

(1) Low irrigation efficiency often leads to degradation of water quality.

(2) Low irrigation efficiency often leads to non-crop evapotranspiration which is unavailable for other use.

(3) High irrigation efficiency results in better yields and product quality.

(4) High irrigation efficiency can reduce water delivery costs per unit of product produced.

(5) High irrigation efficiency results in more production per unit of water applied.

What Oregon State University has been doing:

Since irrigation first started in Oregon, the University has been developing information regarding the requirements and use of water on Oregon farm lands. These studies have taken a wide variety of directions and are generally reported in Station bulletins or other research papers. Support for this research at some time or other has come from nearly every department and Branch Experiment Station in Oregon State University's School of Agriculture. The following are a few of the general subjects studied:

(1) Crop production under irrigation agriculture.

a) Crop response

b) Crop use

c) Plant population levels

d) Fertilizer requirements

e) Irrigation scheduling

f) Labor requirements

(2) Surface Irrigation

a) System design specifications

b) Salinity and alkalinity control

c) Methods of water control

d) Factors affecting irrigation efficiency

(3) Sprinkler Irrigation

a) System design specifications

b) Sprinkler distribution patterns

c) Requirements for frost control

d) Soil intake rates

e) Economic studies

f) Requirements for temperature control

g) Chemical applications through systems

(4) Drip Irrigation

a) System design specifications

b) Emitter plugging

c) Filtration techniques

d) Irrigation scheduling techniques

PURSUING PROBLEMS

Two national goals directly related to irrigation efficiency research are clean water and energy conservation. Of particular interest is the fact that these two goals are in direct conflict with one another. Specifically, efforts to insure clean water in streams requires additional energy inputs, and conversely, efforts to reduce energy requirements in most cases results in practices which have a degradation effect on water quality. The problem is to place values on the trade offs between clean water and energy conservation.

The Agricultural Engineering Department at Oregon State University is currently studying energy and water consumption for irrigation in the Northwest. This study has determined the energy, water, and labor requirements for irrigated agriculture in the Pacific Northwest states of Idaho, Oregon and Washington for the year 1975. It is now using alternative scenarios to determine energy, water and labor requirements associated with irrigated crops as they might exist in the years 1985 and 2000 for the three states.

Another program just initiated is concerned with evaluating pumping plant efficiencies and identifying opportunities for energy savings. Many pumping plants have become worn during their many years of operations and need adjustments. Corrective measures, when needed, can usually be made at moderate cost.

Still another study is concerned with the application of low energy closed-type irrigation systems. Here we are looking specifically at opportunities for use of drip irrigation systems in Oregon.

Research results by themselves, however, do not insure acceptance or adoption of practices by people who can benefit from them. Taking research findings to the public is the responsibility of Oregon State University Extension Service. Faculty members of Oregon State University are located in all 36 counties of the State where they conduct informal educational programs using publications, workshops, demonstrations, applied research, individual consultation, mass media, tours and other educational activities.

SUMMARY

At the start of this discussion we were concerned with irrigation efficiency and we asked the question, "Why should we be concerned about it?" We soon found that many of the popular reasons for looking at irrigation efficiency have questionable validity. But we also saw that maximizing irrigation efficiency can provide significant benefits to both the irrigation farmer and the public at large. In a broad sense they can be classified under headings of clean water, energy conservation and more profitable agriculture. It is towards achieving these goals that research and educational activities are directed through the Agricultural Experiment Station and the Cooperative Extension Service of Oregon State University.

REFERENCES

1. Collins, Margaret, "Sprinkler Irrigation Development in Oregon," OSU Agricultural Experiment Station, Special Report 496, February 1978.

2. Currie, J. A., Wolfe, J. W., and Swarner, L. R. "Irrigation Efficiency, Consumptive Use, Certain Soil Characteristics of the North Unit, Deschute Irrigation Project, Oregon. OSU Agricultural Experiment Station, Miscellaneous Paper 72, May 1959.

3. King, L. D., Wensink, R. B., Wolfe, J. W. and Shearer, M. N. "Energy and Water Consumption of Pacific Northwest Irrigation Systems." Project Report, Project No. EY-76-5-06-2227, Tash Agreement No. 25. Prepared for ERDA via Battelle Pacific Northwest Laboratories, Richland, WA, Oregon State University, Corvallis, OR, September 1977.

4. King, L. D., Hellickson, M. L. and Shearer, M. N. "Supplemental Report: Energy and Water Consumption of Pacific Northwest Irrigation Systems." Project Report, Project No. EY-76-5-06-2227, Tash Agreement No. 25. Prepared for ERDA via Battelle Pacific Northwest Laboratories, Richland, WA., Oregon State University, Corvallis, OR, August 1978.

5. Marsh, A. W., Tileston, F. M., and Wolfe, J. W. "Improving Irrigation in Eastern Oregon." OSU Agricultural Experiment Station Bulletin 558, May 1956.

6. Shearer, M. N., Hagood, M., and Larsen, D. "Sprinkler Irrigation in the Pacific Northwest - A Troubleshooter's Guide." PNW 63, OSU, March 1965.

7. Shearer, M. N., "Comparative Efficiency of Irrigation Systems." 1978 Annual Technical Conference Proceedings, The Irrigation Association, Silver Springs, Maryland.

8. Stammers, W. N., "Improvement of Irrigation Practices in the Umatilla Irrigation Project." OSU Agricultural Experiment Station, Special Report 166, December 1963.

9. "Comparison of Sprinkler and Surface Irrigation Methods, Irrigation Block 1, Columbia Basin Project, Washington." A Summary Report for years 1950, 1951, and 1952. U.S. Department of Interior, Bureau of Reclamation, cooperating with State College of Washington, 1953.

10. "Irrigation Efficiency" <u>Water Research In Action</u>. Texas Water Resources Institute, Texas A & M, Volume 3, No. 3, September-October 1978.

Presented November 9, 1978 by THOMAS C. HOGG, Chairman, Department of Anthropology, Oregon State University.

OSU Social Research and Water Resources

I. Introduction

People directly involved in planning or managing water resource development have for years questioned the value and pertinence of social research as it relates to the water resources field. So, too, has the general public. The reasons are many and varied--some are justified, some aren't.

Social research often is not considered necessary because of a general lack of awareness of what it represents, the kinds of explanations it offers, or is capable of offering, and the possible improvements it might provide. Water resource development projects generally are conceived as being proper and beneficial--providing relief from the ravages of floods and the like, increasing economic production, and adding new jobs in the market. Social research appears to do none of these things. Instead, for many people, it appears to be an unnecessary "tag on" that all too often does nothing more than criticize the development to which it owes its existence.

Then, too, the language of the social sciences is erudite. Expressions normally are verbose or out of ordinary usage and findings commonly are thought to be nothing more than the obvious. The combination of all these factors customarily leads to the conclusion that social research, whether in relation to water projects or slum renewal, is either impertinent, wasteful, or disruptive to progress.

II. The National Context for Social Research in the Water Resources Field

Recent years have brought more credibility to social research especially in the water resource field. This has come in part out of an increased public awareness that matters of life quality and social well-being are significant factors in any inquiry on development. The humanitarian interests of the late 1960's and the environmental movement of the late 1960's and early 1970's heightened public concern for planning for people and attempting to improve their quality of life and social well-being. Legislation of the 1960's and 1970's followed suit and required public agencies to adopt research programs to evaluate the "overall" effects of their developmental programs, including the social parameters of such development.

Shortly after the passage of the National Environmental Protection Act, different federal agencies each developed separate guidelines for social research, and social impact assessment lacked direction. Most important in attempting to correct this problem was the Water Resource Council's "Principles and Standards" (volume 38, no. 174 of the Federal Register, 1973). This document attempted to unify objectives of all federal agencies, especially with regard to assessing project impacts on the quality of life and social well-being of related population.

Solomon identifies over 50 different methodologies for social impact assessment that have hit the literature since 1964. No one approach is generally accepted, but a number of those available could substantially improve assessments (Solomon et al 1977).

Outside of the required social assessments just mentioned, social research in the past five years has diminished in the water resource field. The economic crunch and inflation associated with the energy crisis since the early 1970's has again fixated people on jobs and income levels. Social research on water problems, especially basis research, correspondingly has taken on a back seat role, with many of the same old questions being raised as to its pertinence and justification.

III. Water Related Social Research at OSU

It is precisely in this context that social research in the water related field has developed at Oregon State University. The collective results of research are disjunctive and lack integration. Basic research seems to be a thing of the past; applied work has taken precedence, with customary sources of basic support virtually drying up because priorities have changed.

Little in the way of any social research was accomplished at OSU prior to 1963, except for work in economics, especially agricultural economics. Some of the very first social research at the University was in the water resources field, however.

In 1965, the Agricultural Experiment Stateion embarked on a limited experimental program that expanded through 1967 and received extramural funding through the Office of Water Resources Research (OWRR) and the Water Resources Research Institute at OSU (1968-72). This activity stimulated a number of other investigations from diverse fields such as geography, political science, anthropology, business, and sociology and provided a new base of expertise among certain members of the faculty of the then School of Humanities and Social Sciences. The Water Resources Research Institute itself sponsored small programs in geography and political science during this period. The geography program received additional extramural funding in 1970.

It appeared for a while that social research at OSU in the water resources field would catch fire. For a time it appeared OSU would become the center; it was a pioneer. It did catch fire, but a different variety than people expected. The chief traditional source of extramural funds, the Office of Water Resources Research (OWRR), changed more than its name when it became the Office of Water Research and Technology (OWRT). Clearly its priorities on social research changed after 1972--at least as far as successful OSU proposals were concerned. The guidelines for allocation of local allotment program funds through the Water Resources Research Institute also were affected, especially in regard to its support for social research projects.

The interests of social researchers at OSU have been widely divergent and polydisciplinary; disciplinary jealousies and competition for the scarce federal dollar are partially at fault. The recent low priority for basic social research has not brought about the incentive or directive for its integration. Thus, we haven't been trying to solve a problem. Rather we have paid little attention to one another except in attempting to beat one another to the extramural funding trough.

Social research at OSU can be distinguished according to disciplines, agency supports or pertinence, and directness of function toward the water resources field. I shall discuss only the first two, since projects with indirect or multiple functions constitute a very long list.

From January, 1966 through December 1977, social science projects, excluding economics, have accounted for nearly one-fifth (21.2%) of the Title I funds ($755,000) and one-sixth of the total derived by OSU from OWRR/OWRT. Title II (non-matching) funds from OWRT have been a very different story and reflect the recency of priority changes. Under Title II, no OSU social research has been funded, while nearly a quarter of a million dollars was received by investigators in OSU engineering and science departments between March of 1973 and October 1976. During the period 1965-1977, less than two percent (1.79%-$18,000) of the Institute's allotment funds were used in support of social research. Nearly 7% ($72,000) of the allotment funds supported projects by the Law School staff at the University of Oregon.

Since 1971 and again, through December 1977, only 3.4% of the Title I (matching grant) funds obtained by OSU from OWRR/OWRT were for projects in the social sciences. This is not for want of proposals. One project, that of Dr. Keith Muckleston in Geography, was funded during the period. As previously mentioned, no social research was supported under Title II which recently gave way to emphasis on desalination research. The Institute's allotment support for social research during the period of 1971-1977 increased slightly with just under 3% ($15,880) being devoted to such projects and 2-1/4% going to the University of Oregon Law School.

The results of these figures alone indicate that sources of support in the late 1960's and early 1970's have run dry. The local Institute cannot sustain social research impetus. Even less integration is occurring and research is becoming more oriented to applied dimensions. Some investigators have shifted their foci entirely; others are working in the social impact assessment field, and on problems increasingly defined by agencies. Today researchers most frequently respond to requests for proposals rather than propose their own basic research interests. Perhaps you can say that presently basic social research funding is akin to the availability of free water in the Colorado Basin. There just ain't no free good anymore.

An examination of OSU social research projects through time is further revealing.

Chronology on Social Research in Water Resource Field at OSU

Dates	Investigators	Field	Topic	Funding	Source
7/68-6/70	Hogg	Anth	Soc. Impact Analysis	43500	OWRR
7/69-6/72	Park *et al*	Bus Anth	Decision-Making	63300	OWRR
7/70	Klingeman	Interdisc.	Silvies Environmental	5000	COE
7/70-7/71	Muckleston	Geog	Probs and Issues Implementation of Fed Water Project Recr. Act in NW	3000	Allot
7/70-6/72	Smith/Hogg	Anth	S-C Systems	40200	OWRR-I
7/71-6/72	Muckleston	Geog	Flooding in Or	2000	Allot
7/71-6/72	Muckleston	Geog		13000	OWRR
1972-73	Bella/Klingeman	Interdisc.	Estuarine Plan	38500	COE/PNWRBC
6/74-5/75	Frenkel/Pfister	Geog	Rogue Carrying Cap.	7000	State
7/74-6/76	Doubleday	PolSci	Political State-Local Policy Analysis	12800	Allot
3/75-6/75	Hogg/Honey	Anth	Environ and Attitude on Willamette Greenway	1000	Allot
7/75-6/76	Hogg/Honey	Anth	Days Creek Impact	21900	COE
4/76	Frenkel	Geog	Pleasure Boat	300	State
8/76-9/77	Muckleston	Geog	Rogue Motor Boat	7500	State
10/77-1/80	Hogg/Honey	Anth	Liberty Lake Impact Assess	82000	EPA

This project list shows an early concern with basic problems of social change, policy analysis, and environmental analysis and planning; projects carry through with water organizations and interactions, policy analysis and environmental planning through 1974. Then they shift to attitudinal studies and impact assessments of particular programs and activities. They reflect the availability of funding sources and indicate a diversity over time. Few (3) interdepartmental projects involving social scientists have existed at OSU over the past decade (WRRI, 1977).

These projects really don't reveal much systematic integration except by chance, the temper of the times, and the research interests of agencies as funding sources. By chance the "system" has been complex but none too adaptive. Perhaps this is inevitable at the onset of a new development but the OSU case appears to have been more integrated at its beginnings.

As a result of OWRT's apparent lack of interest in supporting basic social research in recent years, investigators at OSU have sought support from other agencies for new interests. Today contracts for research are more frequent than grants. More applied work now is being conducted than ever before. It is being done on special problems faced by contracting agencies as they define the scope of work to be accomplished. Basic, theoretically oriented work rarely is being funded (or proposed). Research at OSU is more diversified than ever before, with the possible exception of social impact assessment projects. This latter field, as mentioned in the introductory remarks, is undergoing rapid unification as the guidelines for scope of work are implemented more uniformly by agencies.

IV. Results

There can be little question that social research in the water resources field at OSU has influenced decision-making concerning water resource policy and planning. Several investigators in the field have been cited for their leadership roles in methodology development and applications of results. More growth is shown within disciplines than between them. The hoped for interdisciplinary projects between the social sciences have not emerged. Interdisciplinary work that has been accomplished normally involves a team of researchers, one of whom is a social scientist.

V. Directions for Future Social Research in the Water Resources Field

Social Impact Assessment clearly is a chief source of funding for social research and it looks as though it will continue to be. OSU social researchers appear to be included in this trend. Important components of that effort are longitudinally oriented monitoring studies which provide precise projective techniques for impact analyses. Impact assessments are of two kinds--basic empirical studies and projective studies. Methodologies must be refined to the benefit of social theory and social sciences generally.

As Solomon et al (1977) point out, studies must achieve (1) great responsiveness to Principles and Standards, (2) greater comprehensiveness to all kinds of impacts, (3) greater ability to incorporate new variables and techniques, (4) sufficient flexibility to be applicable to various magnitudes and locales of development, (5) greater objectivity in use of either quantitative or non-quantitative data, (6) greater time-cost efficiency, and (7) the ability to be replicated by other researchers using the same methods in the field on the same setting. In addition, Wolfe (1978) points out that these studies must possess the dimension of project monitoring in order to ever attain the required sophistication demanded.

I personally hope to see a greater balance between basic and applied social research in the water resources field. It would be a travesty to the usefulness (both present and future) of social research to see it devoted only to social impact assessment, despite its importance. I would call for both this Institute and the Office of Water Research and Technology in the Department of Interior, as well as the Oregon State Water Resources Board, to examine their priorities and attempt to insure that social research is represented in a balance between contributive basic and applied (problems-solution) projects.

Bibliography

Fitzsimmons, S. J., Stuart L. I. and Wolff, P. C.
1975 A Guide to the Preparation of the Social Well-Being Account: Social Assessment Manual. Abt Associates, Cambridge, Mass. for USDI, Bureau of Reclamation. Denver.

Solomon, R. Charles, Billy K. Colbert, Wm. J. Hansen, Sue E. Richardson, Larry W. Canter and Evan C. Vlachos
1977 Water Resources Assessment Methodology (WRAM)--Impact Assessment and Alternative Evaluation. Environmental Effect Laboratory U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

United States Government
1970 National Environmental Policy Act of 1969. Public Law 91-190 (83 Stat. 842). 1st Session, 91st Congress, 1 Jan.

Water Resources Council
1973 Water and Related Land Resources: Establishment of Principles and Standards for Planning. Federal Register, 38 (174).

Water Resources Research Institute, Oregon State University
1977 Summary Report

Wolf, C. P.
1978 Personal communication, February.

Presented November 16, 1978 by C. DAVID MCINTIRE, Department of Botany, Oregon State University.

Biological Processes in Streams: An Ecosystem Perspective

Ecosystem Modeling

The development of conceptual and more formal mathematical models of ecological systems at the ecosystem level of organization presents some unique problems, many of which are yet to be solved in a way acceptable to both field ecologists and modelers. Systems analysis in ecology from a rigorous perspective involves the translation of physical and biological concepts into mathematical form and the manipulation of the mathematical system thus derived. The principal tool of the systems analyst is the model, which in a broad sense is simply a statement of relationships.

In its most formal, mathematical form, a model consists of variables, functional relationships, inputs, and parameters. Interaction equations express the relationships between variables in the system, and the inputs are introduced by expressions called forcing functions. Parameters are constants in the interaction equations and forcing functions that must be estimated from experimental or observational data sets. Goals of model building usually include both description and prediction.

The ecosystem model is always an imperfect simplification and abstraction of the real-world system of interest. The model never includes everything that is present in the real system. Herein lies the difficulty of reconciling the differences between the modelers and the data collectors. Although modern-day electronic computing machines provide the scientist with an awesome capacity for number crunching, the field ecologist is often surprised to discover how quickly this capacity is approached when the complexities of entire ecosystems are represented in mathematical form. In fact, preoccupation with too much detail is the bane of the ecosystem modeler's struggle for a meaningful identification and representation of the system variables.

A mechanistic model consisting of variables partitioned by taxonomic position is often unsatisfactory, particularly if dynamics revolve around energy flow in the system. A more reasonable approach in some instances is to picture an ecosystem as a nested, hierarchial system of biotic and abiotic processes hooked together by the relevant coupling variables. This approach has been used to model lotic (flowing-water) ecosystems by McIntire et al. (1975) and McIntire and Colby (1978).

Some model properties of particular interest are feedback and control, stability, and sensitivity, all of which are investigated by introducing perturbations to parameters and system inputs. Furthermore, an investigation of model properties often leads to changes in model form, and the procedure tends to be iterative, while presumably increasing the understanding of the corresponding real-world system. Some of the more interesting insights into the real-world system have been obtained when the model fails to give the anticipated behavior or when the structure breaks down and no longer provides an adequate representation. In some respects, nothing suceeds like failure! Bizarre model behavior is an explicit monument to ignorance that is often hard to rationalize without futher scientific inquiry.

Approaches to ecosystem modeling have varied from the development of very large complex models with many state variables and parameters to relatively simple models that attempt to represent coarse resolution dynamics. A good example of the variety of approaches of ecosystem modeling is available in a recent volume which describes the various modeling projects associated with the U.S. International Biological Program (Patten, 1975). W. S. Overton (1975) has developed an especially good approach for ecosystem modeling in the Coniferous Forest Biome (I.B.P.).

This approach conceptualizes ecosystems as hierarchically modular systems and involves the construction of systems and subsystems, each of which can be studied in isolation as long as the coupling structure is identified and its integrity maintained. These concepts have been incorporated by Overton (1972) and White and Overton (1974) into a general ecosystem paradigm called FLEX, based on the general systems theory of Klir, (1969).

The FLEX paradigm is implemented at Oregon State University by the program FLEX2, a general model processor that accommodates both the holistic (FLEX mode) and the mechanistic (REFLEX mode) representations. The principal advantages of Overton's approach is that it allows the investigation of ecological systems at different levels of organization and provides a way to examine the behavior of subsystems in isolation within the structural framework of larger, more complex systems of which they are an integral part.

Ecosystem Processes and Process Capacity

On a basis of the level of biological organization, studies of flowing water ecosystems can be divided into five approaches: (1) investigations of populations and population interactions; (2) trophic level summation (Lindeman, 1941, 1942); (3) paraspecies summation, the functional group approach (Boling, et al., 1975); (4) process aggregation: quasi-organism viewpoint (McIntire, et al., 1975); and (5) process aggregation: process capacity viewpoint (McIntire and Colby, 1978).

Approaches (2) and (3) involve the classification of taxonomic entities into groups of organisms considered to be similar to each other, usually with respect to trophic functions. Therefore, the dynamics of a trophic level of paraspecies is treated analytically (and conceptually) as a summation of activities associated with the constituent taxa of each functional group. In other words, the whole is treated as a sum of the parts. The paraspecies approach provides a refinement which allows a multistage representation of life history phenomena within a structure that can always be mapped into a trophic response.

Here, we are concerned primarily with process aggregation, approaches (4) and (5), as they represent theoretical concepts upon which a stream ecosystem model is based. This model is described in a later section.

Theoretically, an ecosystem can be conceptualized as a hierarchical system of biological processes. For our purpose, a process is a systematic series of actions relevant to the dynamics of the system as it is modeled. Any process can be decomposed into a system of coupled subprocesses if project objectives justify the examination of system dynamics at a finer level of resolution. Alternatively, a process also can be considered as a component of some supraprocess, the behavior of which can be investigated either holistically or mechanistically. At each particular level of resolution, the details of each process can be elaborated in terms of the corresponding variables, functions, and parameters.

In large ecosystem studies, there is some question as to just what state variables associated with each process of interest should represent. This difficulty, the so-called "aggregation problem", was recognized by Overton (1977). In an early version of a stream ecosystem model, McIntire et al., (1975) selected state variables on the basis of the various functional activities of organisms recognized by current concepts of energy transfer in lotic ecosystems. This approach -- here, referred to as the quasi-organism viewpoint -- designates each state variable as the biomass at any instant of time involved in a particular process.

This convention ignores taxonomic position and is therefore different from paraspecies summation which combines taxonomic entities into ecologically similar groups. It is important to emphasize that the individual taxonomic entities are not missing from a process model. Rather, they are simply swept up into a higher level of aggregation to the degree that some of their detailed terminology is no longer appropriate.

An analogous aggregation problem has generated controversy relative to connecting linkages between Forrester's World System Model and human values (Laszlo, 1973). Nevertheless, process aggregation in ecology avoids troublesome problems of dealing conceptually with large numbers of taxa individually and with individual organisms involved in more than one process. However, process modeling can create serious practical problems of parameter estimation, particularly when field data correspond to dynamics at the population level of organization.

Unfortunately, field measurements of process rates in ecosystems are lacking, although measurements of primary production (e.g., Odum and Hoskin, 1958) and leaf pack studies that examine the shredding capacity in streams (e.g., Sedell et al., 1975) are notable exceptions. The paucity of field methods available for process studies is related to the relatively slow development of a corresponding conceptual framework or context within which investigators can base their observations.

A refinement of the quasi-organism viewpoint is to regard each state variable as the capacity to perform the corresponding process. For example, if the species composition of organisms involved in the process of grazing changes seasonally, the rate of food consumption per gram of biomass could exhibit corresponding changes. To account for such qualitative changes in biomass, we can consider the state variable as the capacity for grazing which is some function of biomass and other properties of the community that change with community composition (i.e., the genetic information in the system).

Relative to process potential, a unit of capacity is time invariant, while a unit of biomass can vary over physiological, ecological, or evolutionary time. Therefore, the concept of capacity provides a theoretical basis for representing both qualitative and quantitative changes within each process in an ecosystem model. Problems of estimation and corresponding field methods associated with the capacity viewpoint of process aggregation are virtually unexplored in ecosystem research, and may, in fact, prove to be insurmountable barriers to the practical application of the theory.

Notwithstanding certain practical difficulties, the theory provides strong justification for monitoring community structure in some way during concurrent measurements of selected ecosystem processes.

During the development of the stream model, emphasis was placed on responses of the processes of primary production (periphyton dynamica), grazing, shredding, collecting, predation, and detrital conditioning to inputs of energy, namely light and allochthonous detritus. State variables were conceptualized as biomasses associated with these processes (process aggregation: quasi-organism viewpoint).

However, we were often forced to rely on data associated with the population level of organization for the estimation of many model parameters, and some of these values simply represent means for so-called functional groups of taxonomic entities. Therefore, model parameters are viewed as tentative and may be re-estimated as new field methods provide data more compatible with higher levels of aggregation. Hopefully, the concept of process aggregation will stimulate the development of such methods.

Some Useful Variables

The theory of consumer process dynamics in ecosystems can be examined relative to (1) the potential to expand process capacity; (2) process production; (3) the realized growth of process capacity; and (4) process regulation. In the discussion below, process capacity is stressed, but the concepts obviously apply to process biomass if the qualitative component of capacity is ignored.

The potential to expand process capacity at time k is given by

$$g_o(k) = \frac{1}{S(k)} \, [aD(k) - C(k)] \quad , \qquad (1)$$

where

$S(k)$ = the state variable value at time k, i.e., the process capacity or biomass if quality is ignored;

$D(k)$ = the process demand at time k;

$C(k)$ = the cost of processing at time k; and

a = an efficiency parameter.

Process demand (D) is the rate of consumption of resources by the process (i.e., the process rate) if resources are in unlimited supply. The cost of processing (C) is the metabolic loss of energy during processing. The efficiency parameter (a) expresses the proportion of resource intake that is incorporated into process capacity and may, in fact, be a function of certain physical and biological control variables. The variable g_o is the potential to expand process capacity per unit capacity in the absence of resource limitation and negative effects from other processes. Therefore, g_o is theoretically unaffected by density-dependent factors and is a function of density-independent factors (e.g., temperature). Obviously g_o goes to some maximum, say $g_o$max, as density-independent factors become optimal. If the state variable is expressed as capacity rather than biomass, g_o is a constant for each consumer process.

Process production for consumer processes is defined as the net elaboration of process capacity regardless of the fate of that capacity during the period under consideration. In other words, process production is analogous to the concept of secondary production (Ricker, 1958). The rate of process production is derived from the expression

$$g_1(k) = \frac{1}{S(k)} \left(aR(k) - D(k)\right] \quad , \qquad (2)$$

where R(k) is the realized process rate at time k, i.e., the actual rate at which resources are consumed by the process. The process production rate at time k is therefore aR(k) - C(k) or $g_1(k)S(k)$. Moreover, while g_o is a specific growth rate associated with unlimited resources, g_1 is the analogous rate when resources vary according to the system dynamics. A waste loss rate associated with processing (W) at time k is given by

$$W(k) - R(k) - aR(k) \quad . \qquad (3)$$

Fecal discharge is the principal biological mechanism accounting for W, and this waste usually represents a resource for another process or is exported from the system.

The realized growth of process capacity may be obtained after accounting for export and interactions with other processes. The equations are

$$g_2(k) = \frac{1}{S(k)} [aR(k) - C(k) - E(k)] \quad , \qquad (4)$$

$$g_3(k) = \frac{1}{S(k)} [aR(k) - C(k) - E(k) - B(k)] \quad , \text{ and} \qquad (5)$$

$$g_4(k) = \frac{1}{S(k)} [aR(k) - C(k) - E(k) - B(k) - P(k)] \quad , \qquad (6)$$

Here, E(k), B(k), and P(k) correspond to the export of process capacity, losses of capacity to decomposer processes, and losses of capacity to predator processes, respectively. If process capacity is gained directly from outside the system (immigration), an additional term (i) must be added to equation (6) to account for this import. The variable $g_r(k)$ is defined as the actual or realized specific growth rate associated with a process at time k, and $g_r(k)S(k)$ is the realized process growth rate. For a primary consumer process (e.g., grazing), $g_r = g_4$, while for a top predator process $g_r(k) = g_3(k)$. If the process remains in a steady state relative to the time resolution under consideration, g_r fluctuates around a mean of zero.

Concepts related to autotrophic process dynamics are analogous to concepts associated with consumer process dynamics. When light energy and nutrients are not limiting,

$$g_0(k) = \frac{1}{S(k)} [P_{gmax}(k) - C(k)] \quad , \qquad (7)$$

where P_{gmax} is the rate of gross primary production when resources are in unlimited supply. Again, g_0 can to to g_0max when temperature and other relevant density independent factors are optimal. When resources vary with system dynamics,

$$g_1(k) = \frac{1}{S(k)} [P\ (k) - C(k)] \quad , \qquad (8)$$

where $P_g(k)$ is the realized rate of gross primary production at time k. If the process represents the function of autotrophic organisms only, the rate of net primary production at time k is $g_1(k)S(k)$. However, it is often convenient to include the activities of tightly coupled heterotrophic microorganisms within the process boundary, as in the case of periphyton processes. If so, $g_1(k)S(k)$ simply represents the net elaboration of autotrophic process capacity, and C(K), the cost of processing, expresses metabolic losses of energy from the activities of both autotrophic and heterotrophic organisms. Expressions analogous to equations (4), (5), and (6) for autotrophic processes are

$$g_2(k) = \frac{1}{S(k)} [P\ (k) - C(k) - E(k)] \quad , \qquad (9)$$

$$g_3(k) = \frac{1}{S(k)} [P\ (k) - C(k) - E(k) - B(k)] \quad , \text{ and} \qquad (10)$$

$$g_4(k) = \frac{1}{S(k)} [P\ (k) - C(k) - E(k) - B(k) - G(k)], \qquad (11)$$

where G(k) is the loss to the process of grazing and the other symbols are the same as above.

In large ecosystem models, it is often difficult to understand mechanisms accounting for system dynamics from plots of state variables. In other words, values for state variables go up and down, but it is not always intuitively obvious why such variations occur. The concepts presented above provide a convenient basis for the investigation of regulatory mechanisms. From equations (1), (2), (4), (5), and (6),

$g_0 - g_1$ is the regulating effect of resource limitation;

$g_1 - g_2$ is the regulating effect of export losses;

$g_2 - g_3$ is the regulating effect of decomposer processes; and

$g_3 - g_4$ is the regulating effect of predator processes.

To analyze state variable dynamics, we simply plot g_0, g_r, and all relevant g_i [i=1, 2, ..., g_{r-1}] against time and examine the areas between the curves relative to a plot of the corresponding state variable.

A Stream Ecosystem Model

This section briefly presents the structure and some properties of a stream ecosystem model that simulates the dynamics of small, flowing-water ecosystems in the northwestern United States. Model structure is based primarily on current concepts of functional groups in stream ecology (McIntire 1968, 1973; Cummins 1974) and on the ecosystem modeling approach in the Coniferous Forest Biome, U.S. IBP (Overton, 1975). Update and forcing functions as well as parameter estimates, for the most part, were derived from experimental or observational data found in the literature or data made available through the courtesy of an interdisciplinary group of stream ecologists from Oregon State University, Idaho State University, Michigan State University, and the Stroud Water Research Center. The mathematical details of the model are described by McIntire and Colby (1978) and Colby and McIntire (1978).

The stream model is an expansion and modification of a model of periphyton processes developed by McIntire (1973). Conceptually, the model consists of seven basic processes that are subprocesses of three echelons of higher level processes. The model has 14 state variables associated with the seven basic processes, and is conceptualized in discrete time with a resolution of one day. The basic (fine-resolution) processes are primary production (periphyton dynamics), grazing, shredding, collecting, invertebrate predation, vertebrate predation, and detrital conditioning.

Input and control variables include: light energy; allochthonous detritus; temperature; photoperiod; nutrient concentration; and stream discharge from which such variables as current velocity, shear stress, sediment load, and channel dimensions are derived. Output from the model tracks state variable dynamics and provides trajectories of process growth rates (equations 1-11) that aid in the interpretation of state variable dynamics.

Model Structure

The stream model is conceptualized as a hierarchical system of biological processes (Fig. 1 and 2). At the ecosystem level of resolution, stream processes are considered mechanistically as two coupled subsystems representing processes of primary consumption and predation (Fig. 1). Primary consumption represents all processes associated with direct consumption and decomposition of both autotrophic organisms and detritus, including the internal production dynamics of the autotrophic organisms collectively. Predation includes processes related to the transfer of energy from primary to secondary consumers or from secondary to tertiary consumers. Behavior of each of these subsystems can be partitioned further and investigated in terms of their coupled subsystems.

Figure 1 also illustrates the subsystems of the primary consumption and predation systems. The small, solid arrows represent energy flows, while the dotted arrows emphasize the influence of certain control variables. Predation includes the processes of invertebrate and vertebrate predation, and primary consumption is represented by processes of herbivory and detritivory. Herbivory consists of all processes associated with the production and consumption of autotrophic organisms within the system, whereas detritivory represents the consumption and decomposition of detrital inputs.

In other words, herbivory and detritivory are analogous processes, the only important difference being related to whether the energy resource is generated within the system (autochthonous production) or from outside the system (allochthonous input). Figure 2 depicts the structure of the herbivory and detritivory subsystems in terms of each of their coupled subsystems. Herbivory partitions into grazing and periphyton processes. Periphyton processes include all the processes that are tightly coupled to the primary producers, in this case the periphyton assemblage. Grazing is the set of processes associated with the flow of energy from the periphyton to macroconsumers. Detritivory partitions into shredding, collecting, and detrital processes.

Shredding and collecting are processes associated with flows of energy from large particle detritus (> 1mm) and fine particle detritus (< 1mm) to macroconsumers, shredders and collectors, respectively. Detrital processes include five state variables, each representing the biomass of an arbitrarily designated fraction of the total detrital biomass.

Large particulate organic matter (LPOM) is fractionated into material that decomposes quickly (FLPOM) and material that has a relatively slow rate of decomposition (SLPOM). LPOM remains in the system as either FLPOM or SLPOM for periods representing the time it takes for micro-organisms to convert these fractions into states (CFLPOM and CSLPOM) suitable for consumption by macroconsumers. Sources of material for the fine particle detritus state variable (FPOM) include mechanical (nonbiological) transfers from CFLPOM and CSLPOM and from waste (Fecal) materials associated with the processes of grazing, shredding, collecting, invertebrate predation, and vertebrate predation.

Model Output: An Example

Figure 3 and Table 1 represent the simulated seasonal and annual dynamics, respectively, of a small, first or second order stream that receives an annual input or allochthonous organic material of about 480 g m^{-2}. The hydrologic properties introduced as inputs reflect the annual climatic cycle typical of western Oregon (for details see McIntire and Colby, 1978). Seasonal dynamics (Figure 3) reflect the effects of shading by a dense canopy of terrestrial vegetation and the introduction of a large quantity of allochthonous material during the fall and early winter months. For example, the periphyton biomass reaches peaks during late winter before shading and again during October after the leaf cover disappears. Moreover, processes of collecting, shredding, and grazing are particularly active during late winter and spring, whereas predation reaches its maximum during May and June.

Total annual production of primary consumers representing processes of grazing shredding and collecting is 21.8 g m^{-2} yr^{-1}, while total production for the process of predation is 5.8 g m^{-2} yr^{-1} (Table 1). Production related to primary macrosumer processes is partitioned as 15.6% grazing (consumption of autochthonous material) and 84.4% shredding and collecting (detrital consumption). Gross primary productin for the system is 71.1 g m^{-2} yr^{-1}, and the annual mean ration of gross primary production to community respiration is 0.19. In other words, the model exhibits the typical heterotrophic properties of the small, shaded, headwater streams of western Oregon.

Validation of the stream model is discussed in detail by McIntire and Colby (1978). Briefly, validation was based primarily on comparisons of model output to corresponding ranges of biomass and production values reported in the literature and in unpublished data for natural streams. This was the most reasonable approach, as the model was constructed to examine mechanisms regulating processes in streams--not for the simulation of a particular natural ecosystem.

Analysis of Mechanisms

Although Figure 3 indicates seasonal dynamics for a particular set of inputs and parameters, mechanisms accounting for such dynamics are not necessarily obvious from such plots of state variables. An analysis of the state variable dynamics for the simulation shown in Figure 3 is illustrated by plotting the trajectories of the g variables defined in equations 1-11 (Figures 4 and 5). Areas between the different curves represent the magnitude of the different limiting mechanisms. The process of grazing is clearly food limited throughout the year, though not as strongly so in early spring and mid-fall when periphyton production is relatively high (Fig. 4). Limiting effects of emergence and predation are minor and apparent only during the spring months.

In contrast, food is virtually unlimited (demand is satisfied and $g_0 = g_1$) with respect to shredding, except for a short period in early summer. Emergence limits the process in the spring, late summer, and early fall; whereas predation exerts some control from December through May. Food resources also have relatively little controlling influence on collecting as compared to emergence and predation (Fig. 5); emergence is important during spring and fall, while predation has its maximum effect during the first half of the year. Biomasses related to vertebrate and invertebrate predation tend to grow exponentially from January through April, but then become strongly food limited during the rest of the year. Invertebrate predation is inhibited to some degree by vertebrate predation during the spring.

Summarizing, analysis of state variable dynamics in the example suggests that regulation of biological processes in streams is complex, the mechanisms of which vary in time and from process to process. Figures 4 and 5 simply indicate mechanisms for one particular case, however, we have found it useful to generate plots of specific growth rates from equations 1-11 as part of the regular output for each simulation run. Obviously, in any natural ecosystem biological processes are ultimately constrained by the genetic constitution of organisms involved in each process, a constraint expressed in the model by aspects of the mathematical structure and the parameter values considered appropriate.

Conclusions

Modeling, with or without computer simulation, should be an essential part of ecosystem research. Moreover, it is important that modeling is not relegated to peripheral or subordinate status within the research program, as its principal benefits depend on a central orientation from which research priorities and hypotheses can emerge. Unfortunately, leadership and budget control for large ecosystem research is often dependent on individuals more sympathetic with data collecting than with data analysis. Insufficient cognizance of the role of system modeling and analysis can prove to be costly.

Ecologists appear to be notorious data collectors. Indeed, there are laboratories engaged in ecological research that could easily spend 5 years or more extracting information from data they have already collected. Sometimes, it is not always clear why the data were obtained in the first place; or, if the objectives were clear in the past, they are no longer relevant to the present.

A reasonable approach to ecosystem studies in water research includes: (1) the identification of a well-defined research goal and the establishment of specific objectives that relate to that goal; (2) an exhaustive review of existing information that relates to the various specific objectives; (3) the development of tentative structural and conceptual models of ecosystem dynamics that identify system boundaries and variables; (4) the establishment of research priorities based on the tentative model and the knowledge of existing information; (5) data collection and analysis, and (6) integration and the analysis of system behavior at various levels of organization.

Steps (2) and (3) must proceed concurrently and be performed by biologists with a systems orientation and modelers with a biological orientation. Step (6) should generate understanding of the mechanisms that regulate and control the relevant ecosystem processes. Whether or not a formal mathematical model is required for (6) depends on the objectives of the research program relative to the complexity of the ecological system under investigation.

REFERENCES

Boling, R. H. Jr., R. C. Petersen, and K.W. Cummins. 1975. Ecosystem modeling for small woodland streams. In: B. C. Patten (ed.) Systems analysis and simulation in ecology Vol. III. Academic Press, New York. pp. 183-204.

Colby, J. A., and C. D. McIntire. 1968. Mathematical documentation for a lotic ecosystem model. Internal Report No. 165 Coniferous Forest Biome Ecosystem Analysis Studies. Oregon State University, Corvallis.

Cummins, K. W. 1974. Structure and function of stream ecosystem. Bioscience 24: 631-641.

Klir, G. J. 1969. An approach to general systems theory. Van Nostrand-Reinhold, Princeton, New Jersey. 323 pp.

Laszlo, E. 1973. The World System: Models, norms, applications. George Braziller. N.Y. 295 p.

Lindeman, R. L. 1941. Seasonal food-cycle dynamics in a senescent lake. Amer. Mid. Nat. 26:636-673.

Lindeman, R. L. 1942. The trophic-dynamic aspect of ecology. Ecol. 23:399-418.

McIntire, C. D. 1968. Physiological-ecological studies of benthic algae in laboratory streams. Journal Water Pollution Control Federation. 40:1940-1952.

McIntire, C. D. 1973. Periphyton dynamics in laboratory streams: a simulation model and its implications. Ecol. Monogr. 43:399-240.

McIntire, C. D., J. A. Colby, and J. D. Hall. 1975. The dynamics of small lotic ecosystems: a modeling approach. Verh. Internat. Verein. Limnol. 19:1599-1609.

McIntire, C. D. and J. A. Colby. 1978. A hierarchical model of lotic ecosystems. Ecol. Monogr. 48:167-190.

Odum. H.T. and C. M. Hoskin. 1958. Comparative studies on the metabolism of marine waters. Publ. Inst. Mar. Sci. Univ. Texas 5:16-46.

Overton, W. S. 1972. Toward a general model structure for a forest ecosystem. In: Franklin, J. F., L. J. Demster, and R. H. Waring (eds.) Proceedings, Symposium, Research on Coniferous Forest Ecosystems. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, pp. 34-47.

Overton, W. S. 1975. The ecosystem modeling approach in the coniferous forest biome. In: Patten, B. C. (ed.) Systems Analysis and Simulation in Ecology, Vol. III. Academic Press, New York, pp. 117-138.

Overton, W. S. 1977. A strategy of model construction, p. 50-73. In: C. A. S. Hall and J. W. Day, Jr. (ed.) Ecosystem Modeling in Theory and Practice: An Introduction with Case Histories. John Wiley and Sons, New York.

Patten, B. C. (ed.) 1975. Systems Analysis and Simulation in Ecology, Vol. III. Academic Press, New York. 601 pp.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Bd. Canada Bull. 119. 300 p.

Sedell, J. R., F. J. Triska, and N. S. Triska. 1975. The processing of conifer and hardwood leaves in two coniferous forest streams: I. Weight loss and associated invertebrates. Verh. Intenat. Verein. Limnol. 19:1617-1627.

White C. and W. S. Overton. 1974. Users Manual for the FLEX2 and FLEX3 Model Processors. Bulletin 15, Forest Research Laboratory, Oregon State University.

FIGURE LEGENDS

Figure 1. Schematic representation of a lotic ecosystem showing the hierarchical decomposition of the primary consumption and predation subsystems. The symbols refer to flows of biomass from processes of grazing (G), shredding (S), and collecting (C); large particle (LPOM) and small particle (FPOM) detritus; export or emergence (E); respiration (R); temperature (TEMP); stream discharge (FLOW); photoperiod (PHOT); and nutrient concentration (NO_3).

Figure 2. Schematic representation of the mechanistic structure of the herbivory and detritivory subsystems in a lotic ecosystem. CLPOM represents conditioned large particle detritus; FLPOM, SLPOM, CFLPOM, and CSLPOM are defined in the text; and the other symbols are the same as given for Figure 1.

Figure 3. Seasonal dynamics of the principal state variables of the stream model for a selected simulation. Acronyms refer to periphyton processes (ALGAE) and processes of grazing (GRAZE), collecting (COLLECT), shredding (SHRED), invertebrate predation (I-PRED), and vertebrate predation (V-PRED).

Figure 4. A family of specific growth rates representing processes of grazing and shredding for the simulation illustrated in Figure 3. g_o is the rate in an environment with unlimited resources (food) and g_r is the actual or realized rate.

Figure 5. A family of specific growth rates representing processes of collecting, invertebrate predation, and vertebrate predation. g_o, g_r and the limiting effects are the same as given for Figure 4.

Table 1. Selected output from the stream model representing processes of grazing (GRAZE), shredding (SHRED), collecting (COLLECT), invertebrate predation (I-PRED), vertebrate predation (V-PRED), and autochthonous plant production (ALGAE).

Property	GRAZE	SHRED	COLLECT	I-PRED	V-PRED	ALGAE
Biomass (g m^{-2}):						
Mean	1.08	1.23	2.57	0.41	6.03	0.94
Max	3.09	2.78	5.79	1.02	9.77	1.90
Min	0.25	0.34	1.13	0.07	3.80	0.55
Production (g m^{-2} yr^{-1})	3.40	6.36	12.05	0.84	5.48	**61.10
Turnover (times yr^{-1})	3.16	5.17	4.69	2.07	0.91	65.00
Assimilation (g m^{-2} yr^{-1})	27.05	41.83	70.31	3.60	15.45	*71.14
Losses (g m^{-2} yr^{-1}):						
Respiration or post-Mortum decomposition	23.66(87%)	35.48(85%)	58.26(83%)	2.77(76%)	9.97(65%)	10.04(14%)
Vertebrate predation	1.97(7%)	2.70(6%)	5.56(7%)	0.60(16%)	-	-
Invertebrate predation or grazing	0.77(3%)	1.25(3%)	2.39(4%)	-	-	49.19(69%)
Emergence or mortality	0.66(2%)	2.37(6%)	4.08(6%)	0.26(7)%	5.43(35%)	-
Export	-	-	-	-	-	11.90(17%)

*Gross primary production

**Net community production for periphyton assemblage

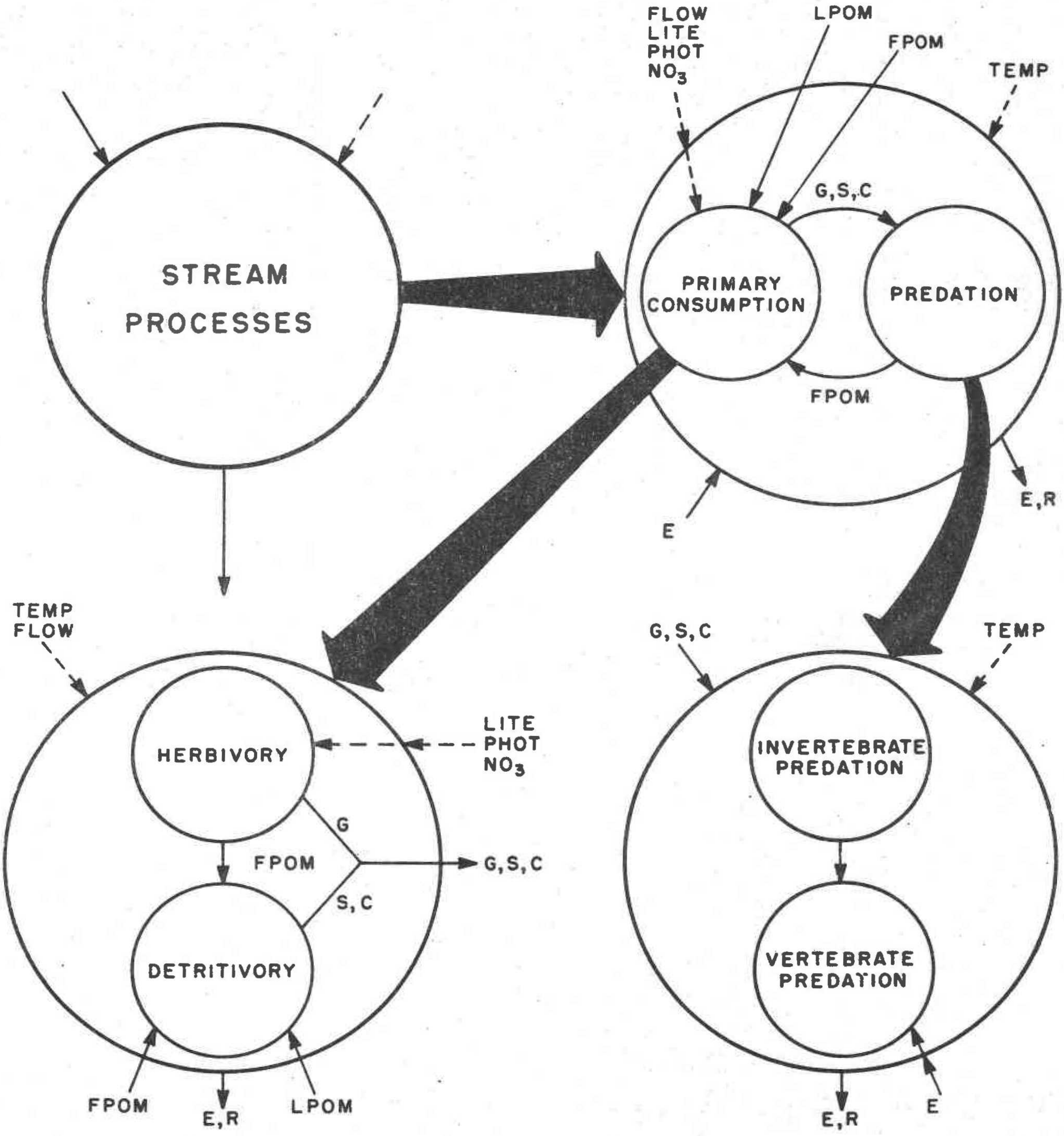
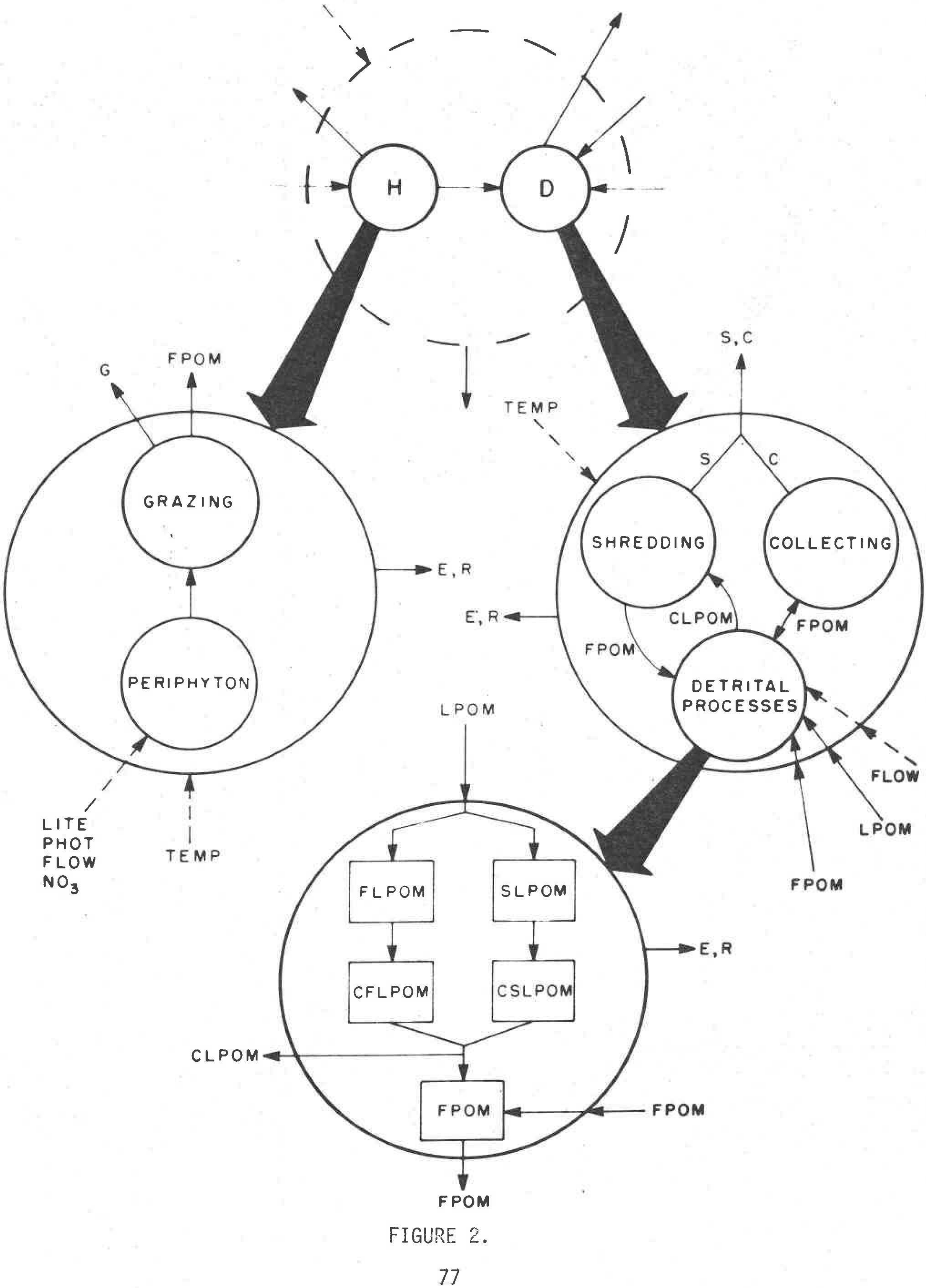

STREAM
PROCESSES
FLOW
LITE
PHOT
NO_3
LPOM
FPOM
TEMP
G,S,C
PRIMARY
CONSUMPTION
PREDATION
FPOM
E,R
E
TEMP
FLOW
HERBIVORY
LITE
PHOT
NO_3
G
FPOM
G,S,C
S,C
DETRITIVORY
FPOM
E,R
LPOM
G,S,C
TEMP
INVERTEBRATE
PREDATION
VERTEBRATE
PREDATION
E,R
E

FIGURE 1.


H
D
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GRAZING
SHREDDING
COLLECTING
E, R
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CLPOM
FPOM
FPOM
PERIPHYTON
DETRITAL PROCESSES
LPOM
FLOW
LPOM
LITE
PHOT
FLOW
NO_3
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SLPOM
E, R
CFLPOM
CSLPOM
CLPOM
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FPOM
FPOM

FIGURE 2.

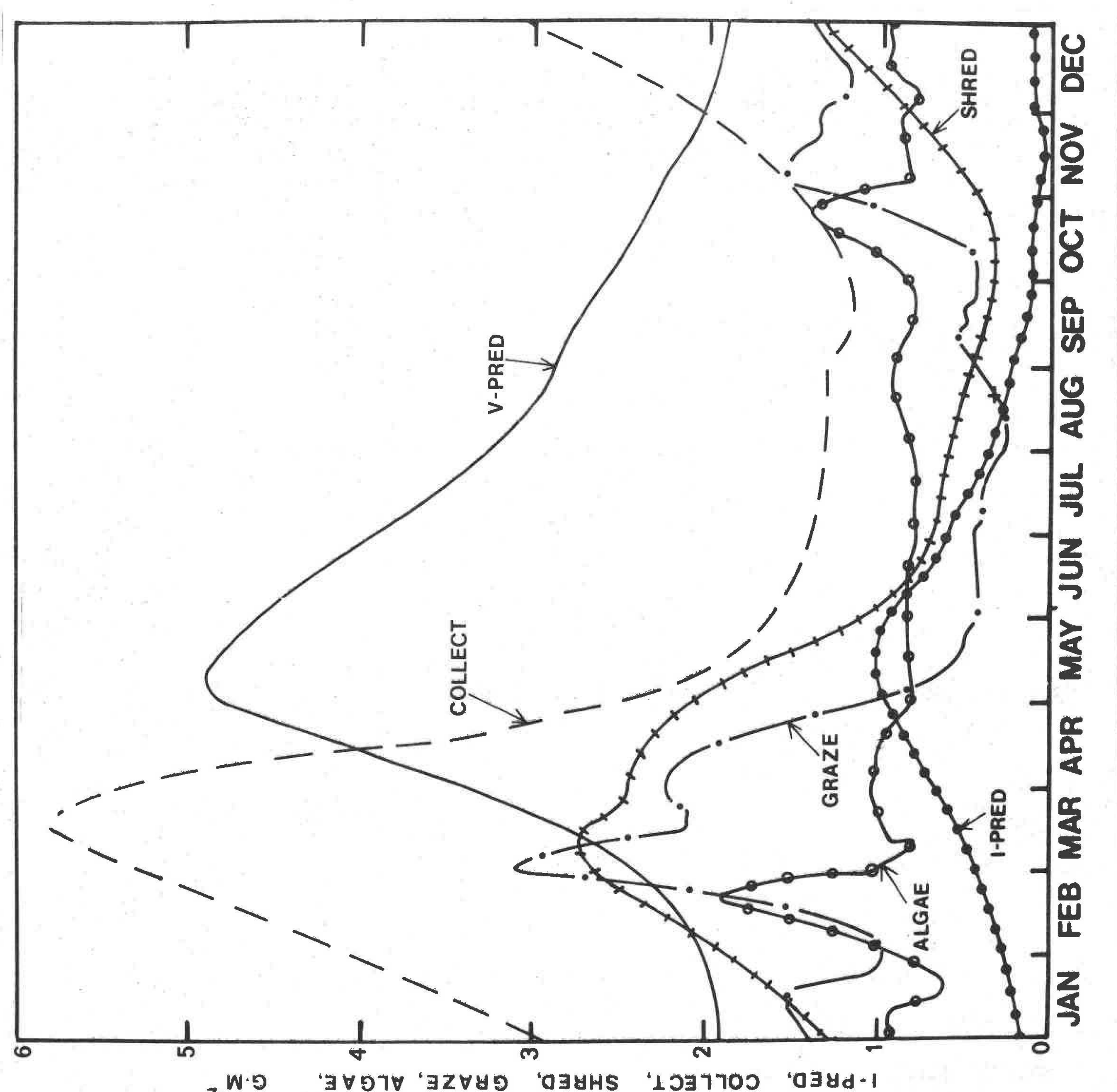
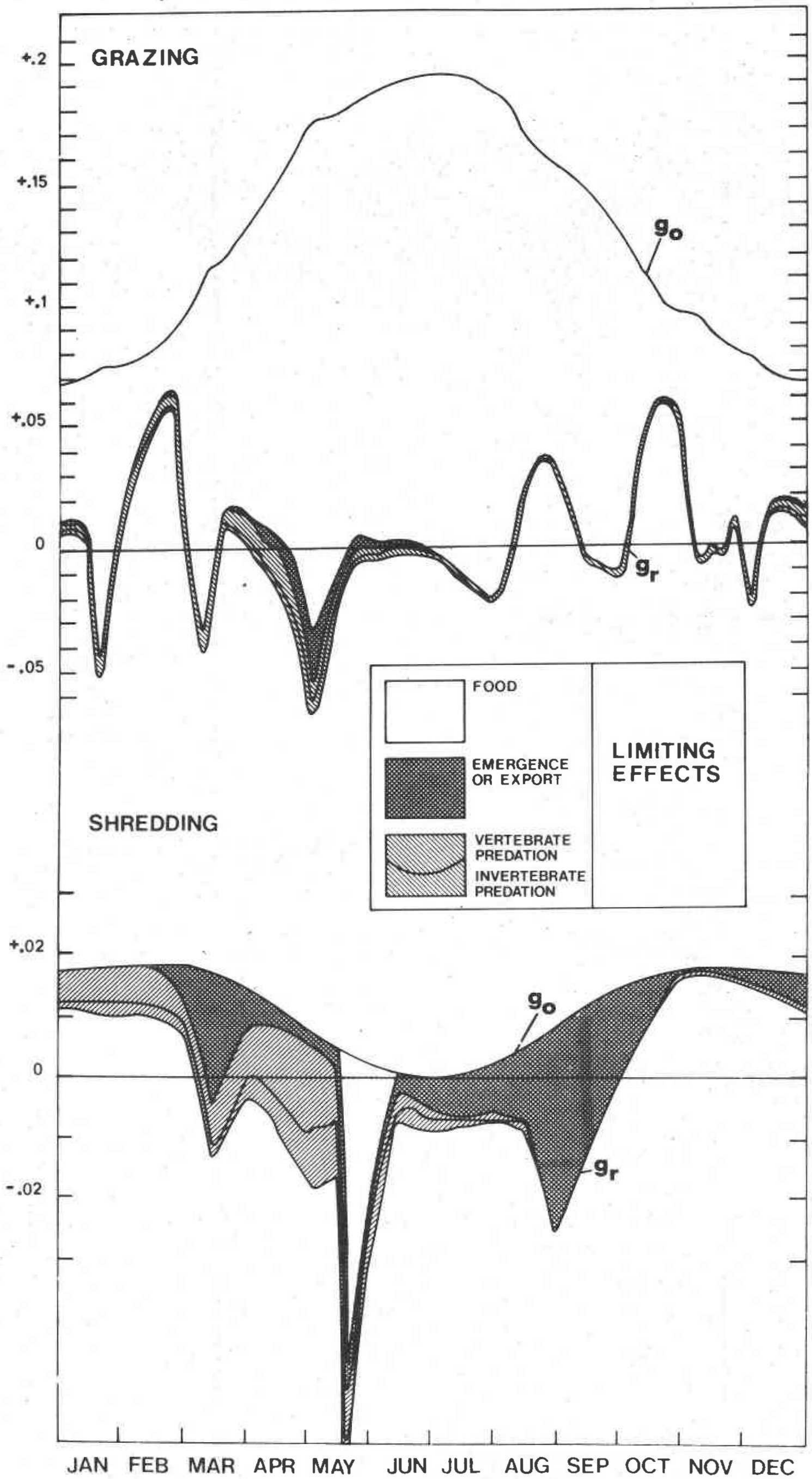

V-PRED
COLLECT
GRAZE
ALGAE
I-PRED
SHRED
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
I-PRED, COLLECT, SHRED, GRAZE, ALGAE, G·M^{-2}
V-PRED, G·M^{-2}
0 1 2 3 4 5 6
0 2 4 6 8 10 12

FIGURE 3.


GRAZING
+.2
+.15
+.1
+.05
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g_o
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FOOD
EMERGENCE OR EXPORT
VERTEBRATE PREDATION
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LIMITING EFFECTS
SHREDDING
+.02
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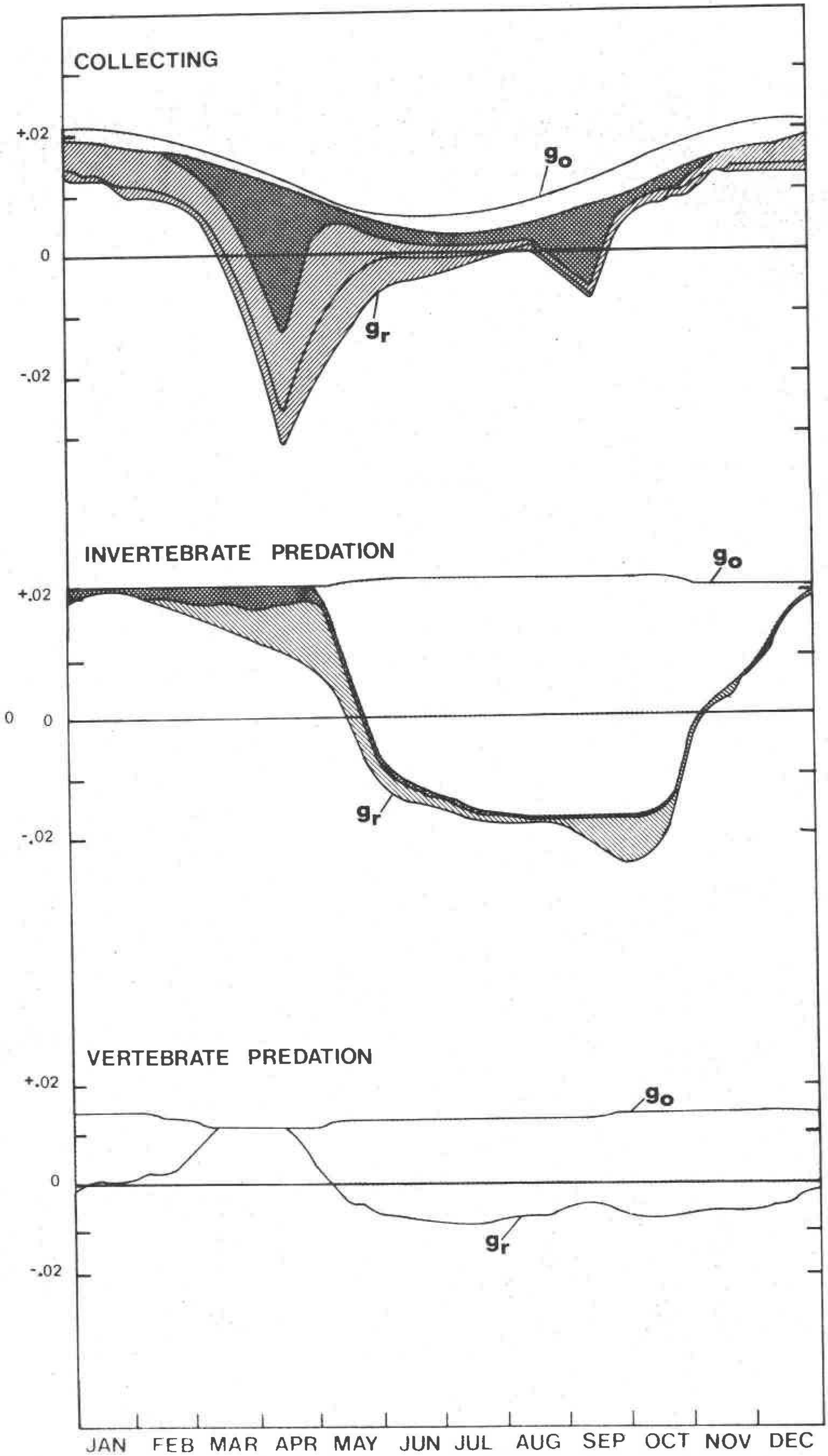
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

FIGURE 4.



COLLECTING
+.02
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-.02
g_o
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INVERTEBRATE PREDATION
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VERTEBRATE PREDATION
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JAN
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FIGURE 5.

Presented December 7, 1978 by PETER C. KLINGEMAN, Director, Water Resources Research Institute, Oregon State University.

Synthesis: The Past and the Future

Key Past Actions

The mid-1960's were significant years to the water resources research community in several ways. Among these, the U.S. Congress passed the Water Resources Research Act of 1964, the Water Resources Planning Act of 1965, the Water Quality Act of 1965, the Water Project Recreation Act of 1965 and the Clean Water Recreation Act of 1966. Concurrently, the Committee on Water Resources Research under the President's Office of Science and Technology completed recommendations for and in 1966 published a Ten-Year Program of Federal Water Resources Research. The first set of actions led to funding for water research and planning activities that has continued to the present, with direct benefactors in Oregon including the Water Resources Research Institute at OSU. The latter action, represented by the "Brown Book", has given broad guidance to the types of water research proposed, funded and completed in the last decade.

The Ten-Year Program identified 14 major problem areas. These are shown in Table I. They are rather broad and general; but each can be recognized as involving important issues. The Ten-Year Program also made several key recommendations as to research needs to address the major problem areas. These are summarized in Table II.

The WRRI's in each state and WRRI research activities in Oregon have generally focused on problems related to each of the 14 major problem areas.

Past Research Aims -- Still Valid

The Ten-Year Program identified three objectives of the national water resources program being conducted in the mid 1960's. These were:

> "To manage our natural water resources and to augment them when necessary as to meet all necessary requirements for water, both in quantity and quality; and to minimize water-caused damages to life and property."

Table I. Major Problem Areas Identified in the 1966 Ten-Year Program of Federal Water Resources Research

1. Water Resources Planning
2. Water Pollution Control
3. Water Conservation
4. Ecological Impact of Water Development
5. Effect of Man's Activities on Water
6. Costs of Water Resource Development
7. Research on "Far-out" ideas
8. Climatic Change
9. Information Storage and Dissemination
10. Problem Assessment
11. Water Resources Research Laboratories
12. Experimental Watershed Studies
13. Coordination of Research
14. Manpower

Table II. Research Recommendations Made in the 1966 Ten-Year Program of Federal Water Resources Research

1. Increase research on methods and criteria for water resources planning and on water law and institutional arrangements for facilitating more effective planning.
2. Increase research into cost allocations, cost sharing, pricing and repayment, to improve knowledge of benefits and alternatives.
3. Expand research on improved methods of waste treatment and on methods of dealing with pollutants from diffuse sources such as fertilizers and acid mine wastes.
4. Institute a program of research on methods of conserving water in industry and municipal use. In particular, steps which reduce the use of water for waste carriage should be intensively studied, both to save water and to reduce pollution.
5. Accelerate research on methods of conserving water in agriculture.
6. Develop research on the possible ecologic impacts of water development in order that probable impacts can be introduced in future project planning.
7. Undertake research on evaluating the effect of certain non-water activities on water and to devise methods to avoid undesirable effects. The effect of urbanization should receive first priority.
8. Special care should be taken to avoid the loss of important new ideas through lack of careful consideration.
9. Press research on evaluating climatic changes and the significance of fluctuations from flood to drought.
10. Assess the extent and character of various water-oriented problems as a prelude to research on specific problems. Funds for such assessments should be a normal part of the research budget.
11. Promptly undertake general assessments of the following problem areas to aid the management of ongoing research programs: potential use of sea and brackish water desalting techniques; potential for water-yield improvement through land management; potential for water conservation through better use of poor quality water; the sources, quantities and characteristics of pollutants in U.S. water sources; potential water recovery through waste water purification.
12. Study the possibility of consolidating federal water research laboratories in the interests of economy and efficiency and to improve communication and coordination between research workers.
13. Review the current federal program of experimental watersheds to define the appropriate scope for such a program, determine the feasibility of consolidating activities at selected experimental areas, consider the possibility that some existing sites may be discontinued, and arrange for the prompt publication of data for the use of all research workers.
14. Promptly strengthen research aimed at increasing the efficacy and at reducing the huge and mounting costs of engineering works of unprecedented magnitude and complexity.

Federal research, in concert with state and other non-federal programs, had the broad goal of providing the knowledge necessary to achieve these objectives most efficiently.

Seven specific aims were part of the federal goal and objectives:

1. To develop methods for conserving and augmenting the quantity of water available.

2. To perfect techniques for controlling water so as to minimize erosion, flood damage, and other adverse effects.

3. To develop methods for managing and controlling pollution so as to protect and improve the quality of the water resource.

4. To develop and improve procedures for evaluating water resource development and management so as to maximize net socio-economic benefits.

5. To understand the nature of water, the processes which determine its distribution in nature, its interactions with its environment, and the effects of man's activities on the natural processes. This is basic to the successful prosecution of items 1 through 4.

6. To develop techniques for efficient, minimum-cost design, construction, and operation of engineering works required to implement the water resources development program. Overriding considerations of effectiveness and safety, and of economy in con nection with the already huge and mounting costs of executing and operating water resource developments that are rapidly growing in number, size, and complexity, require the best efforts we can bring to bear on these problems.

7. To develop new methods for efficient collection of the field data necessary for the planning and design of water resource projects.

Some alteration in emphasis for the objectives and aims might be likely today, after a decade of heightened environmental concern that was just starting to emerge when the Ten-Year Program was developed. But the important fact is that those objectives and aims are still generally valid today and for addressing future water research activity.

An Evolving Situation

Today we are in gradual transition rather than at an abrupt break along the path of water resources research. Heavy federal research funding committments in the 1960's have slowly diminished. National economic problems have reduced the flow of dollars needed for research. The research community has been under growing pressure to demonstrate that useful results do come from the funded research. And most of the simpler problems have already been solved. Society is becoming more complex and so are the water research needs to address society's complex problems.

One might ask if the researchers themselves are showing a similar evolution of aims to stay in the mainstream of effective research? University researchers are continually accused by others of being out of touch with real-world problems and instead devoting their attention to "hobby" research. To some extent this is a valid criticism. But it does injustice to a far larger group of researchers who are "in touch" and who are trying to find rational ways to solve complex problems.

Evolving water problems and problem-oriented research seems to be more of a macro-scale nature than previously. Researchers are talking more about total systems today than they did before. The research of the past predominently dealt with the parts rather than the whole. Or if it dealt with the whole, it did so by means of generalizations due to insufficient knowledge. But now, more researchers are engaged in systems research that seeks to describe the parts and the whole in some cohesive manner that has depth and meaning beyond previous generalities.

Future National Research Directions

Since the mid-1970's, periodic reassessments of research needs have been made for the federal government by the WRRI's and by other entities. The Committee on Water Resources Research, past author of the Ten-Year Program, recently (October 1977) released a statement on Directions in U.S. Water Research: 1978-1982. This suggests a five-year course for "federally sponsored water research so that funds spent in the pursuit of new knowledge will bear upon those problems in which water is a national issue." Six important research areas are identified that could produce meaningful results to impact six major national issues. These are shown in Table III. The categories are broad "umbrellas" containing many unexpressed specific issues and research areas.

The general categories of needed research relate to the national issues in complex ways. Table IV reproduces a summary of the degree of relationship, as developed by the Committee on Water Resources Research.

Many aspects of President Carter's recent review of water policy and his emphasis on better water management suggest that water resources research must focus more on planning and management activities. The need for a dynamic and responsive water research program that considers both the current problems and emerging problems is evident. Most probably the recommendations of the Committee on Water Resources Research will be interpreted from the perspective of the President's Water policy review as federal research budgets are reviewed by the Executive and Legislative branches of federal government.

Water Resources Problems in Oregon Needing Research

Broad Features

Major water resource problems affect Oregon. These stem from disparities in the geographic distribution and abundance of water, compounded by sharp seasonal differences in water availability. Water is generally abundant west of the Cascade Mountain divide, where the majority of Oregonians live. But summer shortages occur. East of the Cascades, drought and water shortage are

Table III. National Issues and Water Research Areas Identified in Directions in U.S. Water Research: 1978-1982.

National Issues:

- Energy
- Food
- The Environment and Public Health
- Population Growth: Urban Problems
- Land Use
- Materials

Water Research Areas:

- Hydrologic and Hydraulic Processes
- Water Quality
- Planning and Institutions
- Atmospheric and Precipitation Processes
- Hydrologic-Ecologic Relationships
- Water Supply Development and Management

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fundamental considerations affecting most water uses.

Many water needs are met directly from streamflow. Reservoir storage has been crucial in providing water for uses throughout the state but has frequently resulted in conflicts among water uses. Ground water supplies have mainly met rural domestic needs but are being more extensively exploited east of the Cascades for agricultural development, in spite of limited information on their availability.

The Snake and Columbia Rivers, bordering much of northern and eastern Oregon, provide both opportunities and problems regarding water use and economic development. Efforts to use the waters have created conflicts involving dams, river blockage, in-stream versus out-of-stream uses. The interstate status of these rivers adds several jurisdictions to greatly complicate water management and use.

Underlying Complications to Decision-Making

Involved in most of the specific water problems and issues are three crucial elements affecting the decision-making process. These are: (1) lack of basic knowledge; (2) problems in the identification of alternative courses of action; and (3) inadequacies in the decision-making process. These elements have been used to organize the discussion that follows and the summary in Table V.

Lack of basic knowledge affects water resources in several ways. First, it is not entirely clear what Oregon hopes to achieve in terms of water resources, economic development and environmental protection of water. Reliable information is needed regarding the present and projected requirements of water. Second, basic information is still lacking concerning many aspects of the physical and the legal availability of water. Third, it is not yet possible to reliably predict droughts and their effects upon water supply depletion.

When water resources are allocated and developed to a significant degree, trade offs among uses and among beneficial and detrimental effects are always involved and must be identified. Several categories of current problems and issues exist: What does Oregon want to achieve with its water resources? What types of alternatives are available to Oregon on interstate waters, particularly the Columbia and Snake Rivers? What alternative actions should be considered for the different in-state river basins? What alternatives are available for water conservation, water quality control, water storage, in-stream flows, or for protection against periods of emergency such as floods and drought? What are the alternative ways for allocating water among competing uses?

The decision-making process regarding water resources is complex and may be inadequate. This is partly due to limited available resource information. Also, the decision-making process is widely dispersed among numerous federal, state, local and other jurisdictions and the methods and procedures whereby decisions are reached may not be adequate to cope with such a multiplicity of entities. Furthermore, some of the methods used for evaluating alternatives among competing and changed uses may be inadequate.

Table IV. Priorities for Water Research Identified in Directions in U.S. Water Research: 1978-1982.

Major National Issues	Important Needed Research					
	Hydrologic-Hydraulic Processes	Water Quality	Planning and Institutions	Atmospheric Precipitation Processes	Hydrologic-Ecologic Relationships	Water Supply
Energy	***	***	xx	xx	xx	***
Food and Fiber	x	xx	x	***	x	***
Environment and Public Health	x	***	xx	x	***	x
Population and Economic Growth	xx	***	xx	x	***	xx
Land Use	xx	x	***	xx	xx	x
Materials	xx	xx	x	x	x	***

*** = primary importance

xx = significant

x = minor

Table V. Water Problem Areas and Research Needs for Oregon, 1978

Problem Area	Types of Research Needs					
	Physical	Biological and Ecosystem	Health and Quality	Economic	Legal	Socio-Political
Basic Knowledge						
Water reqmts. to meet needs	x	x	x	x	x	x
Physical availability of water, especially ground water	x	x	x	x	x	x
Legal availability of water (water rights & claims)	x			x	x	x
Effects of drought	x	x	x	x	x	x
Alternatives						
Goals and objectives	x	x	x	x	x	x
Use of Columbia River	x	x	x	x	x	x
Water storage & streamflow manipulation	x	x	x	x	x	x
In-stream flows	x	x	x	x	x	x
Water conservation	x	x	x	x	x	x
Water quality control, including waste assimilation in waters		x	x	x		x
Water allocation tradeoffs	x	x	x	x	x	x
Adequacy of Decision Making						
Dispersed nature of D-M				x	x	x
Allocation decisions				x	x	x

Specific Problems

Economic development requires water use. This can result in altered water quantity and quality and can have effects throughout a river basin. East of the Cascades, a major water need is for agriculture and agriculture-related businesses and industries. Large quantities of water are required and reservoir storage is essential. As an alternative and supplement to a streamflow and surface water reservoirs, ground water reservoirs have been tapped. Some are now in critical drawdown condition due to excessive use and to limited recharge. Use of irrigation water from in-state river basins has caused problems with competing uses and due to altered quality of return flows. Recreational water uses and fishery protection constrain out-of-stream diversion. The alternative of going to the Columbia River for additional water is only available for nearby lands. Diversion of Columbia River water for thermal energy production is likely. The region's hydropower facilities have been greatly taxed, with associated environmental stress on the basins' fishery resources.

Washington and Idaho have developed specific plans for additional irrigation and to obtain the needed water from such sources as the Snake or Columbia Rivers. This threatens Oregon's agricultural potential due, in part, to upstream depletion of streamflow. Other beneficial uses in Oregon (i.e., thermal power production, hydropower generation, fisheries, recreation, port and waterway uses) may also be threatened by such diversions.

Much planned and potential Oregon industrial development is dependent upon the Columbia River and other major rivers (i.e., bulk oil handling, food processing, aluminum processing, energy production). Any water use that influences such activities is of concern in formulating development plans. Conversely, it is essential to know what effects such activities will have on other water uses and what the crucial issues are.

Industrial sites along the Oregon Coast having adequate supplies of fresh water are hard to find. Thus, water may impede economic development there, including the industrial development potential that involves coastal and offshore fisheries.

Tourism and recreation are largely water-oriented. Expansion of this sector of the economy required clearer understanding of the potential risks of environmental degradation. The future development of tourism along the Oregon coast is also impeded by ground water problems, both of supply and of wastewater disposal.

Dispersion of industrial development and economic activity around the state requires improved water supplies in areas away from the Willamette Valley. Better information on the physical and legal availability of water is needed if industry is to be attracted to the eastern part of the state.

Droughts such as that in 1977, requiring disaster relief and having many repercussions within the state, can be expected to recur. Meanwhile, increased water use makes the effects of droughts more severe with the passage of time. The severity of problems from drought also depends upon the level of development in a river basin. It is essential to better understand <u>in advance</u> the effects of different drought conditions on water supplies, both surface and sub-surface. Otherwise, each period of water shortage will cause greater disruption than need be the case. With sufficient water resource information it may be possible to guide water use and development so as to minimize the risks associated with droughts.

Problems Concerning Basic Knowledge

Water requirements to meet needs. How much water is needed to properly meet present and future state goals and objectives for water resources? What are the best, most reliable projections for future water needs? What are reliable projected needs for energy and other water-related goods and services? How do current practices and full implementation of water conservation, reuse and recycling practices affect the need for water?

The 1969 study by the Oregon State Water Resources Board of Oregon's long-range requirements for water generously estimates water needs to assure that Oregon will adequately protect its water for future uses. But some assumptions made about future conditions need re-examination in the light of changed population growth, lifestyles, energy availability, federal spending policies, and concerns over particular water use that has arisen in the 10 years since projections for that study were made. The assumption made that potential water deficiencies will be met through importation of Columbia and Snake River water avoided the constraints normally imposed on water use due to water scarcity and competition among uses. But competition and other constraints will hold use to lower levels. Possibilities for significant water conservation and reuse have been overlooked. Seasonal variations of water supply and need were also overlooked. Possibilities for coping with water scarcity east of the Cascades were not sufficiently explored. Greater attention must be given to in-basin methods of dealing with water scarcity rather than water importation from other basins. But first, realistic estimates of water needs must be obtained.

Unrealistic projections of water requirements to meet state needs and goals lead to unrealistic planning. Overprojection of needs may lead to unnecessary or early commitment of economic and natural resources, with a risk of idle facilities and capital and of needlessly lost options for alternative resource commitment that cause excessive competition for the available water resources. Either situation is adverse to orderly economic development.

Physical availability of water. The availability of water from smaller drainage areas of the state is still generally unquantified. The streamflow gaging network tends to emphasize data from principal streams, leaving the need to estimate water yields from lesser tributaries. Ground water observation wells do not describe conditions in all aquifers, so that estimates of available water are often speculative.

The hydrologic and water quality data gathering-network is not adequate to answer many important questions that form the basis of decision-making. In some cases, the records may be too short. In many instances, data are not available for the specific location of concern. Extrapolation techniques are available in both situations but are never as reliable as actual on-site data. Particularly with water resources, there is a great deal of short-term and long-term variability as well as geographical variability so that trends, patterns and norms are extremely difficult to identify.

In many parts of the state, ground water use is limited to small local supplies whereas surface waters provide for most needs. In some areas of the state where ground water use is significant, such as the Hermiston area, heavy use has caused problems of falling water levels at wells. Coupled with the high costs of drilling deeper wells, such problems have led many users to seek additional water from surface sources, even though ground water basins are presumably extensive.

Uncertainties regarding the potential ground water supply from aquifers are hampering ground water use. The basalt aquifers found in much of the state are complex and make investigation difficult. More aquifer information is needed to permit informed decisions on both domestic use and economic development of ground water resources.

In areas where little is known regarding ground water conditions, water-dependent economic development is not likely to proceed unless surface water is sufficiently available. But if too much emphasis is placed upon surface waters, conflicts with fishery resources and other competing water uses are likely to be severe. This could retard activities that might not be delayed if ground waters were being used instead.

Legal availability of water. Subsequent to passage of the Oregon Water Code in 1909 and the Ground Water Act of 1955, the adjudication of all prior water rights was undertaken. Due to the complex and time-consuming nature of the work, together with limited budgeting to conduct this activity, water rights still remain unadjudicated on most streams west of the Cascades and for some in eastern Oregon. Because of the backlog of adjudication needs, questions remain regarding who has rights and to how much water at what time of year. Lack of clarification of rights and unsettled old claims preclude a clear knowledge of uncommitted water available for future users and create uncertainty regarding the planning of new water use activities that require water rights.

A major unresolved problem for Oregon and the West is that of quantification of federal and Indian water rights claims. There is concern on the part of states and private water right holders that future actions to assert federal and Indian claims to "reserved" water may seriously impair private water rights. There is a need for clarifying what these claims may be, to minimize the uncertainties involved. The enormous investments already made by non-federal, non-Indian interests based upon the same water supply and new plans for additional development can only be made with the obvious possibility that they might be upset by future court action. To solve these difficulties, information is needed on the scope of federal and Indian rights to water, on tribal and federal needs for waters, on means by which impending conflicts over water can be equitably averted or settled, and on the consequences of various approaches to resolving problems of reserved water rights.

Effects of drought. Water development tends to rely upon near-normal levels of water supply and to rely upon some storage or other reserve capacity to meet periods of brief shortage. But continued expansion of water use results in a growing reliance upon receiving near-normal water supplies to meet all needs. Thus, as the level of water use approaches the level of water availability, any shortage can result in economic difficulties for those directly or indirectly dependent upon the deficient supplies.

Drought is adverse to all water use activities. It is more likely to be an infrequent, short-term setback than a sustained condition. But either way, economic losses are significant to the state and have repercussions throughout the economy. The threat of water shortage is also a hindrance to economic activity.

Beyond the predictability of droughts is the more serious question of predicting water supply depletion during drought periods. It is critical to determine how much water is available from different components of the hydrologic cycle (the atmosphere, snow pack, surface waters, soil, and ground water) and how the depletion of water storage changes with the severity and persistence of drought. The effects will differ geographically in Oregon and this geographic influence must be determined. Any reliability in the prediction of drought offers opportunities to take steps to minimize losses. If the likelihood and location of drought can be foreseen, water storage manipulations and conservation measures might be undertaken to anticipate and offset water deficiencies.

Problems Regarding Alternatives

Goals and objectives. What does Oregon want to achieve with its water resources and how is this expressed in terms of goals and objectives? The Oregon Legislative Assembly and particular state boards, commissions and agencies develop policies, goals, objectives, plans and programs. So do counties and other local governmental entities. Some goals and objectives affecting Oregon's water resources are established at the federal level and may primarily serve national policy. Furthermore, goals and objectives for the use of water resources are not independent of other concerns, such as land use and energy plans or social, economic and environmental objectives.

Policies, goals and objectives become out-of-date with time. Or they may not remain clear, causing confusion as to just what the state wants to achieve in particular instances. Or agencies may not agree over issues due to interpretation conflicts. As long as Oregon's water-related goals and objectives are not clearly and comprehensively defined, friction due to differing goals will occur at local-state-regional-federal interfaces. Plans for land use and development (i.e., thermal power development or metal processing) may become stalled in part because of uncertainties that such plans will be compatible with social and environmental goals to be served by the same water resources.

Use of Columbia River. The management of the Columbia River is a major regional issue requiring attention by Oregon. Tight management of the Columbia River is limited to flood control and hydroelectric energy production. Fishery resources are subject to continual controversies. Conflicts also arise between out-of-stream uses. All of these difficulties hinder that best management of the Columbia River and make it difficult to identify what that management should be.

The Columbia River is a dominant factor in Oregon's economy. Yet the influence of Oregon over management of the Columbia River is unclear. Our "claim" to water in the river, in juxtaposition with Washington, Idaho and federal jurisdictions, has not been established.

Continued uncertainties regarding the physical and legal availability of Columbia River water for Oregon's use could hinder future planning and development. Management of the Columbia River system is sufficiently complex, due to the large number of vested interests and the broad range of potential management scenarios, that the formulation of state policies toward this management is very difficult. This makes unclear the best long-term opportunities that the state might pursue. Clarification of the availability of Columbia River water, establishment of a comprehensive regional management program, and development by Oregon of state policies for the Columbia will all contribute to a firmer basis for identification of water-related opportunities.

Water storage and streamflow manipulation. One of the most critical decisions regarding water use is that on whether or not to manipulate streamflow, making water available when and where it is needed or preventing it from going where it is not wanted. Streamflow manipulation requires water storage or water diversion. This involves dams and reservoirs. These can fulfill many needs. But simultaneously, many problems are caused. All methods of significant flow manipulation have extensive effects in the entire river basin. There is perhaps no other area of water resources management than streamflow storage and manipulation which is more sensitive to questions of environmental impacts and related impacts on all types of water uses.

Insufficient water supplies hinder many forms of water use due to heavy competition for the limited available water. This bottleneck of not having enough water to accommodate all uses not only slows overall economic growth but also favors growth in early-established sectors of the economy with senior water rights. If water is a limiting factor, even the older activities are restricted in growth.

Some water uses clearly benefit from water storage and streamflow manipulation, whereas others do not. The timing of water availability may be as crucial as the quantity of water provided. Major benefits focus on flood control, freshet management and conservation storage for water supply purposes. However, fishery and wildlife uses and water-based recreation are not always benefited and, in some instances, are adversely affected. Hence, water storage involves many tradeoffs between benefited and disbenefited uses.

Conflicts even arise between water uses that jointly benefit from reservoir storage and streamflow manipulation, due to differences in the needed timing of storage and release of water. This leads to competition and tradeoffs in project operation priorities and schedules.

In-stream flows. The preservation of undisturbed or "free-flowing" streams against dam building has been a long-standing controversy. Positive aspects of this controversy have included federal passage of the Wild and Scenic Rivers Act in 1968 and establishment by Oregon of a Scenic Waterways System in 1970 and a Willamette River Greenway Program in 1973.

The controversy over dams has prevented sufficient consideration of the benefits from maintaining adequate in-stream flow. Hydroelectric power generation, navigation and fisheries require adequate in-stream flows. Upstream diversions compete for this water. Many in-stream uses are sensitive to the amount of available flow. This subject needs further investigation to clarify economic impacts of altered in-stream uses.

The economic importance of in-stram flows has not been adequately identified. Fishery resources in free-flowing streams offer obvious opportunities for economic growth. Other opportunities exist that have not been greatly exploited, such as the potential for tourism and recreational activities close to large urban areas.

Water pollution represents an important limitation on activities that can benefit from free-flowing streams (i.e., commercial and recreational activities involving fisheries, shipping and boating). Insufficient in-stream flow limits the amount of use possible for many streams at certain times of the year (late summer and autumn). Competing demands for off-stream uses adversely affect in-stream flows because of water diversions.

Water conservation. The 1977 drought sharpened awareness of the imbalances between water supply and water demand in many parts of the state. Water conservation, recycling and reuse were found to be as effective as the development of new supplies in meeting short-term demands. But can water conservation, recycling and reuse also help to alleviate long-term water shortages caused by limited supplies? Can they relieve water quality problems caused by insufficient in-stream flows and contaminated return flows? The drought experience did not provide answers to these important questions.

There may be some "hidden" benefits of certain presently used non-conservation practices. For example, excessive irrigation or leakage from irrigation canals may recharge aquifers away from streams at times when water tables would otherwise be falling. Also, there appear to be barriers that limit or inhibit conservation practices, such as water rights restrictions, failure to meet water quality standards, health requirements, technological ability to control impurities, capital availability and cash flow.

Large costs associated with current methods of water use might be cut if greater water conservation were practiced. But the opposite could also be true, due to such conditions as economies of scale or need for special equipment to permit recycling without the build-up of undesired water constituents.

Incentives are generally needed to induce water conservation and recycling. Low water bills are effective conservation incentives for municipal and residential uses, where unit water costs are high. But water cost is generally less of an incentive for industrial uses, where water costs often are an insignificant fraction of product costs, or for agricultural uses in many parts of the state if the quality of the agricultural produce is highly dependent upon the quantity of water supplies.

Wasteful and excessive use of water by some users can deny sufficient water for other uses. If water supplies are limited, intensive recycling and reuse might be required as an alternative. But this might require so much water quality control and treatment as to discourage particular types of activities. Also, there may be health standards that preclude recyling and reuse in what might otherwise be an economical practice.

Water quality control and waste assimilation in waters. Wastes continue to be produced and discharged to the state's waters. Protection and enhancement of water quality is a continuing struggle. Limitations on all types of water uses result as water quality deteriorates. It becomes more costly to obtain the needed quality of water for each intended use. There is also a decline in the intensity of some related uses (i.e., aquatic recreation).

The Department of Environmental Quality has formulated a general policy of non-degradation of water quality in order to protect Oregon's streams from headwaters to the ocean. Waste receiving capacities must be considered in planning activities. Industries wishing to expand production on pollution-threatened streams may find that it must be accomplished within the effluent discharge limits already permitted them, requiring improved technology or added capital before such expansion might occur.

Efforts to protect water quality impose limitations on water uses and economic growth. Some types of uses become precluded or diminished unless new costs for pollution control are accepted by the user. Some of these costs must be borne by the general public (i.e., federal construction grants for municipal water and wastewater treatment facilities). Others must be borne by private industry and agriculture. Tax incentives (i.e., tax credits) appear to offer the needed inducement for industry to make important investment in anti-pollution equipment and wastewater treatment. Because public and private investment needs in pollution control can be very substantial, tax-free or low-interest revenue bonds or other incentives may be effective and must be considered.

Water allocation tradeoffs. Not all benefits and disbenefits are known when water is allocated to a particular use. Physical quantities of water can normally be compared under different allocation schemes. But water quality alternatives are not usually clear. And when biological systems are involved, the tradeoffs between different alternative allocations are generally unknown except in rather simplistic terms. Knowledge of economic tradeoffs, other than direct short-term differences among alternatives, is likewise evasive.

Problems Regarding the Adequacy of Decision-Making

Dispersed nature of decision-making. Decisions over water resource policy, rights, management, construction, operation, and other activities are presently spread over a multitude of federal, state and local jurisdictions in Oregon. Such dispersion and fractionation of authority tend to create confusion, inefficiency and delays in getting the needed action on water problems. Centralization of authority would appear to reduce this confusion and increase efficiency in decision-making. But dispersion of authority provides a system of "checks and balances" to assure that all interests to a decision have representation. Nevertheless, the dispersion of authority may leave some interests to a decision uninformed about the pending decision or uncertain as to how to proceed.

Many questions and problems over water use that need to be resolved rationally and with expediency are delayed because of uncertainty as to how "the system" functions. The one-stop permit system and a waterways development handbook have shown ways of dealing with dispersed authority in a relatively efficient and expedient manner.

A stronger approach to the problem of dispersed authority is the possibility of agency reorganization. It is not clear whether internal reorganization of some agencies is needed or whether agency mergers to form a more all-inclusive water agency or natural resources agency might be appropriate.

Dispersed authority for decision-making on water resources can cause difficulties in plan implementation. Water plans, land-use plans and economic development plans are implemented at various levels of government, usually in much different ways. Water plans are often implemented in a vertical hierarchy, as with water quality plans that extend downward from the federal level through the state level to councils of regional (instate) government, counties and cities or by lateral plan implementation for functional activities of different agencies. How does the planning of land use or of water-related economic development activities interface with vertical-hierarchy, lateral-agreement or otherwise fractionated lines of authority among water resource agencies?

Allocation decisions. Allocation of water among competing purposes is a major problem in Oregon, regardless of whether the uses are complementary, conflicting or even mutually exclusive. Part of the allocation problem can be traced to a lack of basic knowledge of water availability, particularly it legal availability and allocation. A second aspect of the problem centers on the alternatives available for allocating available water. The adequacy of the decision-making process represents a third aspect.

Underlying the issue of water allocation is the problem of changing needs and changing interests as to how water should be used. Allocation procedures that rely heavily onwater rights tend to focus on the past; those that rely on economic benefits and costs tend to focus on the present; those that rely on comprehensive planning focus on a "perceived" future. In the multi-jurisdictional arena of institutional water allocation, elements of the past, present, and perceived future all influence how water is shared among competing uses. This directly influences water planning and development.

General Research Needs

The several problems described above are summarized in Table V. Also shown are categories of research needed to allow progress to be made in solving these problems, In general, it is apparent that a wide range of disciplines must address these problems to allow their complete solution.

Needed Planning-Related Research in Oregon

In view of President Carter's emphasis on better water management and Oregon's concern over economic development, future research might well focus on solving those water resource problems described above that are most crucial in water planning and management decision-making.

A team of state agency representatives, at the request of the Pacific Northwest River Basins Commission, recently recommended areas of needed federally-supported programs in Oregon addressing water-related resources. One of these areas dealt with water resource research that should be undertaken in the near future to assist water planning and management activities. The recommendations generally conform to the President's sought after emphasis.

The planning-related research needs identified can be summarized in terms of "umbrella" research categories. These are shown in Table VI.

Table VI. Needed Planning-Related Research in Oregon

Water Quantity Problems
Water Quality Problems
River Basin Water Quantity/Quality Management Models
Impacts on Natural Environment
Aquatic and Riparian Habitat Assessment
Fishery Problems
Economic Impact Assessment
Energy-Water Relations
Water Planning and Management Problems

Water quantity problems that affect planning and management are numerous. Examples include control of excess water by subsurface drainage, influence of river stage on bank erosion, instream flow requirements and potential irrigation efficiencies, artificial recharge of aquifers, combined surface and subsurface storage.

Similarly, numerous water quality problems exist that need resoulution to improve planning and management activities. These include pollutant control from point and non-point sources, assimilative capacities of water for various contaminants, erosion and sediment transport processes, long-term waste treatment requirements, seepage from landfills and septic systems, aquifer uses for industrial cooling and heating and associated risks, urban runoff control.

Water quantity and quality problems have traditionally been dealt with separately. Many states, including Oregon, even have separate agencies to address each. Integration of water quantity management with water quality management is a necessary step. This will require resolution of many problems. Research needs include basic models to provide data on non-point source pollution and how it can be controlled to improve water quantity and quality. Models must be extended to evaluate the benefit to aquatic resources and habitats.

More research is needed to better describe the impacts of water use on the natural environment. Examples of such planning-related research include relation of a aquatic ecosystems to availability of in-stream flows, ecosystems' responses to improved/deteriorated water quality, relation of ecological change to cultural development, ecosystems carrying capacity, effects upon aquatic environment of public use of water resources.

Aquatic and riparian habitats experience many problems that are affected by water planning and management decisions. Research needs include better knowledge of streamflow requirements for key fish species, predictive models for species response to streamflow variability, methods of assessing aquatic and riparian habitats, predictive methods for habitat suitability and resultant fish production, methods for predicting the adverse impacts of water projects on fish and wildlife, and criteria for in-stream flows.

General fisheries research is still needed to assist water resource planners and managers. Hatchery techniques need improvement, fish passage at large dams is a continuing problem requiring better solutions. In general, more research on the maintenance and enhancement of anadromous, estuarine and marine fishery resources is required.

Many problems that affect planning fall under the general category of economic impacts. The economic impacts need assessment for such subjects as promotion of more efficient irrigation water use, economic benefits and tradeoffs in water allocation, public costs of water quality control and before-and-after-use treatments, public acceptance of visual water quality, water pricing structure.

The interrelationships of water and energy use involve numerous problems of concern in water resource planning. Examples include energy requirements and efficiencies for alternative irrigation systems, the potentials and constraints of small-scale and low-head hydropower development and the impacts of energy development on in-stream water use, fish passage, and out-of-stream diversions.

In addition to the above categories of problems and research needs, many problems are more directly a part of the planning process. Examples include water allocation and tradeoff analysis, adequacy of existing institutions to deal with future problems, identification of new trends and technologies, regional jurisdiction problems, institutional and jurisdiction communications, systems analysis improvements, improved basic data, improved decisions from limited data bases, stream corridor management, relation of water quality and water quantity planning.

Researching Outlook

Researchers must be aware of several crucial points as they develop plans to conduct research during the next several years.

1. The golden goose is dead. The time of plenty of money to research all sorts of things disappeared a few years ago and is not coming back.

2. More people are after the same bucks. The competition for research dollars has grown due to the expanding number of water resource researchers each year and to the decline in federal funding.

3. The people who want information still think there is a free lunch--but they're wrong, its the researcher who may be paying for it. The university expert will still be called upon by entities of state, local and federal government to help solve problems. But government probably will be looking for freebies most of the time, rather than being willing to pay for getting the information.

4. A crisis is the time when everyone will be interested in water research findings, and wonder why no one has the necessary answers. The nation is presently willing to undertake the necessary research and development in relatively few water-related areas so that scientific understanding and working technology are available at the time they are needed. (In Oregon, the first heavy rains ending the 1976-77 drought also washed away public interest in drought-related research -- until our next drought!! Then they'll wonder why we don't know more than we did in 1977!!).

5. National problems are in. If its only a state or local problem, its not likely to get federal funding. Federal agencies are having trouble justifying their research programs before Congress and the Administration. They are more likely to fund research of national than of local significance.

6. The buyer wants to know more about what he's getting and whether it will be useful. Researchers have to do a better job of "selling" research ideas by clearly demonstrating the need and applicability of the research. Funding agencies, faced with staff cutbacks, are not likely to support proposals that may not produce usable findings.

7. "Basic research" is a no-no! Big issues have many problems, some due to general knowledge gaps where basic research will allow a general increase of scientific knowledge. But funding agencies got nervous about this and would rather fund practical application that have a demonstrable, immediate effect on some current problem. Proposals to do basic research should be enlarged to include practical application, if possible.

8. Stay in touch with the "real world". (That's where all those people are who create problems and then expect someone else to bail them out -- for free!) Researchers need to maintain a sense of the problem, need and application when engrossed in research. Following up on the possible applicability of completed research is also essential to assure its beneficial use -- which in turn should provide considerable satisfaction to the researcher.

REFERENCES

"A Ten-Year Program of Federal Water Resources Research". Office of Science and Technology, Executive Office of the President. February 1966.

"Executive Summary Directions in U.S. Water Research: 1978-1982". Committee on Water Resources Research, 1977. NTIS publication PB-276 808.