EPA-600/3-77-036
April 1977

Ecological Research Series

# NON-POINT WATER QUALITY MODELING IN WILDLAND MANAGEMENT: A State-of-the-Art Assessment (Volume I--Text)

Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Athens, Georgia 30601

## RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ECOLOGICAL RESEARCH series. This series describes research on the effects of pollution on humans, plant and animal species, and materials. Problems are assessed for their long- and short-term influences. Investigations include formation, transport, and pathway studies to determine the fate of pollutants and their effects. This work provides the technical basis for setting standards to minimize undesirable changes in living organisms in the aquatic, terrestrial, and atmospheric environments.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/3-77-036
April 1977

# NON-POINT WATER QUALITY MODELING IN WILDLAND MANAGEMENT: A STATE-OF-THE-ART ASSESSMENT (Volume I--Text)

by

Forest Service
United States Department of Agriculture
Washington, D.C. 20250

Interagency Agreement No. EPA-IAG-D5-0660

Project Officer

Lee Mulkey
Environmental Research Laboratory
Athens, Georgia 30601

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ATHENS, GEORGIA 30601

## DISCLAIMER

This report has been reviewed by the Environmental Research Laboratory, Athens, Georgia, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation of use.

## FOREWORD

Environmental protection efforts are increasingly directed toward preventing adverse health and ecology effects associated with specific components of natural or human origin. As part of this laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management or engineering tools for assessing and controlling adverse environmental effects of non-irrigated agriculture and of silviculture.

This report presents an assessment and review of: forestry management activities which can increase the non-point pollutant source potential; the effectiveness of demonstated control techniques to reduce this potential; the usefulness and reliability of existing non-point source loading models in planning effective forestry non-point source controls; and an evaluation of the water quality data base available for model development and testing.

David W. Duttweiler
Director
Environmental Research Lab

## ABSTRACT

Predicting non-point pollution from wildland environments is evaluated in three main areas: management activity/pollutant relationship, predictive model review and state-of-the-art assessment, and an inventory of 176 wildland watersheds suitable for model validation and development.

Non-point pollution is directly related to the time and space variability of the hydrologic cycle and existing terrain, and the relationship is site dependent. Impact of sedimentation from site disturbance is the most common.

Predictive models for non-point pollutant loading relating spatial variability and diversity of terrain to management activities are the most important in evaluating the potential on-site impact of planned wildland management activities. Few non-point loading models exist.

The state-of-the-art is represented by process simulation models, not yet extensively used for field application. Their use will require validation and simplification. Modular model development will have the maximum utility in the decision process. The state-of-the-art at the field level lags that of research and is represented by regional regression models and analytical procedures.

Watersheds available for non-point model validation and testing do not have long data records (less than 10 years) except on streamflow and to a lesser extent suspended sediment.

This report was submitted in fulfillment of Interagency Agreement No. EPA-IAG-D5-0660 by the Forest Service, U.S. Department of Agriculture, in cooperation with and under the partial sponsorship of the U.S. Environmentation Protection Agency. This report covers a period from January 24, 1975, to September 30, 1975, and work was completed as of October 25, 1975.

CONTENTS

## FIGURES

TABLES

## ACKNOWLEDGMENTS

The following individuals participated in assembling the information contained in this document.

| | | |
|---|---|---|
| Henry W. Anderson | George Dissmeyer | John Rector |
| Michael A. Barton | David A. Falletti | James Reid |
| James L. Boynton | Ken Holtje | Raymond M. Rice |
| D. Ross Carder | James Hornbeck | James J. Rogers |
| Boyd J. Christensen | J. Sam Krammes | David Rosgen |
| John P. Crumrine | Walt Megahan | Wayne Swank |
| John B. Currier | Marv Meier | Robert B. Thomas |
| Alfred G. Darrach | Logan Norris | Arthur R. Tiedemann |
| Norbert DeByle | Adrian Pelzner | Donald Willen |

In addition, many others provided information. The Forest Service wishes to acknowledge their efforts.

# SECTION 1

# INTRODUCTION

## PURPOSE

The main objective of this report--a result of an interagency agreement between the U.S. Environmental Protection Agency and USDA-Forest Service--is to define the relationship between wildland management practices and non-point sources of pollution. Included are a discussion of predictive techniques related to forest management activities and an inventory of monitored watersheds having data suitable for model development and testing.

## SCOPE

The report is limited to non-point source pollution as it relates to wildland environments and management activities, and excludes the effects of urban, industrial, agricultural, and mining activities on wildlands. It considers only the direct effects on the physical, chemical, or microbiological portions of the aquatic ecosystem and not the related effects on the higher life forms. The report specifically covers work of the Forest Service, but also that of others on non-point source predictive models.

## GENERAL METHODOLOGY AND PROCEDURES

The report was compiled by a task force of 27 Forest Service personnel. Task force members were chosen for their general knowledge of water resources management and their specialized expertise in the various areas addressed in the report.

The three main tasks undertaken were: (1) relating wildland management practices to non-point pollutants and water quality, (2) identifying predictive models, and (3) identifying data bases suitable for model development and testing. The specific methodology is discussed for each of these tasks.

## PROBLEM DEFINITION

Management for water quality requires a knowledge of the terrestrial and the aquatic ecosystems and the hydrologic cycle. These systems are dynamic and are constantly undergoing change due to natural processes and the influence exerted by man. In order to assure that these complex systems are maintained, it is necessary to regulate the limits to which they can be altered. To carry out this protection, it is necessary to understand the processes operating within the system and be able to predict the consequence of activities that will have potential impacts on it.

In order to deal with the potential impacts, it is logical to separate out those that originate from the introduction of pollution by a single source (point source) and those that originate from diffuse sources (non-point source). This distinction (point vs. non-point) has many advantages from a regulatory and predictive viewpoint. Point source pollutants can be described and controlled at the point of discharge into the receiving waters. Non-point sources cannot usually be controlled in the same way because of the multitude of individually small source points and the inability to control the transport mechanism of the pollutants (naturally occurring tributary flows in the hydrologic cycle). The regulatory and predictive techniques for the non-point sources of pollution must therefore be related to the condition of the tributary surfaces and how these surfaces will react to variable amounts of water flow.

The non-point source areas for pollutant loads are all of the surface and subsurface tributary areas; many are forest and range lands (hereafter referred to as wildlands). The condition of these lands and the changes introduced through wildland management activities are important factors in a program of water quality management.

The ability to recognize the inherent spatial and temporal variabilities in this system and to predict what changes in the natural system will result from implementation of various patterns and sequences of management activities is the role that process research and resultant non-point predictive models play in the overall management of the water resource.

Process research and model development require a unique data base for the synthesis of the predictive model. Once the model has been developed, it must be validated and tested to identify its utility for use in a program of water quality management.

This report describes the three main areas identified above: (1) activity/pollutant relationships, (2) predictive models, and (3) data bases for model development and testing.

# SECTION 2

## CONCLUSIONS

The relative importance of any activity in generating pollutant loads from wildlands is site dependent. In general, sedimentation is the most common form of pollution, and the activity having the most widespread potential for sediment production is road and trail construction. Streamflow augmentation is important in areas of unstable channels.

The largest gap in sedimentation modeling is prediction of the sediment contribution from unstable channel sources.

Non-point pollutant loading models (verses in-stream routing models) are most useful in evaluating the potential effects of wildland management on water quality. However, loading models for most pollution parameters (an exception is sediment from surface erosion) are not available.

Regional regression models and analytical procedures represent the state-of-the-art for the prediction of non-point pollutants by field personnel. However, simulation models represent the state-of-the-art in predictive model development.

The validity and utility of any non-point pollution predictive model cannot be determined without calibrating or testing it in the environment for which it will be used.

The behavior of most of the major processes controlling non-point source pollution from wildlands has been researched, but this knowledge has not been integrated to define gaps where additional research is needed.

There is a good distribution of wildland watersheds with baseline water quality data, but most of the data has been collected recently (past 5 to 8 years). Data reflecting the impact of a specific management activity is site dependent, and few watersheds exist where the data base encompasses all major wildland management activities.

The suitability of a data base for use in model development and testing is dependent upon the quality and precision of the data, length of record, and the specific model being tested.

## SECTION 3

## RECOMMENDATIONS

For maximum utility in wildland management, a predictive non-point water quality model should:

1. Be modular in structure within a comprehensive framework.

2. Be able to predict pollutant parameter loading of all orders of streams, but particularly first order.

3. Facilitate comparative evaluation of control or management alternatives (i.e., describe baseline and changes thereto).

4. Represent time and probability variables.

5. Represent spatial variability of conditions and activities within a diverse landscape.

6. Incorporate available knowledge in a form that utilizes available input data, is available for use by field level scientists, and is compatible with the decision-making process.

A comprehensive model framework should be developed along with core process simulation modules for runoff and sediment so as to provide the central components for modeling other non-point pollution processes.

Existing non-point pollutant predictive models and components thereof need to be tested and comparatively evaluated to determine their utility.

Tests of models intended for use by field personnel should be conducted in a management context from the user's perspective, independent of the model's developer and the data used in its development.

Existing data bases should be examined, in light of data requirements to test non-point predictive models, to determine if additional data are needed or if the existing data base can reflect impacts of the major management alternatives.

A concerted effort is needed to integrate existing knowledge of processes controlling non-point source pollution to identify gaps where additional process knowledge is needed.

## SECTION 4

## ASSESSMENT OF NON-POINT POLLUTION AS IT RELATES TO WILDLAND MANAGEMENT

### METHODOLOGY

Identifying the relative importance of the various relationships between water quality parameters and land management activities as non-point sources of pollution required independent evaluation of: (1) the water quality parameter, and (2) the land management activity. The establishment of the relative ranking involved a three-step process.

The first step was the selection and definition of criteria to be used in determining a parameter's importance. Six criteria were selected and defined as follows:

1. Universality--Evaluates how widespread the water quality parameter is relative to non-point discharges.

2. Certainty--Judges the degree of understanding of the impacts of the individual water quality parameters with respect to:

   a. Biological systems (does the parameter definitely affect the aquatic ecosystem?).

   b. Man (how does the parameter affect man's social and economic well-being as well as the potential health hazard?).

3. Breadth of impact--Reflects the number and variety of the beneficial uses affected by the water quality parameter when in the stream and lake environment.

4. Persistence--Describes the persistence of the effects following control of the activity causing the non-point discharge.

5. Synergistic effects--Considers any interactions with other water quality parameters which may result in a compounding of effects of the individual parameters.

6. Tolerance--Indicates the ability of the ecosystem to accommodate a change in the water quality parameter being evaluated.

Once the criteria were selected and defined, each water quality parameter was assessed as to the importance of each criterion and then ranked in one, two, three order. The final priority for a water quality parameter was determined by totaling all the criteria rankings. Water quality parameters with equal totals were given the same priority. The ranking of parameters, in descending order of relative importance, resulted:

1. Sediment
2. Heavy metals
3. Temperature
4. Pathogens
4. Nutrients
4. Pesticides
7. Dissolved oxygen
8. Turbidity
9. Dissolved solids

The list represents the task force's overall estimate of the relative importance of these constituents, recognizing, of course, that in individual cases any one may be more important.

The second step involved the ranking of the individual activities or group of activities according to their importance with respect to non-point source discharges. Four criteria were used for the ranking:

1. How common is the implementation of the activity nationally? Is it an activity which is utilized throughout the United States or is it one that is found only on a regional basis?

2. Does the activity influence a large acreage when it is implemented?

3. Does the activity influence a large number of water quality parameters?

4. Does the activity have long lasting effects (after the activity ceases does discharge of pollutants continue)?

These questions were asked with respect to groups of forest and range management activities. As a result, the relative importance of wildland (forest and range) management activities were ranked in descended order as follows:

1. Road and trail construction and maintenance (site disturbance as a result of road and trail construction, reconstruction, and maintenance).

2. Vegetation manipulation by mechanical means (any activity that uses mechanized equipment to alter or remove the vegetation, excepting timber harvest, e.g., site preparation, vegetative conversion).

3. Fire (wildfire and prescribed burns, recognizing that wildfire usually has the greatest impact; excludes effect of constructing fuel breaks, fire lines).

4. Grazing (the effects of grazing by domestic stock and wildlife animals; excludes impacts of range improvements).

5. Timber harvest (considers only the effect of removing the timber; excludes road construction).

6. Application of pesticides (considers only direct effects of the pesticide application).

7. Recreation (considers recreation as a use and its direct effects; excludes facility construction and maintenance).

8. Fertilization (direct effects of fertilizer application).

9. Waste disposal (direct disposal of wastes by burying the spreading waste).

10. Low-head impoundments and diversions (in-place effects of the impoundments and diversions; does not consider the effects of construction).

The final setup in establishing the relative importance of relationships between parameters and land management activities was to combine the independent rankings established for the pollutant and wildland management actvities (Figure 1). The individual parameter/activity relationships were ranked relative to their potential for water quality degradation in four categories: high, medium, low, and negligible. By necessity this ranking is general, and specific cases may have different potentials. Figure 1 provides a point of reference, but the task force recognizes that it is subject to debate and that the importance of any activity/parameter relationship is site dependent.

| | Sediment | Heavy metals | Temperature | Pathogens | Pesticides | Nutrients | Dissolved oxygen | Turbidity | Dissolved solids |
|---|---|---|---|---|---|---|---|---|---|
| Vegetation manipulation by mechanical means | H | | L | | | L | | M | |
| Roads and trails | H | | L | | | | | M | |
| Fire | H | | M | | | L | | M | |
| Grazing | M | | | L | | | L | L | |
| Timber harvest | M | | M | | | M | M | L | L |
| Application of pesticides | | | | | M | | | | |
| Recreation | | | | L | | | | | |
| Fertilization | | | | | | M | | | |
| Waste disposal | | M | | M | | L | | | L |
| Lowhead impoundments and diversions | | | L | L | | L | L | | |

H = High
M = Medium
L = Low
Blank = Negligible

Figure 1. RELATIVE POTENTIAL FOR WATER QUALITY DEGRADATION FOR INDIVIDUAL PARAMETER ACTIVITY RELATIONSHIPS.

## SOME POTENTIAL EFFECTS OF WILDLAND MANAGEMENT ACTIVITIES ON WATER QUALITY

### Mechanical Manipulation of Vegetation

Manipulation of vegetative cover by mechanical means is done for a variety of purposes. Examples include: site preparation following timber harvest; vegetal type conversions to increase water yields, to convert hardwoods to pines, to construct fuel breaks, to increase or modify range wildlife production; erosion control practices; and clearing of vegetation for special projects such as fire lines, power lines, and pipelines. The work is usually done with bulldozers alone or equipped with various types of plows, rippers, disk harrows, chains, rototillers, choppers, rootrakes, and compactors (Burns and Hebb, 1972). Generally such practices result in varying degrees of removal of the protective cover on the soil surface.

#### Causes and Effects--

Four pollution parameters: sediment, turbidity, water temperature, and, to a lesser extent, nutrients have been identified as having a potential for increase in the tributary waters as a result of the vegetal manipulation practices described above. Potential changes in pollution concentrations are caused by disturbances to vegetation and soils. A variety of impacts are created depending on the type of practice and equipment used and the objective of the treatment. Obviously the vegetation is disturbed to some degree ranging from overstory removal with some disturbance of underlying vegetation to complete removal of all vegetal cover. Soil disturbance varies considerably as well. Burns and Hebb (1972) describe the range in impacts caused by various site preparation measures to reduce competition of scrub oak and wire grass to pine on droughty, acid sand soils in Florida.

> One extreme is represented by the rotary tiller that thoroughly mixes existing vegetation and litter into the topsoil and causes a temporary increase in the porportion of large pores; the process "fluffs" the soil but leaves it in place. A bulldozer [using a standard blade]* represents the other extreme, wherein vegetation and topsoil are removed and deposited in windrows, leaving soils compacted and devoid of topsoil and organic matter.

The more severe soil disturbances tend to decrease infiltration porportionate to the degree of soil compaction caused by the equipment used and the amount of surface soil or protective cover removed during the operation. Tackle (1962) reports reductions in infiltration on a logged area in western Montana

---

*Inserted for clarification.

where the site was scarified with a bulldozer equipped with a brush buncher blade. Infiltration on the scarified area averaged about 15 percent of that on nearby undisturbed areas. In subsequent years, infiltration increased, but still was only about 50 percent of that on undisturbed areas 5 years after logging. Tackle states,

> Ordinarily, a partial removal of a plant cover and disturbance to the soil surface by a tractor should not result in excessive and prolonged infiltration reductions. The reduction shown here most likely reflects the effect of compaction rather than scarification per se.

Steibrenner and Gessel (1955) found infiltration rates reduced by 80 percent following four passes with an HD20 tractor on soils of the Olympic series in Washington. Only one pass was required to cause similar reductions under moist soil conditions.

Some vegetal manipulations by mechanical means may have beneficial effects with respect to infiltration, runoff, and erosion. Skau (1961) calculated that about 0.46 cm of water storage was provided by pits left from a juniper chaining operation in Arizona in which the tree cover was converted to productive grassland by seeding. Gifford and others (1970), on the other hand, found no consistent increase or decrease in infiltration and sediment yield from areas cleared of pinyon-juniper trees and seeded to grass in southern Utah. In a subsequent study, Gifford (1973) reported that chaining, coupled with windrowing, increased runoff and sediment yields on .04 ha plots up to 5 to 6 times, as compared with nearby undisturbed stands of pinyon-juniper. In contrast, chained areas with debris left in place showed no increase in runoff or erosion.

Bulldozing and burning of juniper can cause nutrient losses in the runoff. This loss is related directly to slope steepness, with 6.7 kg/ha of N lost from moderate (19 percent) slopes with 22 to 67 kg/ha of N lost from steep (57 percent) slopes (Wright and others, 1974). Removal of pinyon-juniper by cabling did not alter the sediment concentration-discharge relationship or the yields of bedload or suspended sediment on an Arizona watershed (Brown, 1971). Clearcutting pinyon-juniper and leaving debris in place on another watershed, thus avoiding soil disturbance, produced similar results.

Conversion of deep-rooted vegetation to more shallow-rooted vegetation decreases transpiration and thereby increases runoff potential. Anderson and Gleason (1960) found soil moisture increases of 7 to 15 cm depending on the soil depth following brush removal by bulldozing to mineral soil on a brushfield in northern California. Similar effects followed chaparral removal by burning and herbicide application in Arizona. Streamflow increases of 30 cm or more were obtained with this treatment (Hibbert, 1971).

Watershed rehabilitation practices involving manipulation of vegetation and soil disturbance have been designed specifically to reduce runoff and erosion. Soil ripping, soil pitting, and contour furrowing reduce erosion and the potential for eroded soil to become sediment in streams. Such practices enhance infiltration of water and increase vegetative growth. Soil ripping in New Mexico reduced surface runoff 96 percent and erosion 85 percent in the first year after treatment on rolling rangelands; 3 years later reductions were still 85 percent and 31 percent, respectively, (Hickey and Dortignac, 1963). Contour trenching on steeper, denuded and eroding mountain watersheds reduced overland flow and effectively stopped the washing of sediment from the treated areas (Noble, 1963). Contour trenching on a Utah watershed reduced peak flows but not annual water yields (Doty, 1971). For several years after treatment, the chemical, physical, and bacteriological characteristics of streamflow from the treated and adjacent untreated watersheds were essentially the same (Doty and Hookano, 1974).

Buck (1959) described various treatments in northern California to remove brush competition for ponderosa pine plantings. In all cases, treatments were applied on slopes of less than 35 percent. The most extreme treatment required complete soil removal to a depth of 46 to 61 cm (18 to 24 inches) along terraces to eliminate competition of bear clover to planted ponderosa pine. Terracing work of this type (also called contouring, trenching, scalping, and stripping), common practice in many areas, helps to assure successful establishment of plantations (Curtis, 1964). Terraces are constructed on the contour with strips of varying widths of undisturbed vegetation left between terraces.

Vegetation type conversions (of one type to another) may involve riparian vegetation in or near intermittent to perennial streams or springs. In such circumstances, increases in water temperature may result if vegetation tall enough to shade the stream is removed.

Magnitude of the Problem--

Opportunities for manipulation of vegetation are very widespread throughout the United States. To illustrate, Evanko (n.d.) reports that in northern California approximately 25,000 ha of the woodland-chaparal cover type in National Forests (approximately 27,000 ha) could be treated to some degree to increase productivity. And considerably more treatable area undoubtedly occurs on the additional 7 million hectares (18 million acres) of similar lands in other Federal holdings, State, and private ownership in that State.

In the southeastern United States, Dissmeyer (unpublished) estimated that in the Tar-Neuse watershed, 4 percent of the forest land is undergoing erosion as a result of mechanical site preparation. On those sites, Dissmeyer (unpublished) estimated that suspended sediment carried by storm flow is 988 mg/l of which 701 mg/l is contributed by areas subjected to mechanical site preparation. In the Alabama River Basin, Dissmeyer (unpublished) estimated that 80 percent of the erosion from forested lands occurs on areas treated mechanically to prepare the site for seeding or planting.

Duration of Effects--

Excluding landslides, adverse hydrologic effects of vegetal manipulation by mechanical means are highest immediately after disturbance and decrease over time as vegetation grows (Boster and Davis, 1972). Tackle (1962) reports that infiltration on scarified lands in Montana improved with time, increasing from 20 percent of the undisturbed value to 50 percent in a 5-year period. Gifford (1973) found no time trend in runoff or erosion following pinyon-juniper chaining in Utah, but the lack of observed effect was undoubtedly caused by the sparsity of runoff-producing storms.

The speed of vegetation growth varies considerably depending on site conditions. On seeded areas, a grass stand normally is well established within a year or two. Natural seeding and sprouting of shrubs also varies considerably. In Florida, a luxuriant growth of forbs invaded cleared areas following timber site preparation with 1 year. In addition, oak sprouts were numerous within a few years (Burns and Hebb, 1972). Sprouting of shrubs on treated areas in California can provide a dense cover within 1 or 2 years where scarification has not been deep enough to control the brush (Buck, 1959). For the southeastern United States, Dissmeyer (unpublished) reports that a recovery period of 2 to 4 years is the average for forested sites that were given mechanical site preparation.

Mass erosion resulting from type conversion on steep areas is time-dependent. A lag exists between the time vegetation is removed and root decay has progressed to the point that soil shear strength is reduced. Coupled with this is the need for a storm event large enough to generate the high hazard conditions conducive to mass erosion. Rice and Foggin (1971) reported landslide occurrences in 1965, 1966, and 1969 on chaparral areas converted to grass in 1960.

## Roads and Trails

Road construction on forest lands can create a variety of site disturbances that may accelerate erosion and resultant sedimentation. Numerous researchers document the fact that road construction can lead to increased sedimentation, especially in mountainous terrain (Anderson, 1954; Packer and Haupt, 1965; Colman, 1953; Frederiksen, 1970; Haupt and Kidd, 1965; Lieberman and Hoover, 1948; Reinhart and others, 1963; Rice and Wallis, 1962; Megahan and Kidd, 1971). Most of this potental impact is in terms of accelerated on-site erosion including both surface, channel bank, and mass erosion. Eroded material that enters the drainage system results in sediment and turbidity and often is the transport mechanism for other pollution parameters. Although other pollution may result from road construction, the road-sediment relationship is of primary importance (Bullard, 1963; Packer, 1967; Rice and others, 1972; U.S. Environmental Protection Agency, 1973, 1974).

Other practices including road reconstruction, road maintenance, and trail construction have the potential to create pollution problems. Impacts will generally be less serious than those caused by the construction of new roads, however. Reconstuction to improve standards on existing roads or to re-open closed roads is a common practice in many areas. The magnitude of the effects are comparable to new construction on those portions of the road directly affected by reconstruction (Anderson, 1974). Area affected may vary from the entire road length in the case of extensive road widening to isolated drainage crossings when re-opening a road that has been "put to bed." Poor road maintenance practices aggravate erosion problems, whereas good practices can greatly reduce them. Trail construction involves many of the principles of road construction but on a much reduced scale with lessened erosional impacts. The impacts of trail construction are primarily related to improper drainage (Scott and Williams, 1975; Megahan, 1961, 1962).

Factors Causing Pollution from Roads--

Site disturbances that contribute to accelerated erosion and sedimentation following road construction include: (1) removal or reduction in protective cover; (2) destruction or impairment of natural soil structure and fertility; (3) increased slope gradients on cut and fill slopes; (4) decreased infiltration rates; (5) interception of sub-surface flow by the road cut slope; and (6) decreased shear strength and/or increases shear stress on cut and fill slopes. Poorly designed roads, particularly location and drainage, can also result in erosion.

Erosion caused by road construction is not of concern regarding water pollution until the eroded material enters the drainage system. Thus, proximity to a stream channel is an important factor regulating the amount of pollution. In those instances where roads are immediately adjacent to or encroach on streams, eroded material enters directly into the drainage system. Such close proximity is usually limited to channel crossing sites. However, where stream-grade road locations are used, considerably longer stretches of road can be involved in sediment production (Anderson, 1974). Where roads are located away from stream channels, a number of factors regulate downslope sediment movement including side slope gradient; frequency of cross drainage in the road; the type, frequency and continuity of obstructions below the road; the nature of the soil material eroded; road gradient, etc. (Trimble and Sartz, 1957; Haupt, 1959; Packer, 1967).

Channel encroachment can cause other pollution problems in addition to sedimentation and turbidity. Encroachment both from channel crossings and streamside location destroys streamside vegetation which in turn tends to increase water temperatures primarily because of greater solar radiation heat loads on the streams (Krammes and Burns, 1973). In addition to increased water temperatures, Krammes and Burns reported a decrease in dissolved oxygen levels at isolated locations in a stream near construction activities and in the vicinity of concentrations of logging slash. Finally, applications of surface amendments within the road prism have the potential for creating minor, localized pollution problems. Such amendments include: fertilizers to enhance revegetation of disturbed soils; pesticides to control vegetation and insects; salt for de-icing; and various chemicals for surface stabilization of the road trend and for erosion control.

Magnitude and Duration of Effects--

The magnitude of the potential for road-related pollution problems is illustrated by the extent of forest road systems. Gardner (1967) estimated that there were at that time approximately 322,000 km (200,000 mi.) of maintained roads in existence on National Forests. Additionally, there are probably as many miles or more of forest roads located on other Federal, State, and private lands.

Obviously not all roads create problems; increases in sediment yields caused by road construction vary considerably, depending on the properties of the site in question and care taken in the road development process (Table 1). Note how increases in average sediment yields vary from essentially zero at locations in Colorado and Oregon to increases of 1 to 2 times at other Oregon locations and in Idaho and California. Increased sediment yields of 45 times were measured on steep slopes with highly erodible granitic soils in Idaho.

The data on average sediment yield presented in Table 1 are somewhat misleading because the occurrence of surface erosion and mass failure varies considerably over time. Surface erosion is most easily detected in terms of suspended sediment concentrations; thus time trends in the concentrations following road construction may be expected to be similar to those found for

TABLE 1. EROSION AND SEDIMENTATION FROM LOGGING ROADS*

| Location | Soil parent material | Slope (%) | Type of vegetation | Type of study | Years sampled (No.) | Average sediment removed: Undisturbed (Metric tons/sq km/yr) | Average sediment removed: Disturbed (Metric tons/sq km/yr) | Ratio disturbed/undisturbed |
|---|---|---|---|---|---|---|---|---|
| Idaho | Granitic | 70 | Ponderosa pine | Deposition in dams in small ephemeral drainages | 6 | 9 | 397 | 45.2 |
| Oregon | Sandstone | 20-50 | Douglas-fir | Suspended sediment from watersheds | 1 | 42 approx. | 94 | 2.2 |
| Colo. | Glaciated metamorphic | 30-40 | Lodgepole pine, subalpine fir | Deposition in dams in perennial drainages | 10-14 | 2† | § | 0 |
| Idaho | Granitic | 35-55 | Ponderosa pine, | Deposition in sediment dams in ephemeral and perennial streams | 4-5 | 0 | 1 | - |
| Oregon | Glaciated basalts | 20-30 | Douglas-fir | Suspended sediment at gaging station | 4 | Ave. 10 ppm. | # | - |
| Oregon | Tuffs and breccias | 55 | Douglas-fir | Suspended sediment and bedloads from watersheds | 2 | 26 | 56 | 2.2 |
| Idaho | Granitic | 30-70 | Ponderosa pine, Douglas-fir | Deposition in dams in perennial first and second order streams | 7 | 6 | 11 | 1.7 |
| Calif. | Sandstone | ** | Douglas-fir, redwood, and associated species | Deposition in debris dams | 4 | 33† | 64 | 1.9 |

* Megahan, 1974.
† Assumed sediment volume weight of 1,122 kilograms per cubic meter (70 pounds per cubic foot).
§ Slight increases traced to roads but not significant.
# No change except slight increase during road construction.
** Streamside location.

surface erosion. Such trends have, in fact, occurred at a number of locations in the United States (Anderson, 1972; Frederiksen, 1970; Reinhart and others, 1963; Rice and others, 1969; Dissmeyer, unpublished).

Mass failure is a natural slope sculpturing process which is a function of climate, topography, soils and geology, and vegetation. Failures may occur when sheer strength of a slope is exceeded by gravitational and other stresses. Road construction can increase the tendency for mass failure by undercutting upslope soils, altering the natural drainage pattern of the slope, accelerating weathering of soil parent material, adding weight to the soil mass underlying fill slopes, and by removing deep-rooted vegetation that previously helped to stabilize soil material underlying fill slopes. Numerous reports substantiate the fact that road construction can cause mass failures in areas of high erosion hazard such as in steep, mountainous terrain (Dryness, 1967; Rothacher and Glazebrook, 1968; Gonsior and Gardner, 1971; Brown and Krygier, 1971; Megahan and Kidd, 1972). Mass failures following road construction may be somewhat time-dependent in that they usually occur when large rainstorms and/or snowmelt cause large volume water inputs into the soil. However, some recent unpublished data collected by the Forest Service on the Clearwater National Forest in Idaho, suggest a more consistent time trend where mass failure occurrence on 150 slides was related to road age as follows:

| Road Age (years) | Occurrence of Landslides (percent) |
|---|---|
| 0-5 | 5 |
| 6-10 | 50 |
| 11-15 | 34 |
| 16+ | 11 |

By far the largest percentage of slides occurred on roads from 6 to 15 years of age. Although not conclusive, these data suggest that decay of organic material (primarily roots) contributes to slope failure. Similar results were shown by data collected on logged areas where slide occurrence was related to decay of roots 5 to 10 years after cutting (Swanston, 1969; Bishop and Stevens, 1964).

Channel storage is one additional factor that helps make sediment pollution from road construction time-dependent. This effect is particularly important for bedload sediment where downstream movement is limited by the streamflow energy available for transport. Sediment in excess of the transport capacity of the channel system. Krammes and Burns (1973) speculated that it took 3 years for excessive bedload sediments to move over a 3.2 km stretch of channel at Caspar Creek in California. Similar effects are reported by Platts and Megahan (1975) who found a marked time trend over a 9-year period in channel bottom materials of the South Fork of the Salmon River.

Reduction of Pollution Problems from Roads--

The erosional and consequent sedimentation impacts of road construction need not be passively accepted. There are a variety of principles and procedures available to reduce impacts. These can be summarized as four basic principles as follows:

1. Minimize the amount of disturbance caused by road construction by:

   a. Controlling the total mileage of roads.
   b. Reducing the area of disturbance on the roads that are built.
   c. Fitting the road to the landscape.

2. Avoid construction in high erosion hazard areas and steep stream grades.

3. Reduce potential erosion on areas that are disturbed by construction by using effective erosion control practices.

4. Minimize the off-site impacts of sedimentation by use of debris basins, sediment traps, etc.

To be effective, these principles must be considered throughout the entire road development process proceeding from broad land use planning through road location, design, construction, maintenance, and closure.

## Fire

Fire is a natural constituent of most forest ecosystems in the United States. Consequently, even without human intervention, water pollution resulting from fire will be observed from time to time. The importance of fire as a cause of pollution varies considerably among forest ecosystems, being least important in the rain forests of the north Pacific Coast and deciduous forests in the northeastern United States, and of extreme importance in the forests and semi-arid lands of the southwest.

The term "wildfire" is used to mean any fire which is not purposely set to achieve some management objective. Fires set in conjunction with a fire suppression activity and those fires which are permitted to burn as part of a conscious "natural burn policy" are also considered to be wildfires. In evaluating the effects of both wild and prescribed fires, to the extent that data permit, only the effects of burning are considered. The disturbances resulting from the preparation of fire lines or use of chemicals to prepare the fuel for prescribed burns are not considered here.

Cause and Effect Relationships--

Increased sedimentation is the principal impact of forest fires on water quality. In the immediate post-fire years, the sediment increase is due to removal of the protective vegetative and litter cover and an increase in surface runoff leading to increased sheet, rill, gully, and stream-channel erosion. The amount of sedimentation can be nil for prescribed burns or very high from areas burned by hot fires that consume all protective vegetative cover and litter. However, the effects vary from site to site. In steep terrain prone to mass wasting, fire may lead to increased sedimentation from landslide erosion four or more years after the fire.

Erosion--

Overland flow is unusual in undisturbed forested watersheds because rainfall intensities in most storms fail to exceed the infiltration capacity of the soil. During those rain periods when the infiltration capacity is exceeded, the layer of forest litter on the soil surface helps to mitigate the possible adverse effects of overland flow. Litter provides storage capacity for water in excess of the soil's infiltration rate, and in most circumstances it creates surface roughness which reduces the velocity and subsequent eroding power of overland flow. It also physically protects the soil surface from the eroding action of flowing water. In addition to reducing erosion by retarding runoff, storage of water in the litter layer tends to dampen hydrologic responses, reducing runoff peaks and channel scour. Thus, the damage which a fire does to a watershed can often be measured by the extent to which the litter layer is destroyed.

On some sites where the channel systems are in equilibrium with pre-fire runoff potential, the additional runoff in post-fire situations can cause significant stream bank erosion and stream sedimentation.

Watersheds with coarse-textured, highly decomposed granitic soils or soils which are very strongly aggregated may exhibit accelerated post-fire runoff and erosion due to a creation of a water-repellent layer (DeBano and Rice, 1973). In such circumstances, hydrophobic organic compounds accumulate in a layer a few centimeters below the soil surface. In an unburned condition, the hydrologically active portion of the soil mantle may be as much as a few meters thick. With the creation of a water repellent layer, it is at most a few centimeters thick. Consequently, even a modest size storm can saturate this thin layer causing overland flow and severe erosion.

### Dry Ravel and Mass Wasting--

On steep watersheds in the western United States, fire can also increase erosion and sedimentation by increasing dry ravel (Krammes, 1965; Mersereau and Dyrness, 1972). This type of accelerated erosion, the individual movement of soil particles under the force of gravity, begins immediately with the fire's passing. The soil particles will move downslope until encountering terrain flatter than the soil's angle of repose. Often this location will be in or adjacent to the stream channels. These deposits are a readily available source of sediment which can be transported by fire-induced high discharges or major storm events. Transport of these deposits, and other deposits which have accumulated in the channel over the years prior to the fire, are an important source of post-fire sedimentation (Scott 1971; Rice, 1974).

On sites prone to mass wasting where fire has created a hydrophobic condition, fire tends to reduce landslide incidence for a few years following the burn due to reduced infiltration. Over time, however, as the roots of fire-killed vegetation decay, increased susceptibility to landslides has been noted. With remarkable consistency, regardless of whether the vegetation has been destroyed by fire or logging and, seemingly, regardless of climate, accelerated landslide erosion begins about 5 years after the vegetation is killed (Bishop and Stevens, 1964; Corbett and Rice, 1966; Dyrness, 1967; Rice and others, 1969; Burgy and Papazifiriou, 1971; Rice and Foggin, 1971).

### Water Temperature and Chemical Pollution--

In all probability, wildfire removes less stream shade than logging in the riparian zone. Fuel moisture is normally higher adjacent to live streams and, therefore, burning conditions are less severe. Thus, a fringe of unburned or partially burned stands often remains adjacent to stream channels. The significance of increases in water temperature depends, in part, upon the climate of the area concerned. For example, Barnhart (personal communication) believes that in short coastal streams of northwestern California, small temperature increases would have an overall beneficial effect on anadromous fish because of the increased growth of stream organisms in response to increased light. In other cases, where high summer temperatures may be limiting, similar increases would be detrimental.

The use of fire retardant chemicals during fire suppression action is a possible source of water pollution related to wildfires. Nutrients released when fire destroys the forest floor present another possible source. It is significant to note here that the control of sedimentation provides an important key to the control of water pollution by mineral nutrients. Fredriksen (1971) found that 53 percent of the annual nitrogen loss following burning was incorporated in the sediment. Similarly, DeBano and Conrad (unpublished) reported that nearly 80 percent of the nutrient loss from their burned plots was incorporated into the sediment.

Vegetative Recovery--

Sedimentation and other pollution usually decrease rapidly following a fire. The duration of effect varies with the severity of the fire and climate, recovery being most rapid following light burns in climates favoring rapid vegetative regrowth. Fredriksen (1970) observed that understory vegetation on two logged and burned areas in Oregon returned to near normal in 1 to 4 years. Brown and Krygier (1971) reported that a 100 percent clearcut and burned watershed which had a 5-fold increase in sedimentation was revegetating at a rate that could be expected to return sediment yield to normal in about the 5th or 6th year after burning. Sedimentation effects following chaparral fires in southern California are thought to return to normal in about 10 years (Rowe and others, 1954). Orr (1971) has suggested that watershed recovery coincides with vegetative recovery producing 60 percent ground cover. In the southeastern United States, recovery time following prescribed burns averages 2 years (Dissmeyer, unpublished).

Magnitude of the Problem--

As a result of the cumulative effect of the previously discussed processes, large increases in sedimentation can follow wildfires, particularly in mountainous lands of the West. Prescribed fires are normally associated with lesser increases. Reported increases range from 1.4x from a prescribed burn on gentle topography in Mississippi (Ursic, 1970) to 120x as the result of chaparral fire in California followed by a large storm (Simpson, 1969). Quantitatively, these rates range from about 80 to 43,800 metric tons/km$^2$ for the first runoff season following the fire. Intermediate values of 3.5 tons/km$^2$ for a 4-year period following slash burning in western Montana (DeByle and Packer, 1972) and 5,250 tons/km$^2$ measured during the first summer rain storms following a wildfire in a logged area in Arizona (Rich, 1962).

A slash fire in western Oregon resulted in measured dry ravel at rates of from 66.5 to 1,050 tons/km$^2$ during the 9th to 14th month after burning (Mersereau and Dryness, 1972). In southern California 4,912 tons/km$^2$ dry ravel was measured over a 3-year period following a chaparral fire (Krammes, 1965).

Although delayed, the fire-related increase in landslide erosion can be substantial. Dyrness (1967) reported a 10-fold increase in the frequency of landslides attributable to clearcut logging and slash burning. When comparing burned and unburned chaparral, Rice (1974) found an 18.6-fold increase in the volume of landslide erosion following burning. While there have been no comparable studies in forested areas, presumably the increases would be similar.

The effect of fire on streamflow temperatures appears to be no different than any other type of clearing of riparian vegetation. In a summary of stream temperature responses from six different studies, Helvey (1973) found the elevation of stream temperatures due to wildfire within the range established for the effect of selective logging, clearcut blocks, clearcut, and clearcut and burned.

Preliminary results from a current study in several forest ecosystems evaluating the possibility of pollution by fire retardants (Logan Norris, personal communication) indicate that this activity is not likely to lead to significant water pollution. Water quality was monitored at points where the retardant drops were simulated and at sites downstream. High concentrations of retardants were found only in the treatment zone shortly after application. Concentrations rapidly attenuated downstream and over time. In no case have the investigators observed fish mortality or change in benthic organisms. This, coupled with the fact that retardant drops directly into streams are uncommon (firelines are usually on ridges), leads to the conclusion that the potential for water polution from fire retardant chemicals is slight.

There are numerous reports of flushes of mineral nutrients in streamflow following prescribed fires and wildfires. Three studies on the effects of wildfires indicated negligible increases in mineral nutrients (Lotspeich, Mueller, and Frey, 1970; Johnson and Needham, 1966; and Klock, 1971). However, Fredriksen (1972) found that concentrations of nitrogen and manganese exceeded water quality standards for a 12-day period following slash burning. In other studies DeByle and Packer (1972) and DeBano and Conrad (unpublished) reported very high concentrations of nutrients in runoff water. The discrepancy between the control burns and the wildfires was possibly related to the volume of material being burned. The wildfires were all in young or sparse timber, whereas the control burns were in heavy slash or chaparral.

More research is needed to accurately define the role of fire in nutrient release and its significance to water quality. However, the general opinion of the Forest Service at this time is that prescribed fire or wildfire appear to pose no significant threat to water quality from chemical pollution.

Available Controls and Management Techniques to Reduce the Problem--

To minimize the effect of fire on water quality, it is necessary to reduce the severity of the fire. For wildfires, this requires a long-range fuel management program designed to minimize the quantity of fuel available. Fuel accumulation can be minimized in various ways, such as reducing logging debris by closer utilization of slash material, yarding slash material and heavy fuels to a central point for controlled burning, and by using prescribed burns to keep fuel accumulation to a minimum.

Post-fire techniques of erosion control are usually limited to practices designed to enhance vegetative recovery. These practices include seeding the area to grasses, forbs, shrubs (with or without fertilization), and planting the area to trees.

Surfactants can be used to promote infiltration to counteract fire-induced water repellent layers. In plot studies (Krammes and Osborn, 1968), erosion was reduced about 35 percent for dry ravel and water borne sediment, but the only large-scale test failed to show any treatment effect. Subsequent studies have shown that heavier application of different surfactants should be effective (DeBano and Conrad, unpublished). However, the treatment cost (about $4,000/km$^2$) would be prohibitive under most circumstances.

Grazing

Domestic livestock graze on approximately half of the 111 ha (273 million acres) of public rangeland in the 11 western states alone (Public Land Law Review Commission, 1970). In addition, livestock graze on private lands in these states and on forests, ranges, wild pastures in the East. Wild ungulate populations exist in every state and where concentrated, they can impact water quality similarly to domestic livestock. Therefore, water pollution resulting from livestock or wildlife grazing on watersheds has the potential of affecting a large portion of our Nation.

The pollution parameters resulting from grazing of forests, rangelands, and wild pastures are: sediment, pathogens, nitrogen and phosphorus (nutrients), biochemical oxygen demand, and turbidity. Pollution from heavy metals, temperature changes, pesticides, and other potential pollutants that might stem from grazing are not considered to be sufficiently significant to warrant discussion.

The production of sediment has long been a major problem associated with grazing of wildlands, but only recently have other types of pollution been recognized. A disproportionate amount of the literature deals with erosion and resulting sediment production with some data on turbidity and dissolved solids. Documentation for other pollutants appears not at all or only recently in the literature, and one could falsely conclude that sediment is the only important pollution resulting from grazing.

Cause and Effect Relationships--

Grazing may directly or indirectly cause pollution. Direct pollution comes from urine and manure dropped directly into surface waters or transported to them via overland flow. Dead animals can directly pollute in the same manner as animal wastes. Also, animals often wallow in shallow waters, and at least locally, cause turbidity as well as streambank collapse and cutting. Collapse of streambanks can be attributed also to trail crossings or animals grazing on the banks.

Indirect pollution from intensive grazing comes from disturbing the plant community, removing much of the vegetation, and trampling the soil. This, in turn, may markedly increase overland flow, causing erosion of particulates and transport of dissolved solids into the streams. Excessive grazing sometimes causes gullying of formerly stable meadows thus starting a new cycle of erosion that can only be halted by mechanical structures.

Magnitude of Problem and Some Control Techniques--

In the western United States, streamflow comes from the forested mountains, while the sediment loads in these streams come mainly from the rangelands (Branson and others, 1972). These authors further state that sediment transported by runoff water greatly exceeds, in volume, the combined total of all other substances that pollute our surface water.

On erodible marine shales, grazing was responsible for an increase in sediment yields of approximately 45 percent in western Colorado (Lusby, 1970). In contrast, Dunford (1949) found that on permeable granitic soils of eastern Colorado, moderate grazing resulted in almost no increase in erosion; heavy grazing, however did cause substantial increases. Grazing, depletion of plant cover, and trampling of the soil contributed the most to erosion on the Boise River watershed (Renner, 1936). Packer (1963) stated that ground cover densities of at least 70 percent and soil bulk densities no greater than 1.04 were necessary for restoring and maintaining soil stability on the Gallatin elk winter range in Montana. Better grazing management over a 3-year period in New Mexico brought about improved watershed conditions in which average ground cover doubled and bare ground exposure decreased with marked reductions in sediment yields and runoff (Aldon, 1964).

The relation of grazing to density of plant cover, which, in turn, is related to overland flow and soil erosion, has been explicitly and implicitly shown by many researchers (Rauzi, 1955; Packer, 1953; Meeuwig, 1965; Rauzi and Hanson, 1966). The Australian Commonwealth Bureau of Soils published a bibliography in 1966 citing 120 references related to the effect of the grazing animal on the soil. Much of this research was confined to plot studies and sometimes to small watersheds. Only on watersheds with perennial streams can erosion be related directly to sediment loads in the streams. However, in the opinion of Meiman and Kunkle (1967), bacteria groups and their ratios give a better measure of grazing impact on water quality than suspended sediment or turbidity.

In contrast to the many reports on the effects of grazing and range management on erosion and sedimentation, little information exists on the effects of grazing on dissolved solid content or chemical quality of waters (Branson and others, 1972). In the West, most of the water comes from the mountains, but, as with sediment, most of the dissolved solids come from the lower parts of the drainage area (Irons and others, 1965). Thus, the rolling, mid-elevation, western rangelands contribute from natural sources large amounts of both sediment and dissolved solids to our river systems. However, this literature review disclosed no clear relationship between dissolved solid content of water and grazing.

If increased grazing pressure results in increased overland flow, then it would seem that not only erosion and sediment but also the chemical quality of the streamflow would be altered, at least during storm flows. No literature was found to support or refute this hypothesis.

Grazing can increase the bacterial content of surface waters. Kunkle (1970) found fecal coliform counts only slightly higher than on ungrazed areas when grazing cattle were located away from the Vermont stream he was studying. The source of pollution, he discovered, was the strip immediately adjacent to the stream that yields storm overland flow.

Morrison and Fair (1966) pointed out that cattle grazing adjacent to the Cache la Poudre River in Colorado caused increases in coliform counts and total bacterial counts. They believed that either wild or domestic animals on a watershed are a source of potentially pathogenic enteric bacteria.

Grazing and irrigation of a mountain meadow, according to Kunkle and Meiman (1967), resulted in higher coliform counts, with fecal coliforms being most sensitive to this treatment. They found that storms raised the natural levels of sediment, turbidity, and organisms, and that the difference between the natural and impacted streams were then magnified. Peterson and

Boring (1960) also reported that flood irrigation and presence of cattle in the stream increased coliform densities. Darling (1973) showed significantly higher coliform, fecal coliform, and fecal streptococci counts in Utah mountain streams just below grazed areas than at other locations.

Walter and Bottman (1967) found that a watershed in Montana closed to the public had higher streamwater bacterial counts than one open to public recreation. This unusual relationship was later attributed to elk on the closed, undisturbed watershed by Goodrich and others (1970) and Bissonette and others (1970). Coliform counts rose to 250 per 100 ml of water as the stream flowed through a summer elk range on the closed watershed. Average counts downstream were 160 per 100 ml.

Controls for Reducing Pollution Caused by Grazing--

Present technology and current practices offer means of controlling water pollution from grazing activity. Livestock can be fenced from stream and lake shores. Through proper development, springs and water holes can be protected from wallowing stock. Grazing systems that enhance and maintain good range cnditions minimize or reduce sediment and turbidity in waters coming from grazed lands. Control of wild ungulate numbers and concentrations is possible through adequate harvest of individual herds.

## Timber Harvest

Timber harvest operations are extremely widespread throughout the United States and play a very important role in wildland management. Discussed here are only those aspects directly associated with the cutting and removal of trees. Most of the detrimental effects normally associated with logging result from poor construction practices associated with some roads and skid trails and the use of fire for slash disposal or site preparation. These activities (roads and fire) are discussed elsewhere in this report. The effects of timber harvest considered here approximate the minimum that can be expected if the timber resources are to be managed.

Cause and Effect Relationships--

Of all the possible effects of a timber harvest, the one that appears to be the most inescapable is the release of nutrients (mainly forms of nitrogen) to streams. Opening of the forest canopy accelerates decomposition of organic material and the reduced biomass brings about a subsequent reduction in nutrient uptake by the forest. When evaluating the effect of timber harvest on nutrient release, many factors should be considered. These include: forest soil exchange capacity, microclimate following logging, hydrology of the logged slope, rate of regrowth, character of the litter layer, and degree of surface disturbance. Usually losses to streamflow are <u>inversely</u> related to the exchange capacity of the soil mass and the litter layer and <u>directly</u> related to degree of disturbance.

Water Temperature and Oxygen Depletion--

Logging adjacent to stream channels opens the forest canopy, thus increasing the solar energy reaching the water surface. Longwave radiation from the stream environment and advection energy from adjacent areas are usually increased, producing higher water temperatures. The temperature increase is directly proportional to the increased exposure to radiation.

Oxygen depletion can then result from the combined effects of biochemical oxygen demand of logging debris in the stream and the reduced oxygen solubility in the heated water. The leachate from such debris also may have toxic effects. However, Ponce (1974) believes that oxygen depletion would occur before leachate concentrations could reach a toxic level. In addition to its chemical effects, logging debris may also present physical barriers to fish movement and spawning which degrade the stream as a fish habitat.

Soil Erosion--

Some soil surface disturbance is inherent in timber harvest, the effect of which is dependent upon soil type and other site characteristics. Nevertheless erosion in these disturbed areas is a potential source of stream sediment. The sediment also may be the vehicle by which other pollutants are transported to the stream.

The severity of soil disturbance and its extent is more dependent upon the yarding method and road density than upon the silvicultural method (Table 2). Tractors usually yard in a downhill direction creating a pattern of bare soil which collects and concentrates overland flow. Cable systems, on the other hand, most often yard uphill, creating a pattern of disturbance which disperses surface water. Even when yarding downhill, cable systems do not create a dendritic pattern; consequently, overland flow is only concentrated at the landing. Skyline, balloon, and helicopter yarding cause random disturbances to the soil having little effect on overland flow.

Mass Wasting--

When steep slopes are logged, they may become more vulnerable to landslide erosion. With few exceptions (Ellison and Coaldrake, 1954; Flaccus, 1959) investigators throughout the world have reached similar conclusions. Equally accepted is that 5 years usually elapse following logging before appearance of substantial landsliding (Bishop and Stevens, 1964; Rice, Corbett,

TABLE 2. SOIL DISTURBANCE FROM LOGGING*

| Logging system | Percent bare soil | Location | Reference |
|---|---|---|---|
| Tractor - selection | 87.7 | N. California | Boe, N.D. |
| Tractor - clearcut | 70.0 | N. California | Boe, N.D. |
| Tractor - clearcut | 29.4 | E. Washington | Wooldridge, 1960 |
| Tractor - clearcut | 26.1 | W. Washington | Steibrenner and Gessel, 1955 |
| Cable - selection | 20.9 | E. Wash. and Ore. | Garrison and Rummell, 1951 |
| High lead - clearcut | 18.8 | W. Oregon | Dyrness, 1967a |
| High lead - clearcut | 15.8 | W. Oregon | Ruth, 1967 |
| Tractor - selection | 15.5 | E. Wash. and Ore. | Garrison and Rummell, 1951 |
| Skyline - clearcut | 12.1 | W. Oregon | Dyrness, 1967a |
| Skyline - clearcut | 11.1 | E. Washington | Wooldridge, 1960 |
| Skyline - clearcut | 6.4 | W. Oregon | Ruth, 1967 |
| Balloon - clearcut | 6.0 | W. Oregon | Dyrness, N.D. |

*Rice, Rothacher, and Megahan, 1972.

and Bailey, 1969; Nakano, 1971). Rice and Krammes (1971) estimate that landslides are triggered by storms with return periods of about 7 years. There has been little American research concerning trends in slope strength to be fully restored. He also noted that the frequency of landsliding tends to increase again as decadent forests begin to deteriorate.

Magnitude of the Problem--

Nutrient losses were studied in New Hampshire on the Hubbard Brook Experimental Forest. Here, in contrast with normal logging, Watershed 2 was totally devegetated by repeated applications of herbicides. This study showed that increased losses of nutrient ions can be important in the nutrient capital of the watershed. For example, Pierce and others (1970) reported increased nitrogen losses for the first 3 years amounting to 9 percent of the original nitrogen capital of the site. Two factors are thought to be the main causes of this high release. First, herbicides were used for the 3-year period to prevent any vegetative regrowth, and second, the soils here are strong podzols which are especially vulnerable to the treatment applied (Pierce, 1972). A subsequent study on a similar watershed in this experimental forest, using a conventional harvesting method, a strip cut, disclosed that the nitrogen losses were much less dramatic, amounting to less than 1 percent of the nitrogen capital of the site (Hornbeck and others, 1975). Studies in other areas also show small nutrient releases from logged areas (Aubertin and Patric, 1972; Fredriksen, 1971).

The implication of the 1975 study on Hubbard Brook and others is that under most conventional logging methods the nutrient loss will be a very small percentage of the nutrient capital of the site. While it is recognized that the temporary increase of nutrients in the receiving waters will occur, it is not thought to present a major impact on the water quality of the first order streams draining the cut areas. This conclusion is tentative and subject to further examination.

In a summary of stream temperature responses in six different studies, Helvey (1973) found the elevation of stream temperatures to be about 3° to 7° C. due to wildfire, selective logging, clearcut blocks, clearcut, and clearcut and burned.

In the Hubbard Brook Experimental Forest, the effect of total vegetation removal was to raise the maximum summer stream temperature 6° C. (Pierce and others, 1970). The subsequent strip cut of a similar watershed showed only about a 1° C. increase in the maximum summer stream temperature (Hornbeck and others, 1975).

Stream temperature increases may have either a beneficial or negative effect depending upon the desired condition of the stream and the history of water temperature in the stream.

Froelich (1973) reported considerable variability in the amount of organic debris in undisturbed forest streams. He has also shown that with a modest amount of care, an area may be logged without an appreciable increase in total organic debris in the stream channel. After logging, only four of the nine study channels that he studied had amounts of fine debris within the range of natural variability, pointing out the difficulty in controlling the accumulation of such material. Only in one channel was the amount of fine debris below the average for natural water courses. If this fine debris enters the stream during summer low flows, it can present a serious threat to fish during the first 3 weeks following entry (Ponce and Brown, 1974).

Usually the surface erosion following logging is minor compared to that resulting from landslides and the effects of slash burning. Megahan (1972) found about 11 metric tons per $km^2$/yr of surface erosion from felling and skidding on a skyline logging area in Idaho. In another skyline logging area in Oregon, Fredriksen (1970) measured only 0.8 percent (4.9 metric tons/$km^2$) of the post-logging sedimentation output during the 3 seasons after logging but before slash burning or landslides. Other studies indicate little or no sedimentation from logging (Meehan and others, 1969; Lull and Satterlund, 1963; Packer, 1967; Brown and Krygier, 1971). However, surface erosion can sometimes be serious. For example, Kawaguchi and others (1959), using 20x40 m plots in a 30-year-old pine forest, found surface erosion to increase exponentially with the size of the area clearcut.

The amount of eroded material that will move off-site is dependent on the trap efficiency of the site. The trap efficiency is highly variable and can vary from nil to 100 percent. The quantification of the amount of erosion from channel sources is difficult, and the literature is sketchy regarding this source of sedimentation as a result of logging. The recent work by Rosgen (1975) on the Idaho Panhandle National Forests shows that channel erosion can account for as much as 90 percent of the total sediment load for a channel system.

Increased stream channel erosion may occur where the harvest of trees causes changes in the streamflow hydrograph. The magnitude of this increase in channel erosion is dependent on the pre-harvest stream channel stability and the magnitude and duration of the post-harvest streamflow increases.

Studies on the volume of landslide erosion on logging areas are relatively rare. Nonetheless, many investigators have reported it is an important erosional process in mountainous forested areas that are prone to mass movement, accounting for 25 to 50 percent of the total erosion. Characteristically, 10-fold increases in landslide erosion are observed following clearcut logging (Nakano, 1971; Dryness, 1967). Fredriksen (1970) measured 189 metric tons/km$^2$ sedimentation (about a 2.3x increase) from a recently clearcut watershed following a storm that resulted in a landslide. The landslide occurred in 1964 and the measurements wre made from 1964 to 1966. Later, after slash burning had removed obstructions to sediment movement, an additional 445 metric tons/km$^2$ (1268.2 tons/sq.mi.) were measured. These measurements were made from 1966-68.

Available Controls and Management Techniques to Reduce the Problem--

Technology is currently available to reduce water pollution from logging. Generally, the strategy is to adopt low impact logging methods, to refrain from entering potentially unstable areas, and to schedule logging activity so as to allow interim recovery. To adopt a more sophisticated strategy permitting greater utilization will require more information about processes and a higher level of on-the-ground expertise than is currently available.

It is doubtful that there is enough information to adequately model the nutrient outflow from logged sites. Only a few climate and soil types have been investigated. However, it does not appear that carefully planned logging activity will have on-site or in-stream nutrient impacts that are intolerable.

The effect of canopy removal on water temperature can be predicted (Brown, 1969). Such predictions can be accurate for stream reaches which are either fully sheltered or fully exposed. Prediction of the effects of intermediate amounts of canopy removal is more difficult and the results less precise (Brazier and Brown, 1973). Under most circumstances, water quality problems related to organic debris or stream temperature may be minimized by the preservation of a buffer strip along water courses. Buffer strips would also decrease the severity of oxygen depletion resulting from the fine debris entering a stream. Ponce and Brown (1974), observing a synergistic effect between fine organic debris and sunlight, concluded that "clearcutting [of buffer strips] may affect the rate at which oxygen is depleted as well as the amount of depletion."

The widespread use of low impact logging methods to minimize surface erosion may not be economically feasible under the present timber market structure.

The levels of disturbance indicated for skyline and baloon clearcutting (Table 2) probably represent the minimum for current technology. On the H. J. Andrews Experimental Forest, Fredriksen

(1970) could detect no rise in sediment rate from watersheds logged by these methods until several large landslides occurred as a result of a major storm. In view of that observation and the trends in disturbance shown in Table 2, it appears that present technology should be able to reduce surface erosion from logging disturbance to negligible levels. The effect of increased water yields on channel stability and erosion is beginning to be recognized in areas where it is a problem. The work by Rosgen (1975) reflects the latest predictive methods to analyze the impact of stream channel erosion caused by increases in water yields.

Although the general outline of the relationship between timber harvest and landslide erosion (mass wasting) appears quite clear, much needs to be learned before reasonably accurate quantitative estimates can be made of the landslide risks from logging a particular site. Such estimates need to incorporate trends in slope stability following logging by various silvicultural systems, the probability distribution of storms of varying sizes, and the rate of regrowth of vegetation. For the present, the only available strategy is to avoid potentially unstable land or at least to forego clearcutting such slopes. There have been no quantitative tests of the precision of landslide prediction in forested areas, but in chaparral forecast accuracy of 84 percent has been achieved (Kojan, Foggin, and Rice, 1972).

Application of Pesticides

The word pesticide is a general term applied to a wide variety of chemicals (and to a lesser degree biological agents) incuding insecticides, herbicides, fungicides, rodenticides, etc. Pesticides are defined as chemical or biological agents used to control, mitigate, or modify pests, but this definition ignores the fact that pesticides are used as a management tool to help achieve some end. In forestry, the end goal is seldom simply to control or mitigate the pest but more likely to protect or enhance a forest value.

Pesticides play an important role in both modern American agriculture and forestry, but the magnitude, intensity, and pattern of pesticide use is vastly different. In intensive agriculture, one or more pesticides may be applied one or more times during a crop cycle. Crop cycles are short, and repeated applications in agriculture are common. In forestry, most land will not be treated with pesticides at any time during a crop cycle. Lands that are treated seldom receive more than a single application in 1 year or more than one treatment in a crop cycle ranging from 20 to more than 100 years. A large number of compounds are registered for use in agriculture, while in forestry, the principal pesticides used number less than 10. Forestry accounts for only slightly more than 1 percent of the total pesticide use in the United States.

Magnitude and Scope of Pesticide Use--The potential impact of pesticides on forest water quality depends largely on the chemical and its pattern of use. In 1973, more than 1 million pounds of pesticides were applied to forest lands in the United States. The figures in Table 3 represent chemicals used by the Forest Service and also chemicals used on projects involving Federal assistance provided by the Forest Service.

TABLE 3. PESTICIDE USE IN FORESTS, 1973

| Use | Hectares | Percent | Kilograms used* | Percent |
|---|---|---|---|---|
| Herbicide | 105,813 | 24.9 | 310,802 | 57.6 |
| Insecticide | 289,944 | 68.7 | 139,455 | 25.8 |
| Fumigant | 207 | 0.6 | 52,079 | 9.7 |
| Vertebrate control | 27,200 | 6.4 | 7,146 | 1.3 |
| Fungicide | 563 | 0.1 | 30,051 | 5.6 |

* Pounds of active ingredients.

Figures in Table 3 do not include use by other Federal land management agencies or by various state and private groups. In general, these figures underestimate the total use in forestry except for insecticides. The vast majority of insecticides used in forests in the United States are applied on Forest Service lands or through Federal cooperative insect control projects for which the Forest Service has responsibility. Thus, herbicide use reflected in Table 3 probably approaches or exceeds insecticide use in terms of acreage treated annually.

These data suggest that only 0.2 percent of forest land in the United States receives pesticides in any given year. Therefore, interaction between pesticides and water quality is not an extensive problem. In those areas where pesticides are used, however, the interaction, though local, can be intense.

Insecticides--

There are few insecticides which are registered for use on forest lands. Insect damage problems in recent years have been handled as special projects, usually with approval for a particular compound granted by regulatory agencies on a case-by-case basis.

The chlorinated hydrocarbon insecticides are not usually selected for use in forestry when alternate chemicals are available. Insecticides most likely to be used in forestry are various organo-phosphates and carbamates. There is considerable research currently being done to develop hormones and microbial insecticides including bacteria and viruses.

Applications are almost exclusively by air. Large or contiguous areas may be treated in an infestation zone. In any one year, a large percentage of the total amount of given insecticide applied to forests in the United States may be applied in only one region. Several to many years may elapse before application of any magnitude may be made in that region again. The potential for impact of insecticides on water quality may be relatively widespread on a regional basis but is relatively infrequent in occurrence. The gypsy moth control program is a current exception to these generalizations.

Herbicides--

Herbicides are used for a wide variety of purposes in forestry, including fuel break management; vegetation control on powerline, road, and railroad rights-of-way; conversion of hardwood brush to stands of conifers; release of established conifers from competing hardwood brush; thinning; and cull tree removal in established stands. The most commonly used herbicides are the phenoxy herbicides (2,4-D,2,4,5-T, and Silvex), picloram, amitrole, atrazine, and the organic arsenicals (MSMA and cacodylic acid).

Herbicides are applied by a variety of means, including rotary and fixed wing aircraft, through low pressure-high volume ground spray equipment, low volume ground-spray equipment, pellets and granules, and as undiluted concentrate in several stem injection devices. Treatment areas are typically small (2 to 80 ha) and widely scattered. Large contiguous blocks are seldom treated. The annual extent of herbicide use remains reasonably constant on a regional basis, therefore, the potential interaction between herbicides and streams occurs frequently but is of limited scope in any one drainage system.

Fungicides and Rodenticides--

Fungicides receive intensive use in forest tree nurseries but are seldom used in forest land management. Nursery culture is similar to agriculture and is not included in this discussion. Use of rodenticides has dropped sharply in recent years. They are relatively unimportant in terms of potential impact on water quality and are not considered further. Avicides and piscicides receive little or no significant use in forestry and are not discussed here.

Causes and Effects--

There can be direct and indirect effects, as well as short- and long-term effects on the aquatic environment associated with the use of pesticides in forestry.

Indirect Effects--

Indirect effects do not require physical contact between the pesticide and the aquatic system. Such effects would include changes in temperature, pH, nutrient or light levels or other changes in water quality, or energy transport to the water resulting from vegetation management.

Herbicides are most likely to generate indirect effects by changing the density or composition of streamside or upslope vegetative communities (Gratkowski, 1967; Moore and Norris, 1974). Herbicide-treated areas usually have considerable remaining vegetation biomass after application, and vacated ecological niches are rapidly occupied. The resulting conservation and recycling of available nutrients limits their movement to streams.

Insecticides can also have indirect effects. Some effects, such as protection of foliage from defoliating insects is advantageous to the aquatic environment while a sharp reduction in the supply of terrestrial insects as food for aquatic organisms may be a temporary disadvantage. Terrestrial insect populations, however, are seldom completely destroyed by insecticide applications, and although species composition may be dramatically changed, insect biomass changes are usually transitory (Macdonald and Webb, 1963; Dixon, 1972; Thomas and McCluskey, 1974).

In general, forest ecosystems tend to be remarkably resilient, and long-term indirect effects associated with pesticide use will be transitory and likely pass unnoticed except under close scrutiny.

Direct Effects--

As opposed to indirect effects, direct effects require the entry of the pesticide into the aquatic system. The nature of the effect on the organisms depends on the chemical, the magnitude and duration of exposure, and a large number of biological factors (Terriere, 1971). The magnitude and duration of exposure of organisms in forest waters is largely determined by the route of pesticide entry to the stream and the subsequent behavior of the chemical.

Chemicals can enter the aquatic environment by one or more of the following routes: (1) direct application to surface waters, (2) drift from nearby spray areas, (3) rain washing from foliage overhanging streams, (4) overland flow, (5) erosion, and (6) leaching.

The route most likely to introduce significant quantities of pesticides into surface waters is direct application. Such application has the potential to produce the highest concentrations and therefore cause the most pronounced toxic effects, although the duration of entry will be brief (Norris and Moore, 1971). The resulting concentration depends on the rate of application and the ratio of stream surface area to its volume. The resistence of the chemicals in the application zone depends on the length of stream treated, the velocity of stream flow, and the nature of the water course. Pesticide concentrations normally decrease markedly with downstream movement as dilution by incoming uncontaminated water occurs; and as the chemical interacts with the stream bottom, is decomposed by chemical, physical, or biological means, or is taken up by various organisms (Norris, 1971a; Lichtenstein and others, 1966; Guerrant and others, 1970; Schwartz, 1967). Aquatic organisms' exposure will typically be intense but brief when direct application to surface water occurs. The pattern of direct impact will be most intense in the application zone and will diminish with time and with distance downstream. Direct application to stream surfaces can usually be avoided.

A modification of direct application is the drift from nearby spray areas to surface waters. The same characteristics of direct application apply except that peak concentrations of pesticide residues will be lower, and consequently impacts on stream organisms will be less. The accidental drift of chemical from nearby spray areas to stream surfaces is the most likely means of pesticide entry to surface waters.

Pesticides deposited on streamside vegetation either from direct application of drift may be washed by rain into streams. This is less important than either direct application or drift because the amount of chemical involved is likely to be small, and entry will occur only during rainy periods when stream levels might be rising, thereby resulting in additional dilution (Norris and others, 1967). The probability of occurrence diminishes markedly with time after application because of the reduced availability of residues for washing action. Volatilization, uptake and metabolism by the plant, and photo and biological degradation all combine to reduce pesticide residue levels on vegetation surfaces with time (Wilcox, 1971; Back, 1965; Norris and others, 1975).

The possibility of pesticide pollution from overland flow is not great as such flow occurs only infrequently on most forest lands. The infiltration capacity of the forest floor and soil is usually far greater than rates of precipitation (Rothacher and Lopushinsky, 1974). Areas of bare and compacted soil may yield surface runoff but these are not widespread and would seldom be treated with pesticides.

Pesticides absorbed on soil particles frequently enter the aquatic environment from agricultural areas, but seldom from forested areas (Barnett and others, 1967). Erosion is relatively common in managed forests, but the principal sources are road construction and landslides after site disturbance (Rice and others, 1972). Pesticides will seldom be applied in such a temporal and special relationship with either of these events to result in the significant entry of chemicals to streams.

Leaching of pesticides through the soil profile is the process of pesticide entry to streams most feared by the general public but is the process least likely to occur. The pesticides used in forestry are fairly immobile in soil (Harris, 1967, 1968). Heavier, intense leaching may cause movement from a few centimeters to a meter in depth, but these distances are short in comparison to distances to surface water (Norris, 1971a). Most forest pesticides are also quite transitory and do not persist long enough for significant movement to occur even if leaching was an important process (Upchurch, 1972; Edwards, 1972).

The nature and intensity of the effects of pesticide residues which enter streams will vary with the organism, the pesticide, a wide variety of physical and biological parameters, and the magnitude and duration of exposure. Except for the generalizations which follow, this extensive topic is beyond the scope of this document.

For a given organism in a particular environment, the nature and intensity of its response to a given pesticide can be estimated from studying established dose-response relationships developed in standard bioassay tests. Typically acute responses, like death or the loss of locomotion or various senses, are the result of relatively short-term exposure to relatively high concentrations of pesticide (Norris, 1971b; Terriere, 1971; Thut and Haydu, 1971). Chronic effects, such as reduced growth or reproductive success or gradual shifts in species composition, are more likely to result from long-term exposure to relatively low concentrations of pesticide (Holden, 1973).

On forest land, direct application and drift are the principal routes of pesticide entry to forest streams. These will result in only short-term exposure. Therefore, probable effects can be easily determined from the toxicological literature on acute effects. Forest chemicals in use today are sufficiently immobile and of such short persistence that long-term, low-level entry to aquatic systems is unlikely. This largely precludes chronic exposure. These subjects are considered in detail in several recent volumes (Gould, 1966 and 1971; Guenzi, 1974; Goring and Hamaker, 1972; White-Stevens, 1971; House and others, 1967; Pimentel, 1971; Gunsalus and others, 1972).

Management Techniques and Available Controls--Pesticide use is one of the most heavily regulated activities on forest land. Regulation comes from Federal and state regulatory agencies, and in the case of public land management agencies, from agency policies as well. EPA has a predominant role through their pesticide registration and labeling process. Pesticides used in forestry have been subjected to close scrutiny to determine their behavior in the environment and their impact on a wide variety of aerial, terrestial, and aquatic organisms. Those materials or patterns of use which will impact significantly on the aquatic environment are not registered. Only those chemicals which are registered may be used. Only patterns of use specifically mentioned on the label may be used.

Despite regulatory efforts, however, pesticide labels are the subject of considerable interpretation in the field, and pesticide applicators have some latitude in actual practice. All chemicals have some degree of toxicity, and it is possible through the use of improper practices to cause serious impact on stream organisms. Reconsideration of the processes involved in pesticide entry to streams shows direct application to the stream surface and accidental drift of spray materials from nearby treatment units to be the principal processes involved. These processes are not a property of the chemical in use, but rather the technique of application.

It is easy to avoid direct application to surface waters. Norris (1971a) admonishes, "If you don't want chemicals in the water, then don't put them there." Pre-project planning to locate and mark live streams to be sure they are excluded from the spray area is necessary. Pre-spray briefing and orientation for the applicator is also necessary to insure streams are not sprayed.

Avoiding drift is more difficult, but is can be accomplished. Careful attention to atmospheric conditions, formulation, and spray equipment operation will help minimize the formation and movement of small particles of spray material (Maksymiuk, 1971a, 1971b; Witt, 1971).

## Recreation

For some time recreational use of forested and associated land has been on a steady increase (Hetherington, 1971). The magnitude of various activities may be derived from the National Forest summary report on recreation for 1974 (Table 4). Approximately two-thirds of the recorded use for 1974 was associated

TABLE 4. ESTIMATED NATIONAL FOREST RECREATION USE
SERVICE-WIDE SUMMARY, CY 1976, BY ACTIVITIES

| Activity | | Public use | |
|---|---|---|---|
| | | Visitor-days* | Percent |
| Camping | | 51,543,500 | 26.7 |
| Picnicking | | 6,933,200 | 3.6 |
| Recreation travel (mechanized) | | 44,332,900 | 23.1 |
| Automobile | 37,385,200 | | |
| Scooter & motorcycle | 3,580,300 | | |
| Ice & snowcraft | 3,022,500 | | |
| Other | 344,900 | | |
| Boating | | 5,790,100 | 3.1 |
| Powerboats | 3,679,300 | | |
| Self propelled boats | 2,110,800 | | |
| Games & team sports | | 747,800 | .4 |
| Waterskiing & other water sports | | 1,154,100 | .6 |
| Swimming & scuba diving | | 3,928,800 | 2.0 |
| Winter sports | | 8,377,800 | 4.3 |
| Skiing | 6,935,000 | | |
| Other | 1,442,800 | | |
| Fishing | | 16,402,500 | 8.5 |
| Hunting | | 14,422,800 | 7.5 |
| Hiking & mountain climbing | | 8,514,300 | 4.4 |
| Horseback riding | | 2,815,100 | 1.5 |
| Resort use | | 3,934,200 | 2.0 |
| Organization camp use | | 4,232,900 | 2.2 |
| Gather forest products | | 6,979,900 | 3.6 |
| Nature study | | 1,011,800 | .5 |
| Viewing scenery, sports, & environment | | 6,186,000 | 3.2 |
| Visitor information (talks, etc.) | | 3,420,700 | 1.8 |
| Service-wide Total | | 192,915,800 | 100.0 |

* Recreational use of National Forest land and water which aggregates 12 person-hours. May entail 1 person for 12 hours, 12 persons for 1 hour, or any equivalent combination of individual or group use, either continuous or intermittent.

with four major elements: camping, recreation travel, fishing, and hunting, listed in order of importance. The remaining use is scattered among many activities. This basic relationship seems likely to hold, but there may be some shifting of use in the future due to changes in the nation's economy.

Recreational use of wildlands is concentrated on or near physical developments such as camping or picnic grounds, roads, trails, and water. Fishing and hunting vary from this somewhat but are usually closely associated with existing roads and trails.

The centers of wildland recreation are the most likely locations for water pollution problems to develop. It is here that most of the past effort to provide sanitary facilities, improved roads and trails, and other site improvements has been concentrated.

Cause and Effect Relationships--

Five pollution elements have been considered as problems where recreation is concerned: sediment production, pathogens, nutrients, dissolved oxygen levels, and turbidity.

The occasional hiker tramping the wooded hills leaves no trace. A multitude over the same route often causes a problem. Trampling of the existing ground vegetation usually is a major cause of recreation site deterioration (Wagar, 1964; Orr, 1971; and Frissell and Duncan, 1965). A frequent side effect of trampling is soil compaction. In some cases this may actually be an asset to a recreation site (Magill, 1970), for compaction of trails is essential in providing strength to support traffic loads. But compaction may cause considerable damage to the soil structure. Lutz (1945) showed that soil density and field capacity are increased, while pore volume, air space, and infiltration are greatly reduced following compaction. Where infiltration has been reduced to the point that overland flow occurs, there is a chance that erosion and sediment may result if proper drainage is absent.

Probably the most readily observed impact of trampling on recreation sites is the abrasive effect upon vegetation, often with a pronounced deterioration of the vegetative cover during the first 2 years (Magill, personal communication). The original vegetation lost though trampling is usually partially replaced by more resistant species in time. Site deterioration tends to stabilize and a new balance of vegetative cover and use occurs where proper management practices are followed (Magill, 1970; LaPage, 1967).

If the pressure from recreationists becomes too great, areas of concentrated use, such as unprotected hiking trails, may begin to erode and wash. The resulting sediment production is a source of pollution as observed in the Adirondack Mountains by Ketchledge (1971). He also noted erosion problems caused by heavy hiking use on fragile alpine soil and plant communities.

In situations where site deterioration has gone beyond trampling and compaction, physical displacement of soil by the traffic takes place. Hikers and animals cause this type of damage and so do many sorts of recreation vehicles. Estimates have placed the ratio of damage by vehicles to the landscape at nearly 200 times that of a hiker (Hope, 1972).

Many factors affect the amount of erosion that may become sediment from recreation facilities. The elements of greatest importance are the climate, soil or surface erodibility, slope, and ground cover. The main factor in sediment delivery is the distance eroded material must travel to a stream course and whether it passes through a buffer strip.

There are procedures available for application to intensively managed recreation sites that help to control many of the worst attributes of heavy use. Among these practices are improved recreation layouts, surfacing traffic areas, and the separation of mechanized vehicles from foot traffic (Lime, 1971; Magill, 1970).

Vectors of disease are always a threat when human waste and refuse are present. This is particularly true in areas of concentrated use, such as campgrounds or along heavily used trails and water courses. The potential for contamination becomes still greater where recreation takes place near or on waters used for municipal supply.

Recreational use of reservoirs has shown an increase of coliform organisms with use. This has been observed at several locations, including sites in California, Missouri, and New Hampshire (Karalekas and Lynch, 1965; Minkus, 1965; Ongerth, 1964; and Rosebery, 1964).

The use of forested watersheds at locations other than organized recreation sites sometimes poses a threat to public health. Stream and lake-side fishing sites and heavily used trails that are near open water are usually the greatest problem areas. Where this situation exists, the traffic should be reduced to safe levels or sanitary facilities provided.

Coliform count in some range and forested areas can be attributed to wildlife or domestic livestock. In such cases it may be difficult to distinguish the pollution effect from recreation taking place on the same area.

Nutrients from recreation sites may come from leached material derived from human and other waste deposited on the site. This problem has been reduced to a minimum on organized recreation sites by providing proper sanitary facilities and trash containers. In areas of shallow soils and soils of low exchange capacity, nutrient loading may become a real problem (Barton, 1969). The greatest hazard to water quality seems to exist on bodies of water that are already naturally enriched and need little additional nutrition to cause biological problems. The most noticeable effects, however, accompany the additon of small amounts of nutrients to relatively infertile bodies of water.

In fast-flowing mountain streams dissolved oxygen concentration is usually high. Recreation is not thought to reduce oxygen levels at these sites, but where slow-moving waters occur, the potential exists. Lakes and rivers in this category used by recreationists can receive enough nutrition to cause excessive plant growth and occasional algal blooms with associated effects on oxygen levels. It should be noted that the Boundary Waters Canoe Area in northern Minnesota has suffered some of these effects (Barton, 1969).

Any action that places fine particulate matter in water will increase turbidity and reduce light penetration in a lake or stream. Plant life that is dependent upon the sunlight can be reduced or killed by this pollutant. Recreation activity affects turbidity primarily through sediment. Some disturbance of stream and lake bottoms may occur because of contact sports such as swimming, boating, or fishing, but these activities are considered of minor importance and only a local annoyance.

Magnitude of the Problem--

The potential pollution problem from forest recreation naturally increases with site use (Annon, 1961). It is diminished by the degree of recreation dispersion and site distance from functioning water courses. Some management practices available to minimize pollution potential are: harden parking lots and foot paths, provide improved sanitation facilities, install various traffic barriers, and use plants resistant to heavy use.

Recreation sites that are easily damanaged by trampling and those exhibiting low levels of pollutants are of major concern in evaluating the impact of recreationists on water quality. Some of the lakes within the Boundary Waters Canoe Area are in this category and many alpine meadows, small lakes, and bogs also have similar problems. Efforts are being made to control the amount of recreation in areas of this type through permit, closure, and other administrative devices. On-site physical improvements are also used to reduce site damage and lower pollution potential.

Nutrition of waters associated with recreation is not considered to be a problem except in a few special cases. The presence of adequate sanitary facilities reduces the chance for nutritional loading, and proper sanitary conditions lessen the opportunity of pathogens to enter the water. The sediment from recreation areas is thought to be small compared with other wildland activities. Proper site management and initial layout can reduce this pollutant. The greatest hazard usually presented by recreation is the close proximity of much of the wildland recreation to the water bodies themselves.

## Forest Fertilization

Application of fertilizer to wildlands is currently being practiced for a variety of reasons: to rehabilitate burns, improve ranges, restore watersheds, but mostly to increase wood production.

Operational forest fertilization is a growing forest management practice in the United States. Bengston (1972) hails it as a treatment to increase growth rate on designated lands principally in the Pacific Northwest and the pine regions of the southern and southeastern states (Groman, 1972; Norris and others, 1971). Groman (1972) points out that other forested sections of the United States may practice forest fertilization to some degree in the future. For example, small-scale fertilization appears imminent in the Lake States. Moore (1972) explains that operational forest fertilization began in 1963 in the Pacific Northwest and in the southeastern pine region in 1968. Bengston (1971) states that most of the fertilized forest land in the United States before 1971 was treated after 1966. Moore (1972) indicates that in the Pacific Northwest from 1963 to 1970, only 222,400 ha had been fertilized, while 247,100 ha were fertilized each year in 1970 and 1971. He predicts that the annual rate of fertilization will exceed 494,200 ha by the late 1970's. On a national basis, Groman (1972) notes that the total fertilized area through 1971 was 741,300 ha.

### Cause and Effect--

Both Moore (1972) and Groman (1972) stress the importance of two characteristics of the forest environment that influence the impact fertilization may have on water quality:

1. The first decimeter of a forest soil generally has a high content of organic matter which provides a large number of adsorption sites for applied chemicals.

2. Most well-established forest stands, including the understory, have massive root systems that offer great opportunity for interception and rapid uptake of chemical fertilizer nutrients.

On the basis of this knowledge of the forest ecosystem, and assuming proper application, Moore (1972), Cooper (1969), and Loehr (1974) are of the opinion that wildland fertilization will probably not significantly affect water quality.

Magnitude of Potential Water Quality Problem--

Nitrogen is the principal fertilizer used in the Northwest (Groman, 1972; Moore, 1972; Klock, 1971; Malueg and others, 1972; Fredricksen, 1972; and Norris and others, 1971).

In the Southeast, however, both phosphorus and nitrogen are applied to forest stands, and in the Northeast and Lake States, conifer plantations on sandy soils have responded to applications of potassium (Moore, 1972; Beaton, 1972).

Aubertin and others (1973) discuss urea fertilization of young hardwood stands in West Virginia. Hornbeck and Pierce (1973) explain that of these three forms of fertilizers, phosphorus will be of least concern with respect to water quality. Taylor (1967) believes that almost all the phosphorus is converted to water insoluble forms within a few hours. Phosphorus fixation potential of the forest soils of the Northeast is so great that the main problem is not with leaching, but the unavailability of the phosphorus for plant use (Hornbeck and Pierce, 1973).

Hornbeck and Pierce (1973) believe that potassium has a strong tendency to be tied up in certain clay minerals. However, they explain that potassium may be leached from acid sandy soils, but this can be controlled to some degree by using a formulation of potassium calcium pyrophosphate. The commonly used potassium chloride is the most susceptible formulation to leaching loss.

Most research to date has dealt with nitrogen fertilizers in the form of urea pellets and ammonium sulfate. These studies yield some preliminary answers to questions about the amount of nitrogen entering surface streams after fertilizing watersheds with nitrogen.

Consistently shown is a rapid increase in nitrogen forms in surface waters shortly after fertilization (Klock, 1971; Malueg and others, 1972; Norris and others, 1971; Moore, 1972; Tiedemann, 1973). The first peak concentration in streams after application is comprised of urea-N, ammonia-N, and nitrate-N. Nitrite-N was not found in significant concentrations. Moore (1972) and Norris and Moore (1971) report that: urea-N reached a maximum concentration of 1.39 ppm 48 hours after application; ammonia-N increased slightly above background but never exceeded 0.10 ppm; and nitrate-N reached a peak concentration of 0.168 ppm 72 hours after application and returned to pre-treament levels in 9 weeks. They estimated that this increase in stream nitrogen lasted 9 to 15 weeks and accounted for only 0.01 percent of all the nitrogen applied to the watershed and only 7 percent of all nitrogen lost to the stream the first year after application.

The above investigators found that about half of the nitrogen lost to the streams during the first 15 weeks after application resulted from direct application to the stream surface and the other half entered the stream as nitrate-N. Tiedemann (1973) recognized this same relationship but did not believe the concentration of nitrate-N in urea pellets was adequate to account for the concentrations of nitrate-N observed following direct application.

A second peak concentration in nitrate nitrogen was observed in response to rainfall and increased streamflow (Malueg and others, 1972; Moore, 1972; Norris and others, 1971; Fredriksen, 1972). Tiedeman (1973) also observed this second peak but prior to the time of maximum discharge. He indicates that moisture moving from the snowpack into and through the soil during the winter carried soluble nitrate-N to the stream. All of these investigators agreed that the nitrate-N resulted from the conversion of urea to nitrate-N in the soil by hydrolysis and nitrification. Moore (1972) reported that approximately 92 percent of the nitrogen loss for the first year after application occurred in this second period. The concentrations of nitrate-N were approximately the same for both periods; however, the high flows in fall, winter, and spring resulted in a larger total loss of nitrate-N during the second period. The total loss for the watershed during this first year was 0.17 percent of the total applied nitrogen.

Management Techniques and Available Controls--

Forest fertilizers are applied by conventional ground methods and by air with both fixed winged aircraft and helicopter (Norris and Moore, 1971). Urea fertilizer, the most popular form of nitrogen fertilizer being used in the Northwest, is applied at the rate of 28 to 91 kilograms/ha.

The use of large, especially coated urea granules (forest prills) has eliminated the problem of drifting dust experienced in early applications (Norris and others, 1971). Klock (1971) applied approximately 46 kilos/ha of ammonium sulphate to accelerate vegetative establishment for erosion control following a fire. He pointed out that those who made the application did not avoid stream channels because they desired the establishment of vegetation in the streamside zone for erosion control. He added that when fertilizers are applied only to increase wood production, the streamside zone can be avoided.

Direct application of fertilizers to the stream surface is recognized as the principal source of nitrogen input following fertilization and should be minimized by marking and avoiding larger streams (Norris and others, 1971; Malueg and others, 1972). In areas where channels are small and only partially exposed, it is the common practice to fertilize without buffer strips along stream channels. Norris (1975) suggests that avoiding the streams and streamside zone may effectively reduce the magnitude of the second peak discharge. He further suggests that the majority of the nitrate-nitrogen comprising the second peak is leached from the streamside zone and is not leached uniformly from the entire area treated. He raises questions similar to those of Aubertin and others (1973). What is the source of the nutrients? Did some areas of the watershed contribute more than other areas? And what would have been the results had an unfertilized buffer strip been provided along the stream channel?

Recapitulation and Conclusions--

Application rates of 28 to 91 kg nitrogen per hectare have not resulted in concentrations of urea-, ammonia-, nitrite-, or nitrate-nitrogen in streams that are toxic to fish, wildlife, aquatic organisms, or man. Losses to the streams occur twice during the first year following application; once in response to direct application to the stream (including some leaching of nitrate to streams) and again, in response to soil moisture movement probably from the streamside-zone in the winter and spring. The first loss amounts to 7 percent of total nitrogen lost while the second loss amounts to 92 percent. The total amount lost the first year after application is approximately 0.2 percent of the total nitrogen applied to the watershed.

Little is known about the short-term effects on water quality of other fertilizer compounds that may be used in wildland management activities. It is expected that phosphorus would be readily tied up in soils. Potassium is also generally immobile, being readily incorporated in weathered clay minerals and organic compounds. However, some leaching has been observed in acid soils.

Thut and Haydu (1971) believed it unlikely that the addition of nutrients by forest fertilization would increase stream productivity significantly. The long-term and repetitive effects of forest and range fertilization on water quality are not known. Aerial forest fertilization with nitrogen and phosphorus is a process by which important nutrients can be added to the aquatic ecosystem. It is recognized that, while concentrations and amounts of nitrogen lost from fertilizer applications are small, the accumulative effects of nutrients on downstream impoundments must be considered.

## Waste Disposal

Solid waste disposal on wildlands may be a potential pollutant source to the ground water supply. The four types of solid waste disposal used most often that can pollute water are open dumps, sanitary land fill, incineration materials, and on-site disposal. From these types of disposal, leached substances may reach surface or ground waters. Permeable areas with high water tables are most likely to be polluted (Schneider, 1970). Little of the total wildland area of the country is presently used for these purposes either because access is difficult or suitable sites are too distant from a population center where waste material is generated.

At times, wildlands near towns are used by some individuals to dispose of waste. In most cases this activity is not legal and presents a regulatory problem. Seldom does this activity become a hazard to water quality unless the dumping takes place within a flood plain. For the most part, solid waste disposal by individuals in wildlands is thought to be nominal and it is not considered further. Where dumps and land fills exist within wildland areas, however, they are considered point sources of pollution and fall under the regulation for point sources.

Of potential importance to the subject of non-point pollution is the disposal of municipal sewage upon forest land. This practice is not widespread but has been encouraged as a tentative treatment for sewage for some industrial units and towns. It may well develop into a major wildland use near towns and villages of moderate size.

### Cause and Effect Relationships--

In sewage disposal operations, primary treatment usually eliminates over half of the suspended solids and most of the grit and settleable solids. Sedimentation removes some of the biochemical oxygen demand, organic nitrogen, phosphorus, and heavy metals (Metcalf and Eddy Inc., 1972). Pathogens, dissolved solids, and colloidal matter are not readily removed (Sepp, 1971).

Secondary waste treatment oxidizes most of the dissolved and colloidal organic material. In addition, natural settling of colloidal meterial and treatment procedures help to trap some pathogens. Various types of disinfection and extended holding times for the treated effluent also provide control of pathogens. Where additional treatment is needed to meet water quality standards, tertiary processes are used. Spray irrigation can accomplish this phase of the waste water renovation by stripping the effluent of much of its nutrients and pathogens as it passes through the soil.

Sopper and Kardos (1973), studying waste water renovation by spray irrigation, found that most of the phosphorus in the effluent was removed as it percolated through the soil. Nitrate-nitrogen was not removed as efficiently by forests as it was by old-field herbaceous and grass cover. When spray volumes were limited to 1-inch per week, drinking water standards were met (Sopper, 1973). These reports indicate that there is little change in soil water chemical quality for P, K, Ca, Na, H, and Mn as a result of waste water application. Similar studies, in New Hampshire, of effluent disposal on forest lands support the Pennsylvania work (Frost, 1973). Here none of the water supplies tested during the spray operation showed any discernible water quality changes.

Liquid wastes from municipal or individual sources have been applied to wildlands by various irrigation methods, but usually in the form of sprays. Potential pollution from the spray process can result from overland flow with the effluent moving directly into the surface water or with spray drift reaching water through the air. A third pollution potential exists when liquid waste moves through the soil into the ground water system with little renovation.

Pore clogging appears to be one of the main causes of effluent overland flow. This happens when solids plug the soil channels at or near the surface (Jones and Taylor, 1965; Thomas and others, 1966). Usually the process is accompanied by flooding in which case anaerobic conditions may prevail for a considerable time. Fortunately this is not the general condition on wildlands used for this purpose. Even under the heavier forest soils the structure remains porous (Evans, 1970; Parizek, 1973).

Frost and icing of the surface have been a concern where irrigation methods of waste disposal are used. Storey (1955) recorded the types of frost most often found in forest soil. In nearly all cases the open honeycomb frost type prevailed in the forest while the closed concrete type was found in plowed fields. Exceptions have been noted by Bay (1960) where concrete frost formed under some even-aged conifer stands--a condition thought to be limited in extent. Bay (1958) recorded concrete frost for 20 percent of the sample points taken in a balsam fir stand, none in aspen, white pine, or hardwood stands, and about 50 percent in an open grazed area in Minnesota. Even where concrete frost does occur, it is not usually a problem since some porous areas remain.

Because forest soils are normally porous year long, it is believed that there will be little clogging of forest soil by irrigation of sewage waste as long as good management practices are followed. This is verified by experience gained in 10 years of spray irrigation of forest and cropland in Pennsylvania (Sopper and Kardos, 1973).

Overland flow can occur almost anywhere if too much irrigation waste water is applied. A moderately-well-drained to well-drained soil is recommended by Parizek (1973). Soil depth recommended for use varies depending on location, seasonal ground water changes, and climate. For humid regions, 3 to 4 feet of soil is desirable with 20 or more feet of unconsolidated deposits below this level. Each site must be analyzed individually. Proper management procedures can often overcome natural deficiencies in a given site.

The last major pollution source to be considered occurs when waste water moves through the soil too fast to be renovated. When soils are in the very rapid infiltration class, there may not be enough time for renovation. The process takes days, not hours, and will vary with climate and season (Parizek, 1973; Urie, 1973).

Another point must also be considered. Treated effluent reduces the presence of pathogens in the waste, but it does not eliminate the potential for a health hazard (Shuval, 1967). There is evidence in this same work that viruses may survive the chlorination applied in a secondary treatment process. Sproul (1967) pointed out, however, that over 99 percent of the viruses can be removed from waste waters by soil percolation. Knowledge of virus survival after reaching the soil is not well documented (Miller, 1973), and it is not understood, to date, what level of viral removal is required to eliminate the public health hazard.

Magnitude of the Problem--

Bendixen and others (1969) found over 2,400 irrigation waste water disposal systems in the United States. With today's energy shortage and high cost of tertiary treatment, the option for irrigation may be valid (Seabrook, 1973), and in general it seems plausible that spray irrigation will increase in the future. For the most part this will probably be confined to relatively small municipal or industrial units, but there is considerable effort being made by some larger water treatment networks (Cleveland-Akron Metropolitan and Three Rivers Watershed) to utilize spray irrigation.

There has been no indication of irrigation failure where the facility was properly maintained and operated. With an increase in such treatment the pollution potential will increase, but nearly all of the carefully planned and monitored spray irrigation projects have thus far shown little variation in the quality of water renovated. This does not mean that problems are unlikely. If waste waters from a highly variable source are utilized, results may be uncertain. This could occur where industrial waste is incorporated into sanitary sewage. Industrial accidents may put surges of pollutants into the treatment system that would alter the effectiveness of the various stages of treatment, including the spray irrigation.

The effect of a catastrophic variation in renovated water quality might well result in the contamination of a water supply. Fortunately this has not happened in the more than 2,400 systems now in operation. With reasonable care the problem should remain nominal.

## Low-Head Impoundments and Diversions

Small, low-head impoundments (with a head of less than approximately 2.5 meters) have been developed on forest and range lands for watering livestock, improving habitat for waterfowl and fish, and for water chances. (Water chance is a term used here for small impoundments in live streams from which water may be pumped into tank trucks for use elsewhere.) While the size of individual impoundments is usually not of major concern, the large number of these developments requires their consideration. The fisheries and waterfowl habitat impoundments generally have 75 percent of their area covered by 0.4 to 0.6 meters of water.

### Magnitude of the Problem--

While the construction of low-head impoundments is not widespread, more and more of them are being built so their potential on-site and downstream affects on water quality may become important. Verry (1975) reports that in Michigan 9,300 ha have been developed within 60 major waterfowl habitat improvement projects, and 1,600 ha within 450 smaller projects. These are small, permanent developments with earth-filled dams 1.8m to 2.5m high. The water level is regulated to control vegetation and enhance the impoundments' productivity.

Impoundments for livestock are developed on intermittent streams to provide a continuous, permanent water supply and, in some cases, to increase forage and range use. Such developments also create a useful habitat for waterfowl and fish (USDA, 1975).

Water chances, along roads, are somewhat different. Impoundments in this case raise the water level sufficiently to form a pool from which water may be pumped into tank trucks. The dam normally provides a head of water from 1 to 2 feet. The water chance is usually used on an annual basis, being reconstructed each year.

While little is known about the downstream effects of low-head impoundments on perennial streams (Verry, 1975), there is concern in the Lake States that such impoundments might raise downstream water temperatures (Verry, 1975; Mathisen, 1975, and Lee and others, 1975). This is particularly important where stream temperatures are already critical for cold water fish.

The increased exposure to solar radiation, due to slowed velocities and increased surface area in the shallow impoundments, results in increased temperatures of impounded waters. Thus, the temperature of the water being released from these impoundments could create significant changes in the aquatic ecosystem downstream.

Studies on the nutrient content of impoundments to provide habitats for fish and waterfowl indicate that the water chemistry can be regulated by drawing down the impoundment and allowing the bottom sediments to dry (Cook and Powers, 1958; Kadlec, 1962; Lathwell and others, 1969; and Linde, 1969). Drawing down impoundments to improve productivity not only stimulates plant growth within the impoundments but affects the chemistry of the water to be released downstream. Extensive and prolonged blooms of blue-green algae after a drawn-down filling cycle have been experienced (Verry, 1975).

Lee and others (1975) describe wetlands as a complex hydrologic, chemical, and biochemical system in which they found wide diurnal fluctuations in dissolved oxygen, pH, and temperature. In some cases in late summer, dissolved oxygen ranged from zero in the early morning to over 8 ppm in late afternoon, rendering this water unsuitable for fish habitat. Taste, odor,and color problems developed in the fall where these impoundments were used as water supplies.

While recognizing some adverse effects of impoundments on downstream water quality, Lee and others (1975) identified some beneficial effects. They pointed out that denitrification reduced the concentration of nitate in waters being released from wetlands and that nutrients are released from these impoundments in the spring during periods of high discharge, thus minimizing algal blooms. Impoundments also serve as excellent traps for sediment and usually reduce downstream streambank erosion. Moreover, they reduce fluctuation of stream levels and peak discharges.

Small multi-purpose impoundments (developed for the benefit of waterfowl, fish, and livestock) on small intermittent streams are common in some wildlands. Because of their streambottom location they receive concentrated livestock use. As a result, nutrient and bacterial contaminants may be concentrated in these impoundments. Impounded waters may become highly enriched through the combination of evaporation and pollutant input (urinating and defecating by livestock and waterfowl). However, this water is normally transported downstream only after it has been diluted by intermittent runoff that causes the impoundment to overflow. While presently not considered a problem, this situation warrants consideration in forest and range management, particularly when a number of these impoundments are located in the upper reaches of a municipal water supply.

The potential water quality problems associated with water chances are sedimentation and temperature changes. The total number of water chances on a single stream are normally few. While this constitutes a consumptive use, the loss in flow is generally not considered to be a major problem.

Sedimentation and erosion associated with water chances may result from road drainage at the site or from erosion of the site itself. Design of water chances in some cases diverts surface runoff from the access road, causing erosion and sedimentation. Also, there is the annual washing away of the earthen structure. Although temporary, not uncommonly the structure is left in place where it, along with any impounded sediment, may subsequently be washed out by peak flows.

LITERATURE CITED, SECTION 4

Aldon, Earl F. 1964. Ground cover changes in relation to runoff and erosion in west central New Mexico. USDA Forest Serv. Res. Note RM-34, 3 p. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo.

Anderson, Henry W. 1954. Suspended sediment discharge as related to streamflow, topography, soil, and land use. Trans. Amer. Geophys. Union 35(2): 268-281.

Anderson, Henry W. 1972. Major floods, poor land use delay return of sedimentation to normal rates. USDA Forest Serv. Res. Note PSW-268, 4 p. Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif.

Anderson, Henry W. 1974. Sediment deposition in reservoirs associated with rural roads, forest fires and catchment attributes. Symp. Effects of Man on the Interface of the Hydrological Cycle with the Physical Environment. IAHS-AISH Publ. No. 113.

Anderson, Henry W., Gleason, Clark H. 1960. Effects of logging and brush removal on snow water runoff. IASH Comm. of Surface Waters Pub. 51, pp. 478-489.

Annon. 1957. Operation outdoors: part 1: national forest recreation. U.S. Govt. Printing Office, Washington, D.C. 14 p.

Annon. 1961. Administrative guide covering public health problems in recreational areas. U.S. Dept. Health, Education and Welfare, Public Health Service.

Annon. 1969. Lesson reference file--compaction and soil trafficability." U.S. Army Eng. School, Fort Belvoir, Virginia. 33 p, illus.

Annon. 1973. Annual pesticide use report. USDA Forest Service, Washington, D.C.

Aubertin, G. M., and Patric, J. H. 1972. Quality water from clearcut forest land? In: Logger 20(8): 12-23.

Aubertin, G. M., Smith, D. W. and Patric, J. H. 1973. Quantity and quality of streamflow after urea fertilization on a forested watershed--first year results. In: Forest Fertilization Symp. Proc. pp. 88-100, USDA Forest Serv. Gen Tech. Rpt. NE-3, Northeastern Forest Exp. Sta., Upper Darby, Pa.

Back, R. C. 1965. Significant developments in light years with sevin insecticide. J. Agric. Food Chem. 13:198.

Barnett, A. P., and others. 1967. Loss of 2,4-d in washoff from cultivated fallow land. Weeds 15:133-137.

Barnhart, Roger A. 1975. Personal communication, Fisheries Biologist, California Cooperative Fisheries Unit, Humboldt State, Arcata, California.

Barton, Michael A. 1969. Water pollution in remote recreational areas. J. Soil and Water Conserv. 24(4): 132-134.

Bay, Roger R. 1958. Occurrence and depth of frozen soil. J. Soil and Water Conservation, 13: 232-233.

Bay, Roger R. 1960. Soil freezing observations after changes in forest cover. USDA Forest Serv. Tech. Note 576, 2 p. Lake States Forest and Range Exp. Sta., St. Paul, Minn.

Beaton, J. D. 1973. Fertilizer methods and applications to forestry practice in: Forest Fertil. Symp. Proc. USDA Forest Serv. Gen. Tech. Rep. NE-3, p. 55-71. Northeastern Forest Exp. Sta., Upper Darby, Penn.

Bendixen, T. W. and others. 1969. Cannery waste treatment by spray irrigation runoff. J. Water Poll. Cont. Fed. 41(3): 385-391.

Bengston, G. W. 1971. Trends in forest fertilization in searching the seventies: 72-77. TVA Nat. Fert. Develop. Cent. Bull. 1-34. 116 p., Muscle Shoals, Ala.

Bengston, G. W. 1972. Forest fertilization: promises and problems. Proc. Soc. Amer. For., pp. 231-234.

Bishop, Daniel M., Stevens, Mervin E. 1964. Landslides on logged areas in southeast Alaska. USDA Forest Serv. Res. Pap. NOR-1, 18 p. Northern Forest Exp. Sta., Juneau, Alaska.

Bissonette, G. K., Stuart, D. G., Goodrich, T. D., and Walter, W. G. 1970. Preliminary studies of serological types of enterobacteria occurring in a closed mountain watershed. Mountain Academy of Sciences Proc. 30: 66-76.

Boster, Ron S. and Davis, Lester R. 1972. Soil loss considerations in chaparral to grass conversions. Proc. Symp. on Watersheds in Transition. Eds. Csallany, Sandor C., McLaughlin, Thad G. and Striffler, William D., Ft. Collins, Colo. Series No. 14, p. 243-250.

Branson, Farrel A., Gifford, Gerald F., and Owen, Robert J. 1972. Rangeland hydrology. Soc. Range Management Series No. 1, 84 p.

Brazier, Jon R., and Brown, George W. 1973. Buffer strips for stream temperature control. Forest Research Lab. Research Paper 15, April 1973, School of Forestry, Oregon State University, Corvallis, Oregon, 9 p.

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

Brown, George W. 1971. Effects of forest management on stream temperature. Proc. of the Symp. on Interdisciplinary Aspects of Watershed Management. Bozeman, Mont., Amer. Soc. Civ. Engr., August 1970, p. 93-103.

Brown, George W. and Krygier, James T. 1971. Clearcut logging and sediment production in the Oregon coast range. Water Resources Res. 7(5): 1189-1198.

Buck, J. M. 1959. Site preparation for forest regeneration in California. USDA Forest Serv. California Region, 26 p.

Bullard, William E. 1965. Effect of highway construction and maintenance on stream sediment loads. Proc. Fed. Inter-agency Sed. Conf., 1973. USDA-ARS Misc. Publ. No. 970, pp. 52-56.

Burgy, Robert H., and Papazifiriou, Z. G. 1971. Effects of vegetation management on slope stability. Water Resources Center Advisory Council Meeting, Los Angeles, Calif.

Burns, Russell M., and Hebb, Edwin A. 1972. Site preparation and reforestation of droughty, acid sands. USDA Forest Serv. Agric. Handbk. 426, 61 p.

Campbell, F. R. and Webber, L. R. 1971. Contribution of rangeland runoff to lake eutrophication. 5th International Water Pollution Research Conference Proc.

Colman, E. A. 1953. Vegetation and watershed management. Ronald Press Co., N. Y., 412 p.

Cook, A. H., and Powers, C. F. 1958. Early biological changes in the soils and waters of artificially created marshes in New York. New York Fish and Game Jour. 5(1): 9-66.

Cooper, Charles F. 1969. Nutrient output from managed forests, eutrophication--causes, consequences, correctives. Printing and Pub. Office, Nat. Acad. Sci. Washington, D.C. pp. 446-463, illus.

Corbett, E. S., Rice, R. M. 1966. Soil slippage increased by brush conversion. USDA Forest Serv. Res. Note PSW-128, 8 p. Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif.

Curtis, James D. 1964. What do you mean, 'site preparation?' Res. Note 15, 8 p.

Darling, Leslie A. 1973. The effects of livestock grazing on wildland water quality. M.S. Thesis, Utah State Univ., 99 p.

Debano, L. F., and Conrad, C. E. Unpublished. The chemical composition of debris and runoff water from a burned chaparral watershed in southern California. To be submitted to third interagency sedimentation conference, Denver, Colorado, March 1976.

Debano, L. F. and Rice, R.M. 1973. Water repellent soils--their implications in forestry. J. Forestry 71(4): 220-223.

DeByle, Norbert V. and Packer, Paul E. 1972. Plant nutrient and soil losses in overland flow from burned forest clearcuts. Proc. Symp. on Watersheds in Transition. Editors Csallany, Sandor C., McLaughlin, Thad G. and Striffler, William D., Ft. Collins, Colo., June 19-22. Series no. 14, pp. 296-307.

Dissmeyer, George. Unpublished. Erosion and sediment from forest land uses, management practices and disturbances in the southeastern United States. Review Draft, 1975. To be submitted to Third Federal Interagency Sedimentation Conference, Denver, Colo., March 1976.

Dissmeyer, George E. N.D. Estimating the impact of forest management on water quality. Presented at: Cooperative Watershed Managemement Workshop, USDA Forest Service, Atlanta, Ga.

Dixon, J. D. 1972. The impact of forest bird and non-target arthropod population of the use of the insecticide sevin for gypsy moth control. Ph.D. Thesis. Rutgers University. 102 p.

Doty, Robert D. 1971 Contour trenching effects on streamflow from a Utah watershed. USDA Forest Serv. Res. Pap. INT-95, 19 p. Intermountain Forest and Range Exp. Sta., Ogden, Utah.

Doty, Robert, and Hookano, Ezra, Jr. 1974. Water quality of three small watersheds in northern Utah. USDA Forest Serv. Res. Note INT-186, 6 p., Intermountain Forest and Range Exp. Sta., Ogden, Utah.

Dunford, E. G. 1949. Relation of grazing to runoff and erosion on bunch-grass ranges. USDA Forest Serv. Research Note 7, 2 p. Rocky Mountain Forest and Range Exp. Sta.

Dyrness, C. T. 1967. Mass soil movements in the H.J. Andrews experimental forest. U.S. Forest Serv., Res Pap. PNW-42, 12 p., illus. Pacific Northwest Forest and Range Exp. Sta., Portland, Ore.

Edwards, C. A. 1972. Insecticides. In: C.A.I. Goring and J. W. Hamaker, eds., Organic Chemicals in the Soil Environment. New York: Marcil Dekker. p. 515-557.

Ellison, Lincoln, and Coaldrake, J. E. 1954. Soil mantle movement in relation to forest clearing in southeastern Queensland. Ecology 35(3): 280-388.

Evanko, A. B. N.D. Manipulation of brush cover on California national forests. USDA Forest Service, California Region, 70 p.

Evans, James O. 1970. The soil as a resource renovator. Environ. Sci. and Technol., 4: 732-735.

Flaccus, Edward. 1959. Revegetation of landslides in the White Mountains of New Hampshire. Ecology, 40(4): 692-703.

Fredriksen, R. L. 1970. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small western Oregon watersheds. USDA Forest Serv. Res. Pap. PNW-104, 15 p. Pacific Northwest Forest and Range Exp. Sta., Portland, Ore.

Fredriksen, R. L. 1972. Impact of forest management on stream water quality in western Oregon. In: Milton H. Mater, Ed. Symp. Proc. Pollution Abatement and Control in the Forest Products Industry, 1971-72, June 18-23, 1972, pp. 37-50, 26th Ann. Meeting of Forest Products Res. Soc., Dallas, Texas.

Fredriksen, R. L. 1971. Comparative chemical water quality--natural and disturbed streams following logging and slash burning. Proc. Symp. Forest Land Use and Stream Environ. Oregon State Univ., Corvallis, 1970, pp. 125-137, illus.

Frissell, Sidney S., Jr, and Duncan, Donald P. 1965. Campsite preference and deterioration. J. Forestry 63: 256-260.

Froelich, Henry A. 1973. Natural and man-caused slash in headwater streams. Pacific Logging Congress 'Loggers Handbook,' Vol. XXXIII, 8 p.

Frost, Terrence P., Towne, R. E., and Turner, H. J. 1972. Spray irrigation project, Mt. Sunapee State Park, New Hampshire. Proceedings Symp. Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland, pp. 371-384.

Gardner, R. B. 1967. Major environmental factors that affect the location, design, and construction of stabilized forest roads. Loggers Handbook 27, pp. 1-5, Pac. Logging Congr., Portland, Ore.

Gifford, G. F. 1973. Runoff and sediment yields from runoff plots on chained pinyon-juniper sites in Utah. J. Range Manage. 26: 440-443.

Gifford, G. F., Williams, G., and Colthrap, G. B. 1970. Infiltration and erosion studies in pinyon juniper conversion sites in southern Utah. J. Range Manage. 23: 402-406.

Gonsior M. J. and Gardner, R. B. 1971. Investigation of slope failures in the Idaho batholith. USDA Forest Serv. Res. Pap. INT-97, 34 p. Intermountain Forest and Range Exp. Sta., Ogden, Utah.

Goodrich, T. D., Stuart, D. G., and Bissonette, G. K., and Walter, W. G. 1970. A bacteriological study of the waters of Bozeman Creek's south fork drainage. Montana Academy of Sciences Proceedings 30: 59-65.

Goring, C. A. I. and Hamaker, J. W., eds. 1972. Organic chemicals in the soil environment. New York: Marcil Dekker. 965 p.

Gould, R. F., Ed. 1966. Organic pesticides in the environment. Advances in Chemistry Series No. 60. Amer. Chem. Soc. Wash. 309 p.

Gould, R. F., Ed. 1971. Fate of organic pesticides in the aquatic environment. Advances in Chemistry Series No. 111. Amer. Chem. Soc. Wash. 280 p.

Gratkowski, H. 1967. Ecological considerations in brush control. In: Herbicides and Vegetation Management. Oregon State University, Corvallis. pp. 124-140.

Groman, William A. 1972. Forest fertilization: (a state-of-the-art review and description of environmental effects). National Environmental Research Center Office of Research and Monitoring. EPA, Corvallis, Oregon, EPA-R2-72-015.

Guenzi, W. D. 1974. Pesticides in soil and water. Soil Sci. Soc. Amer., Madison. 562 p.

Guerrant, G. O., Fetzer, L. E., Jr., and Miles, J. W. 1970. Pesticide residues in Hale County, Texas, before and after ultra low volume application of malathion. Pest. Monit. J. 4: 14-20.

Gunsalus, I. C. and others. 1972. Degradation of synthetic organic molecules in the biosphere. Nat. Acad. Sci. Wash. 35 p.

Harris, C. I. 1967. Movement of herbicide in soil. Weeds 15:214-216.

Harris, C. I. 1968. Movement of pesticides in soil. J. Agric. Food Chem. 17:8-82.

Haupt, Harold F. 1959. A method for controlling sediment from logging roads. USDA Forest Serv. Misc. Publ. No. 22, 23 p. Intermountain Forest and Range Exp. Sta., Ogden, Utah.

Haupt, Harold F., Kidd, W. Joe, Jr. 1965. Good logging practices reduce sedimentation in central Idaho. J. Forestry, 63(9): 664-670.

Hetherington, John W. 1971. The snowmobile. Recreation Symposium Proceedings. USDA Forest Service, Northeastern Forest Exp. Sta., pp. 143-148.

Helvey, J. D. 1973. Watershed behavior after forest fire in Washington. Proceedings of the Irrigation and Drainage Division Specialty Conference, Fort Collins, Colo., April 1973, pp. 403-422.

Hibbert, Alden R. 1971. Increases in streamflow after converting chaparral to grass. Water Resources Res. 7(1): 71-8.

Hickey, Wayne C. Jr., Dortignac, E. J. 1963. An evaluation of soil ripping and soil pitting on runoff and erosion in the semiarid southwest. Int. Ass. of Sci. Hydrol. General Assembly of Berkeley, 1963, Pt. 5, Eng. Lib. Publ. No. 65, pp. 22-33.

Holden, A. V. 1973. Effects of pesticides on fish. In: C. A. Edwards, ed., Environmental Pollution by Pesticides. New York: Plenum. pp. 213-249.

Hope, Jack. N.D. The invasion of the awful ORV's. Audubon, 74(1): 36.

Hornbeck, J. W., G. E. Likens, R. S. Pierce, and F. H. Bormann. 1975. Strip cutting as a means of protecting site and streamflow quality when cutting northern hardwoods. In: Proceedings of the Fourth North American Forest Soils Conference held at Laval University, Quebec, pp. 209-225.

Hornbeck, James W., and Pierce, Robert S. 1973. Potential impact of forest fertilization on streamflow. In: Forest Fertilization, Symposium Proceedings. USDA Forest Serv. Gen. Tech. Report NE-3, pp. 79-87. Northeastern Forest Exp. Sta.

House, W. B. and others. 1967. Assessment of the ecological effects of extensive or repeated use of herbicides. Final report Midwest Research Institute. Kansas City, Missouri, 367 p.

Irons, W. V., and Hembree, G. H., and Oakland, G. L. 1965. Water resources of the upper Colorado River basin. U.S. Geological Survey Professional Paper 441. 378 p.

Johnson, C. M. and Needham, P. R. 1966. Ionic composition of Sagehen Creek, California, following an adjacent fire. Ecology, 47(4): 636-639.

Jones, J. H., and Taylor, G. S. 1965. Septic tank effluent percolation through sands under laboratory conditions. Soil Sci. 99: 301-309.

Kadlec, John A. 1962. Effects of a drawdown on a waterfowl impoundment. Ecology 43(2): 267-281.

Karalekas, Peter C., and Lynch, John P. 1965. Recreational activities of Springfield, Massachusetts water reservoirs past and present. J. New England Water Works Ass. 79: 18-31.

Kawaguchi, Takeo and Yamamoto, Katsuichi. 1948. On the relationship between forest cutting and sediment. Report of Government Forest Experiment Station, No. 57. pp. 1-19.

Kawaguchi and others. 1959. Landslides and soil losses of the mountain districts of Izu Pennisula in the flood of 1958 and their control. Japan Forest Exper. Sta. Bull. No. 117, pp. 83-120.

Ketchledge, Edwin H. 1971. Facility rehabilitation. Recreation Symposium Proceedings. USDA Forest Service, Northeastern Forest Exp. Sta., Upper Darby, Penn. pp. 166-173.

Klock, G.O. 1971. Streamflow nitrogen loss following forest erosion control fertilization. USDA Forest Serv, Res. Note PNW-169, 9 p. Pacific Northwest Forest and Range Exp. Sta., Portland, Ore.

Kojan, Eugene, Foggin, G. T. III, and Rice, Raymond M. 1972. Prediction and analysis of debris slide incidence by photogrammetry, Santa Ynez-San Rafael mountains, California.

Proc. 24th International Geological Congress, Montreal, Canada. August 1972. Section 13: 124-131.

Krammes, J. S. 1965. Seasonal debris movement from steep mountain side slopes in southern California. Proceedings of the Federal Interagency Sedimentation Conference, 1963, USDA, Agricultural Research Service, Misc. Pub. No. 970, pp. 85-88.

Krammes, J. S. and Osborn, J. 1968. Water repellent soils and wetting agents as factors influencing erosion. Proc. Symp. Water Repellent Soils, Univ. of Riverside, May 1968, pp. 177-187.

Krammes, J.S. and Burns, David M. 1973. Road construction on Caspar Creek watersheds--10 year report on impact. USDA Forest Serv. Res. Pap. PSW-93. Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif.

Kudrna, Frank L. and George T. Kelly. 1973. Implementing the Chicago prairie plan. Proceedings Symposium Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland. pp. 365-370.

Kunkel, Samuel H. and Meiman, James R. 1967. Water quality of mountain watersheds. Hydrol. Papers, Colo. State Univ., Ft. Collins, Colo., No. 21: 1-53.

Kunkle, S. H. 1970. Sources and transport of bacterial indicators in rural streams. Interdisciplinary Aspects of Watershed Management Symposium. Montana State University, Bozeman, (mimeographed paper).

LaPage, Wilbur F. 1967. Some observations on campground trampling and ground cover response. USDA Forest Serv. Res. Paper NE-68, 11 p., illus., Northeastern Forest and Range Exp. Sta., Upper Darby, Pa.

Lathwell, D. J., Mulligan, M. F., and Bouldin, D. R. 1969. Chemical properties, physical properties and plant growth in 20 artificial wildlife marshes. New York Fish and Game Jour. 16(2): 158-183.

Lee, G. L., Bentley, E., and Amundson, R. 1975. Effects of marshes on water quality. In: Ecological Studies X, Coupling of Land and Water Systems, Springer-Verlag, New York, Inc., p. 105-127.

Leopold, Luna B. and Gordon Wolman. 1957. River flood plains: Some observations on their formation. U.S. Geological Survey Paper 282-C, pp. 87-107.

Lichtenstein, E. P. and others. 1966. Toxicity and fate of insecticide residues in water. Arch. Environ. Health. 12:199.

Lieberman, J. A., and Hoover, M. D. 1948. Protecting quality of streamflow by better logging. Southern Lumberman, Dec. 15, p. 236-240.

Likens, Gene E. and others. 1970. The effects of forest cuttings and herbicide treatment on nutrient budgets in the Hubbard Brook watershed ecosystem. Ecol. Monogr. 40:23-47.

Lime, David W., and Stankey, George H. 1971. Carrying capacity maintaining outdoor recreation quality. Recreation Symposium Proceedings. USDA Forest Service, Northeastern Forest Exp. Sta., Upper Darby, Penn. 174-184 p.

Linde, Arlyn F. 1969. Techniques for wetland management. Dept. of Nat. Res., Madison, Wis. Res. Rpt. No. 45, 156 p.

Loehr, Raymond C. 1974. Characteristics and comparative magnitude of nonpoint sources. Water Pollution Control Federation Journal, Vol. H6, No. 8, August, p. 1849-1872.

Lotspeich, Frederick B., Mueller, Ernst W., and Frey, Paul J. 1970. Effects of large scale forest fires on water quality in interior Alaska. USDI, Federal Water Pollution Control Admin., Alaska Water Laboratory, College, Alaska, 115 p.

Lull, Howard W., and Satterlund, Donald R. 1963. What's new in municipal watershed management. Soc. Amer. Foresters Proc. 171-175.

Lusby, Gregg C. 1970. Hydrologic and biotic effects on grazing versus nongrazing near Grand Junction, Colorado. Geol. Surv. Res. Chapter B, U.S. Geol. Surv. Prof. Pap. 700-B: 232-236, illus.

Lutz, H. J. 1945. Soil conditions of picnic grounds in public forest parks. J. Forestry 43: 121-127.

Macdonald, D. R. and F. E. Webb. 1963. Insecticides and the spruce budworm. In: R. F. Morris, Ed. The dynamics of epidemic spruce budworm populations. Memoirs of the Entomol. Soc. of Can., No. 31. pp. 288-310.

Magill, Arthur W. 1970. Five California campgrounds: conditions improve after 5 year's recreational use. USDA Forest Serv. Res. Pap. PSW-62, 18 p. Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif.

Magill, Arthur W. 1975. Personal communication. Pacific Southwest Forest and Range Experiment Station: Forest

Recreation and Landscape Management Research. Berkeley, California.

Maksymiuk, B. 1971a. Kinetics and physics of pesticidal aerial sprays. In: J. Capizzi and J. Witt, eds., Pesticides, Pest Control and Safety in Forested Range Lands. Oregon State University, Corvallis. pp. 171-179.

Maksymiuk, B. 1971b. How to minimize drift of pesticidal sprays. In: J. Capizzi and J. Witt, eds., Pesticides, Pest Control and Safety in Forested Range Lands. Oregon State University, Corvallis. pp. 180-187.

Malueg, K. W., Powers, C. F., and Krawazyk, D. F. 1972. Effects of aerial forest fertilization with urea pellets on nitrogen levels in a mountain stream. Northwest Sci. 46: 52-58, Illus.

Mathisen, J. E. 1975. Personal communication with Forest Wildlife Biologist. Chippewa National Forest.

Meehan, W.R., Farr, W.A., Bishop, D.M., Patric, J.H. 1969. Some effects of clearcutting on salmon habitat of two southeast Alaska streams. USDA Forest Serv. Res. Pap. PNW-82, 45 p. Pacific Northwest Forest and Range Exp. Sta., Juneau, Alaska.

Meeuwig, Richard O. 1965. Effects of seeding and grazing on infiltration capacity and soil stability of a subalpine range in central Utah. J. Range Manage. 18(4): 173-180.

Megahan, W. 1961. Hydrology of the Boulder Lake watershed, Sublette Co., Wyoming. Unpublished report, Region 4, USDA Forest Service, Ogden, Utah.

Megahan, W. F. 1975. Sedimentation in relation to logging in the mountains of central Idaho. Proc. of Sediment Yield Workshop, Oxford, Miss., Nov. 28-30, 1972.

Megahan, W. F. 1974. Erosion over time on severely disturbed granitic soils: A model. USDA Forest Serv. Res. Paper INT-156, 14 p., Intermountain Forest and Range Exp. Sta., Ogden, Utah.

Megahan, W. F., and W. J. Kidd. 1972. Effects of logging and logging roads on erosion and sediment deposition from steep terrain. J. Forestry 70: 136-141.

Megahan, Walter F. 1962. Soil and hydrologic analysis of the portion of the Alaska basin trail within the crest management zone. Unpublished report, Region 4, USDA Forest Service, Ogden, Utah.

Megahan, Walter F., and Walter J. Kidd. 1972. Effect of logging roads on sediment production rates in the Idaho batholith. USDA Forest Serv. Res. Pap. INT-123, 14 p. Intermountain Forest and Range Exp.Sta., Ogden, Utah.

Meiman, James R., and Kunkle, S. H. 1967. Land treatment and water quality control. J. Soil and Water Conservation 22(2): 67-70.

Mersereau, R. C. and C. T. Dyrness. 1972. Accelerated mass wasting after logging and slash burning in western Oregon. J. Soil and water conservation, 27(3): 3.

Metcalf and Eddy, Inc. 1972. Waste water engineering. McGraw-Hill Book Co., New York, N. Y.

Miller, R. H. 1973. The soil as a biological filter. Proc. Sym. Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland. pp. 71-94.

Minkus, Alexander, Jr. 1965. Recreational use of reservoirs J. New England Water Works Ass. 79: 32-40.

Moore, D. G. 1972. Fertilization and water quality. In: Western Reforestation, West. Refor. Coord. Comm. Proc. 1971, pp. 28-31.

Moore, Duane G. and Logan A. Norris. 1974. Soil processes and introduced chemicals. In: Environmental Effects of Forest Residues Management in the Pacific Northwest. USDA Forest Service Gen. Tech. Rep. PNW-24. pp. C-1 to C-33. Pacific Northwest Forest and Range Exp. Sta., Portland, Ore.

Morrison, S. M., and Fair, J. F. 1966. Influence of environment on stream microbial dymamics. Hydrology Paper No. 13. Colorado State University, Fort Collins, 21 p.

Nakano, Hidenori. 1971. Soil and water conservation functions of forest on mountainous land. Forest Influences Division, Government Forest Experiment Station, Japan. Bulletin of the Government Forest Experiment Station, No. 14, pp. 1-66.

Noble, Edward L. 1963. Sediment reduction through watershed rehabilitation. USDA Forest Service, Region 4, Ogden, Utah. 29 p.

Norris, Logan A. 1971. Chemical brush control--assessing the hazards. J. For. 69(10): 715-720.

Norris, Logan A. 1971a. The behavior of chemicals in the forest. Pesticides, Pest Control and Safety on Forest Lands. Oregon State University, Corvallis, Ore. pp. 133-141.

Norris, Logan A. and Duane G. Moore. 1971. The entry, fate and toxicity of forest chemicals in streams. In: Forestry and Water Quality, School of Forestry, Oregon State Univ., p. 45-67.

Norris, L. A., M. A. Montgomery, and E. D. Johnson. 1975. Residues of 2,4,5-t in the forest. In: Abstracts, 1975 Meeting, Weed Sci. Soc. Amer. p. 23.

Norris, L. A., M. Newton, and J. Zavitkowski. 1967. Stream contamination with amitrole from forest spray operations. Res. Prog. Rep. Western Soc. Weed Sci. p. 33-35.

Ongerth, Henry J. 1964. Watershed management and reservoir use--public viewpoint. J. Amer. Water Works Assoc. 56.

Orr, Howard K. 1971. Design and layout of recreation facilities. Recreation Symposium Proceeding. USDA Forest Service, Northeastern Forest Exp. Sta., Upper Darby, Penn. pp. 23-27.

Packer, Paul E. 1953. Effects of trampling disturbance on watershed conditions, runoff, and erosion. J. Forestry 51(1): 28-31.

Packer, Paul E. 1963. Soil stability requirements for the gallatin elk winter range. J. Wildlife Management 27(3): 401-410.

Packer, Paul E. 1967. Criteria for designing and locating roads to control sediment. For. Sci. 13: 1-18.

Packer, Paul E. 1967. Forest treatment effects on water quality. In: Int. Sym. Forestry Hydrol., Proc., W. E. Sopper and H. W. Lull (eds.), New York, Pergamon Press., pp. 687-699.

Packer, Paul E., and Harold F. Haupt. 1965. The influence of roads on water quality characteristics. Soc. Amer. For. Proc.

Parizek, R. R. 1973. Site selection criteria for waste water disposal--soils and hydrogeologic considerations. Proc. Symp. Recycling Treated Municipal Waste Water and Sludge through Forest and Crop Land, p. 95-147.

Peterson, N. J., and Boring, J. R. 1960. A study of coliform densities and escherichia serotypes in two mountain streams. American Journal of Hygiene. 71: 134-140.

Pierce, R. S., J. W. Hornbeck, G. E. Likens, and F. H. Bormann. 1970. Effect of elimination of vegetation on stream water quantity and quality. In: Symposium on Results of Research of Representative and Experimental Basins held at Wellington, New Zealand, IASH No. 96, 311-328.

Pierce, Robert S. 1972. Nutrient loss from clearcutting in New Hampshire. National Symp. on Watersheds in Transition, Ft. Collins, Colo., June 1972, pp. 285-295.

Pimentel, D. 1971. Ecological effects of pesticides on non-target species. Executive Office of the President, Office of Sci. and Technol. June 1971. 220 p.

Platts, William S., and Megahan, Walter F. 1975. Time trends in channel sediment size composition in salmon and steelhead spawning areas: south fork Salmon River Idaho. Paper to be printed in the Transactions of the North American Wildlife and Natural Resources Conference.

Ponce, Stanley L. and Brown, George W. 1974. Demand for dissolved oxygen exerted by finely divided logging debris in streams. Forest Research Laboratory, Oregon State Univ., Research Paper 19.

Ponce, Stanley L. 1974. The biochemical oxygen demand of finely divided logging debris in stream water. Water Resources Res. 10(5): 983-988.

Public Land Law Review Commission. 1970. One-third of the nation's land. U.S. Government Printing Office, Washington, D.C. 343 p.

Rauzi, Frank. 1955. Water infiltration studies in the Bighorn N. F. Wyoming Agricultural Experiment Station Memo Circular. 58: 1-10.

Rauzi, Frank, and Hanson, Clayton L. 1966. Water intake and runoff as affected by intensity of grazing. J. Range Management 19(6): 351-356.

Reinhart, Kenneth G. 1973. Critique: Forest fertilization impacts on water and environment. Regional Forest Symp. USDA Forest Serv. Gen. Tech. Report. NE-3. pp. 242-246. Northeastern Forest Exp. Sta., Upper Darby, Penn.

Reinhart, K. G., A. R. Eschner, and G. R. Trimble, Jr. 1963. Effect on streamflow of four forest practices in the mountains of West Virginia. USDA Forest Serv. Res. Pap. NE-1, 79 p. Northeastern Forest Exp. Sta., Upper Darby, Pa.

Renner, F. G. 1936. Conditions influencing erosion on the Boise river watershed. USDA Technical Bulletin 528. 32 p.

Rice, R. M. and J. R. Wallis. 1962. How a logging operation can affect streamflow. For. Ind. 89(11): 38-40.

Rice, R. M., and G. T. Foggin III. 1971. Effect of high intensity storms on soil slippage on mountainous watersheds in southern California. Water Resources Research 7(6): 1485-1496.

Rice, R. M., Corbett, E. S., and Bailey, R. G. 1969. Soil slips related to vegetation, topography, and soil in southern California. Water Resources Research, 5(3): 647-659.

Rice, R. M. and Krammes, J. S. 1971. The significance of mass wasting processes in watershed management. New York. Amer. Soc. Civ. Engr., p. 232-259.

Rice, R. M., J. S. Rothacher, and W. F. Megahan. 1972. Erosional consequences of timber harvesting: An appraisal. In: Watersheds in Transition. Amer. Water Resour. Assoc. and Colorado State Univ., Fort Collins. pp. 321-329.

Rice, Raymond M. 1974. The hydrology of chaparral watersheds symposium on living with the chaparral, Riverside, Calif., March 1973, pp. 27-34.

Rich, L. R. 1962. Erosion and sediment movement following a wildfire in a ponderosa pine forest of central Arizona. USDA Forest Serv. Res. Note 76, 12 p. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo.

Rosebery, Dean A. 1964. Relationship of recreational use to bacterial densities of forest lake. J. Amer. Water Works Ass. 56: 43-59.

Rosgen, Dave. 1975. Preliminary report procedure for quantifying sediment production. North Zone Planning Unit, USDA Forest Service. Sandpoint, Idaho, 13 p.

Rothacher, J. and W. Lopushinsky. 1974. Soil stability and water yield and quality. In: Owen P. Cramer, ed., Environmental Effects of Forest Residues Management in the Pacific Northwest. A State of Knowledge Compendium. USDA Forest Serv. Tech. Rep. PNW-24. pp. D-1 to D-23. Pacific Northwest Forest and Range Exp. Sta., Portland, Ore.

Rothacher, J. S., and Glazebrook, T. B. 1968. Flood damage in the national forests of region 6. USDA Forest Service, Pacific Northwest Forest and Range Exp. Sta., Portland, Ore., 20 p.

Rowe, P. B., Countryman, C. M., and Storey, H. C. 1954. Hydrologic analysis used to determine effects of fire on peak discharge and erosion rates in southern California. USDA Forest Service, California Forest and Range Exp. Sta., 49 pp.

Schneider, W. J. 1970. Hydrologic implications of solid-waste disposal. USDI, Geol. Survey Circ. 601-F, 10 p., Illus.

Schwartz, H. G. Jr. 1967. Microbial degradation of pesticides in aqueous solution. J. Water Pollut. Contr. Fed. 39: 1701-1714.

Scott, Kevin M. 1971. Origin and sedimentology of 1969 debris flows near Glendora, California. U.S. Geol. Surv. Prof. Paper 750-C. pp. C242-C247.

Scott, Kevin M. and Williams, Rhea P. 1974. Erosion and sediment yields in mountain watersheds of the transverse ranges, Ventura and Los Angeles Counties, California. U.S. Geol. Surv. Water Resources Investigations 47-73, 128 p.

Seabrook, Bedford L. 1973. Land application of waste water with demographic evaluation. Proc. Joint Recycling Municipal Sludges and Effluents on Land. Environmental Protection Agency, USDA, National Association of State Universities and Land Grant Colleges. pp. 9-24.

Sepp, E. 1971. The use of sewage for irrigation--a literature review. Bureau of Sanitar. Eng., Calif. State Dept. of Public Health.

Shuval, Hille XI. 1967. Public health implications of wastewater utilization. International Conf. on Water for Peace. 57 p.

Simpson, Larry D. 1969. Hydrologic report on storms of 1969. Los Angeles County Food Control District, 286 p.

Skau, C. M. 1961. Some hydrologic influences of cabling juniper. USDA Forest Serv. Res. Note 62, 2 p. Rockey Mountain Forest and Range Exp. Sta., Ft. Collins, Colo.

Sopper, William E. 1973. Crop selection and management alternatives--perennials. Proceedings of Joint Conf. Recycling Municipal Sludges and Effluents on Land, U.S. Environmental Protection Agency, USDA, Nat. Assoc. of State Universities and Land Grant Colleges. pp. 143-153.

Sopper, William E., and Kardos, Louis T. 1973. Vegetation responses to irrigation with treated municipal waste water. Proc. Symp. Recycling Treated Municipal Waste Water and Sludge through Forest and Cropland. pp. 270-294.

Sproul, Otis J. 1967. Virus problems in water resource systems. International Conf. on Water for Peace. 406 p.

Steibrenner, E. C. and S. P. Gessel. 1955. Effect of tractor logging on soils and regeneration in the Douglas-fir region of southwestern Washington. Proc. Soc. Amer. Foresters, pp. 77-80.

Storey, H. C. 1965. Watershed management research. In: Who's Responsible for Water Resources Research. Oregon State University, Corvallis. Water Resources Research Institute Lemn. WR 004.66. pp. 55-64.

Storey, H. D. 1955. Frozen soil and spring and winter floods. Water, Yearbook of Agriculture, U.S. Dept. of Agriculture. pp. 179-184.

Swanston, Douglas N. 1969. Mass wasting in coastal Alaska. USDA Forest Serv. Research Paper PNW-83, 15 p. Pacific Northwest Forest and Range Exp. Sta., Portland, Ore.

Tackle, David. 1962. Infiltration in a western larch-Douglas-fir stand following cutting and slash treatment USDA Forest Serv. Res. Note 89, 7 p. Intermountain Forest and Range Exp. Sta., Ogden, Utah.

Taylor, Alan W. 1967. Phosphorus and water pollution. J. Soil and Water Conserv. 22:228-231.

Terriere, L. C. 1971. The toxicology of insecticides. In: J. Capizzi and J. Witt, eds., Pesticides, Pest Control, and Safety in Forested Range Lands. Oregon State University, Corvallis. pp. 107-118.

Thomas, J. W., and D. C. McCluskey. 1974. Effects of aerial application of DDT for tussock moth control on nesting survival of mountain bluebirds and house wrens. USDA Forest Serv. Res. Pap. PNW-185, 37 p. Pacific Northwest Forest and Range Exp. Sta., Portland, Oreg.

Thomas, R. E., Schwartz, W. A., and Bendixen, T. W. 1966. Soil chemical changes and infiltration rate reduction under sewage spreading. Soil Sci. Soc. of Amer. Proc. 30(5): 641-646.

Thut, Rudolph N., and Haydu, Eugene P. 1971. Effects of forest chemicals on aquatic life. In: Proc. Symp. Forest Land Uses and Stream Environment, 1970. Oregon State University, Corvallis, pp. 138-158.

Tiedemann, A. R. 1973. Stream chemistry following a forest fire and urea fertilization in north central Washington. USDA Forest Serv. Res. Note PNW-203, 20 pp. Pacific Northwest Forest and Range Exp. Sta., Portland, Ore.

Trimble, G. R., and Sartz, R. S. 1957. How far from a stream should a logging road be located. J. For. 55: 339-341.

U.S. Environmental Protection Agency. 1975. Logging roads and protection of water quality. Region X, Water Division. EPA 910/9-75-007, March 1975. 312 p.

U.S. Environmental Protection Agency. 1973. Methods for identifying and evaluating the nature and extent of non-point sources of pollutants. EPA-430/9-73-014, October 1973, 261 p.

U.S. Environmental Protection Agency. 1974. Water quality protection guide--logging roads. Draft Edition, Part I, 66 p.

Upchurch, R. P. 1972. Herbicides and plant growth regulators. In: C. A. I. Goring and J. W. Hamaker, ed., Organic Chemicals in the Soil Environment. New York: Marcil Dekken. Vol. II. pp. 444-498.

Urie, Dean H. 1973. Phosphorus and nitrate levels in ground water as related to irrigation of jack pine with sewage effluent. Proc. Symp. Recycling Treated Municipal Waste Water and Sludge through Forest and Croplands. Ed: W. E. Sooper and L. T. Kardos, Penns. State Univ., pp. 176-183.

Ursic, S. J. 1970. Hydrologic effects of prescribed burning and deadening upland hardwoods in northern Mississippi. USDA Forest Serv. Res. Paper SO-54, 15 p. Southern Forest Exp. Sta., New Orleans, La.

USDA, Forest Service. 1975. Draft environmental statement triangle ranch wetlands land exchange, Modoc National Forest, 49 p.

Verry, Elon S. 1975. Improving the basis for managing water fowl impoundments in forested areas. A problem analysis for problem no. 2. Research Work Unit NC-1602, USDA, Forest Service, North Central Exp. Sta., Grand Rapids, Minnesota.

Wagar, J. A. 1964. The carrying capacity of wild land for recreation. Forest Sci. Monograph. 7. 24 p.

Walter, W. G., and Bottman, R. P. 1967. Microbiological and chemical studies of an open and closed watershed. J. Environ. Health. 30(2): 157-163.

White-Stevens, R., Ed. 1971. Pesticides in the environment. Vol. I, Parts 1 and 2. 629 p. New York: Marcil Dekken.

Wilcox, H. N. 1971. The effects of dylox on a forest ecosystem. Lake Ontario Environ. Lab., State University, College, Oswego, N. Y. Progress Report.

Wischmeier, W. H. and Smith, D. C. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. ARS, Agricultural Handbook 282, USDA. GPO, Washington, D.C. 47 p.

Witt, J. 1971. Principles of drift of pesticide sprays. In: J. Capizzi and J. Witt, eds. Pesticides, Pest Control and Safety in Forested Range Lands. Oregon State University, Corvallis.

Wright, H. A., Churchill, F. M., and Stevens, W. C. 1975. Effect of prescribed burning on sediment, water yield, and water quality, from dozed juniper lands in central Texas. NTIS, Completion Report 1974. Springfield, Va., No. PB-238 036. 29 p.

# SECTION 5

# ASSESSMENT OF MODELS FOR PREDICTING NON-POINT POLLUTANTS FROM WILDLANDS

## INTRODUCTION

A systematic effort was made to search out and subjectively evaluate existing models dealing with non-point source pollution resulting from wildland management activities. To accomplish this objective, the predictive models were classified into three categories: (1) physical, (2) chemical, and (3) biological. Five principal sources were used in collecting information on current water modeling technology: (1) National Technical Information Service (NTIS) maintained by Lockheed; (2) the Water Resources Abstracts (WRA) file located on RECON at Oak Ridge; (3) the Smithsonian Scientific Information Exchange (SSIE); (4) the personal FAMULUS file of hydrologic information maintained by Henry Anderson at the Forest Service's Pacific Southwest Forest and Range Experiment Station; and (5) personal knowledge and contacts of those engaged in the project.

Of the models located, evaluation was undertaken for those that were:

1. Related to wildlands.

2. Related to wildland resource management activities.

3. Related to non-point source pollutants.

4. Reflected spatial variability and diversity of landscape and mananagement activities.

Appendix A contains a summary listing of all models located that, in the judgment of the evaluators, met the above criteria. Each model is numbered and the numbers are used in the "Predictive Model Suitability Matrix" and evaluation forms. This matrix shows the simulation type models that were believed to warrant more intensive evaluation, and was used as a basis for making the state-of-the-art assessment. It also shows gaps in technology for simulation modeling.

Two important points must be considered in reviewing this report. Models developed outside the Forest Service were reviewed, but a totally exhaustive search was not attempted and undoubtedly some models that should have been evaluated were overlooked. The second point is that many of these evaluations were made from the perspective of practicing field professionals rather than from that of a research scientist.

## MODEL REVIEW AND SUMMARY

Three basic types of models have been used to simulate the effects of forest management on water resources. In this review, models were typed as being regression, simulation programming, or process simulation. The classification was made on the basis of dominant traits even though in a few cases the models are hybrids of components that fall in two or all three of these categories.

A regression model is a statistical procedure used to relate measurable values of a set of variables to measurable values of the variable to be predicted. The predictor variables are selected, and often the structure of the model determined, by considering the known or assumed relations among the variables. Regression modeling is usually employed when dealing with a poorly defined process, and the tendency is to focus on the statistical relationships found to exist among the variables based on a sample. These relationships are utilized to improve a model's predictive capability by selecting or rejecting predictor variables as well as by governing the form of the model itself.

In simulation programming, a model is developed which represents the general processes involved, but not the process mechanisms. These models require and often include features that allow them to "calibrate" themselves using internal curve fitting procedures. Once "calibrated" the model is used to simulate the effects of the activities and processes for which it was designed.

In process simulation the model is developed to directly represent the process mechanisms involved. In this approach the components are designed to model the specific processes involved without internal calibration.

The model review is summarized in Table 5.

### Physical Model Review

Physical models include those models relating to the surface runoff and erosion-sedimentation processes. Because of the amount of past modeling effort that has gone on in this area, the models were subdivided into the following categories: streamflow, surface erosion, channel erosion, mass movement, and total sediment output (sediment and runoff).

## TABLE 5. PREDICTIVE MODEL SUITABILITY MATRIX[a]

| Activity class | Pollutant or index: Sediment source: Total | Surface | Channel | Mass wasting | Temperature | Dissolved oxygen | Pathogens | Nutrients | Dissolved solids | Pesticides | Heavy metals | Streamflow or water yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vegetative manipulation by mechanical means | b | 38,48 [49] (85) (86) | c | | [125] 143 | | | | | | | 7 (14) [20] (82) (84) (85) (86) 98 |
| Road and trail constructions and reconstruction | b | 38,48 [49] (86) | c | | [125] 143 | | | | | | | [20] (82) (84) (86) 98 |
| Fire | b | 38,48 [49] (85) (86) | c | | | | | | | | | 7 (14) [20] (82) (84) (85) (86) 98 |
| Grazing | b | 38,48 [49] (85) (86) | c | | | | | | | | | 7 (14) [20] (82) (84) |
| Timber harvest | b | 38,48 [49] (85) (86) | c | | (85) [125] 143 | | | (118) | | | | 7 (14) [20] (82) (84) (85) (86) 98 |
| Recreation | | | | | | | | | | | | |
| Fertilization | | | | | | | | | | | | 7 (14) [20] (82) (84) (86) 98 |
| Waste disposal | | | | | | 136 | (84) 136 | 136 | 136 | | (84) 136 | |
| Low head impoundments | | | | | | | | | | | | (84) 98 |
| Pesticides | | | | | | | | | | (84) 99 | | 7 (14) [20] (82) (84) (86) 98 |

[a]Selection criteria: (1) upstream loading model, (2) not regression model, (3) distributed inputs, (4) documentation available.

[b]Models Nos. 83 and 84 suitable if no mass wasting.

[c]Model No. 86 simulates aggredation/degradation but not channel erosion for upland channel systems.
Model No. 49 represents Musgrave approach and its derivatives.
Model No. 48 represents Universal Soil Loss Equation (USLE) approach and derivations.
Model No. 136 represents the HSP-QUALITY model.

LEGEND: [N] - models in operational use by USFS water quality staff specialists
(N) - models in active advanced development and testing
N - models available but not being widely used or tested by the USFS

High / Moderate / Low — Overall activity/pollutant impact rating

Streamflow--

Streamflow models are particularly important in evaluating the effects of wildland management on all the aquatic ecosystem processes that are flow dependent.

Streamflow, as the prime carrier of pollutants, often is highly correlated with both the concentration of pollutants in a particular system and with the total discharge of pollutants. Moreover, streamflow often furnishes a basis for the time distribution of events which produce and transport pollution. As such, streamflow can be used as the frequency base for predicting long-term expectance of pollution and for putting particular samples of pollution into a time frame perspective. The outputs from streamflow models vary widely, from daily or peak flows to single events.

Most of the regression models reviewed relate streamflow parameters to meteorological variables, differences in site variables, and land use activity variables. They are usually developed for a specific area and are rarely considered to have general applicability. In addition, these models are not normally tested widely as the data available in different areas varies, and it is usually easier to develop new models than to test old ones. A general weakness of regression models for use in wildland management is that the variables reflecting land use and conditions are not specific enough to reflect the effects of many individual management activities. Further, they are not usually able to represent or predict time-dependent processes.

Most simulation programming models are based on the Stanford model approach, such as HSP (Donigian and Waggy, 1974), and have not generally been tested in wildland management situations. In most cases, their ability to reflect the effects of management activities occurring on small complex upland watersheds has not been determined.

Process simulation techniques such as those of Rogers (1975a), Leaf (1975), USDAHL (Holton and Lopez, 1971), and others, utilize knowledge of the basic processes being modeled and how these processes react on land areas under various management activities. Process simulation models have been developed to predict streamflow for short-term events as well as daily and monthly flows. These models generally evaluate effects over time, are tied to individual land units, and can yield information on the status of other components of the hydrologic cycle.

The variable source area concept proposed by Hewlett and Troendle (1975) presents a different conceptual basis for predicting streamflow and needs to be investigated further.

A great deal of research has been conducted on the components within the hydrologic cycle. In many cases, this research will provide the necessary ingredients for model building, and many component models have been formulated (e.g., for processes such as evapotranspiration, snowmelt, and interception). In developing non-point pollution models, this body of information provides an excellent resource. These component models may not relate directly to activity evaluation and should be regarded as pure hydrologic entities. The decision whether or not a component is usable will depend upon the management objective and need for a model.

Surface Erosion--

Although many surface erosion models exist today, most have originated from the basic approaches used by Musgrave (1947) or the Universal Soil Loss Equation (Wischmeier and Smith, 1965) developed for crop land. These basic equations and modifications of them have been used to predict erosion on forest and range lands (Anderson, 1969; and Dissmeyer, 1973). These approaches appear to be most useful in the comparative analysis of before and after predictions rather than in the absolute values obtained. Other recent regression approaches to developing surface erosion models for specific areas and conditions include those of Leaf (1974) and Megahan (1974).

Simulation approaches to surface erosion (both sheet and rill) are becoming available and rely upon fluid and erosion mechanics. Foster and Meyer (1972) and Simons and others (1975) have developed mathematical simulations of surface erosion which use fundamental erosion mechanics. In these models, components such as detachment, shear stress, and transport capacity are described mathematically. The Foster model has been used to predict erosion for small plots on agricultural land. The Simons model has only recently become available and is currently being tested on forested watersheds in the western United States to determine its utility.

Channel System Erosion--

Predictive techniques for channel and gully erosion in small stream systems have received very little attention in modeling and basic research. No model reviewed indicated quantitatively the contribution of channel material to total sediment production.

Stream channel erosion and subsequent sedimentation over time and space is great. Limited knowledge of the processes involved restricts development of a model to adequately quantify changes in sediment production associated with particular resource management activities. One approach that can be used to approximate sediment concentrations within stream reaches is the sediment rating curve approach. Workers who utilize this approach for sediment determinations include: Campbell and Bauder, 1949; Miller, 1951; Anderson, 1954; Leopold, 1954; Negev, 1967; Woolhiser and Todorovic, 1974; Bolton and others, 1972; Flaxman, 1972; Livesey, 1972; Strand, 1972; Thomas, 1974; and Rosgen, 1975.

The widespread applicability of such an approach is shown by Flaxman (1972). This procedure for estimating the amount of sediment increase from the channel source can be readily adapted to timber harvest or other activities where changes in the hydrograph can be predicted. Some sediment models (Thomas, 1974; Negev, 1967) utilize this approach to determine changes in the water-sediment mixture by various stream reaches.

There are several models available which route a water-sediment mixture in stable channels and account for scour and deposition. The primary value of these models in resource management is to evaluate the relative consequence to stream systems and reservoirs of increases in sediment concentrations from upper watersheds (Thomas, 1974; Simons and others, 1975). The Thomas model was designed to route sediment in a very large river system; the Simons model for ephemeral and first order streams in small watersheds.

A great deal of research has been directed at transport and deposition models involving bedload, tractive force, and discharge formulas. Many of these models operate on the same basic premises and a few minor modifications will create new models. The Agricultural Research Service (USDA) in conjunction with Pennsylvania State University reviewed over a dozen of these models to determine major differences. Their work, as reported by Morrill and Van Dok (1974), indicated that there is no best universal formula or method for the solution of bedload transport and deposition problems.

Mass Movement--

Mass movement includes a number of processes of downslope transfer of particulates, such as soil creep, landslides, debris flows, and mud flows. This contributes to sediment loading when exposed to running water at stream channel or to raindrop splash and/or surface runoff on slopes away from stream channel.

Many research studies have been made of mass movement processes and their short-term quantitative measurement. Some conceptual models have been developed of such processes. However, there is no model which will predict when a particular slope will be subject to major mass movement such as landslides and mud flows.

Some models based on hydraulic and soil mechanics considerations have been outlined by Jones and others, 1961; Bell, 1968; and Gray, 1969. However, the application of these models require on-site measurements which may be difficult to obtain for a forest activity under operating conditions.

Total Sediment Output Models--

Total sediment output models are used to predict the physical streamflow parameters (notably sediment) from watersheds associated with wildland management activities. The outputs are in the form of suspended sediment concentration or discharge, predicted total sediment discharge (suspended and bedload), and predicted duration of various sediment concentrations.

Total output models of the regression type are similar to the streamflow regression models but also include parameters which represent sediment. Measured sediment output together with measurements of suspended sediment concentration are the basic output data normally used to develop total sediment regression models by associating watershed attributes, climate, and land use. For a specific land use, these models can relate sediment yields to frequency and normalized expectancy of long-term meteorological events.

For comparative analysis, simulation models and analytic procedures that lead to predictions of total sediment outputs can be useful in quantifying the relative effect of a wildland management activity on total sediment production. The analytic procedures used to predict total sediment output are basically allocation processes that distribute measured sediment among land areas and disturbances above the point of measurement. The FASS model (Dissmeyer, 1973) uses plot studies and the Universal Soil Loss Equation to distribute suspended sediment to source areas. The Rosgen model (1975) uses sediment rating curves, channel stability ratings and changes in streamflow, and on-site erosion to determine total sediment output.

Some simulation models for predicting total sediment output have been recently developed. Simulation programming approaches, such as those of Negev (1967) and WHTM (Patterson and others, 1974), allow total sediment from surface and channel sources other than mass wasting to be related to streamflow by manipulating power function coefficients to produce the measured sediment from a watershed. These approaches have generally not been tested in wildland management situations. Methods emphasizing process simulation of total output are also under development, such as the current work of Rogers (1975b) and Simons and Li (1975). At the present time predicting total sediment output from wildland watersheds can best be done by regression models. These models generally work when applied to the area on which they were developed, although most cannot specifically represent changes in individual management practices. This makes them difficult to use in evaluating land management alternatives.

## Biological Model Review

Biological modeling for purposes of this effort includes consideration of microoranisms that originate from non-point sources and the effect of land management activities on dissolved oxygen and temperature. Dissolved oxygen and temperature were included as biological components because of the critical effects of these two physical parameters on the aquatic habitat. Models dealing with the effects of microorganisms, temperature, and dissolved oxygen on higher order aquatic life are beyond the scope of this report. Estuary models are referenced but not evaluated.

Approximately 400 models were located for possible evaluation and then categorized into those dealing with microorganisms, dissolved oxygen, or temperature. Approximately 75 percent of the models were eliminated because the evaluators felt they did not apply to the wildland situation. Models which treated more than one parameter category were placed in the most appropriate category. Comprehensive ecological models were identified in the references but not evaluated since these models required a high level of skill and complex data bases to operate.

### Water Temperature--

Water temperature was found to be a well-studied topic. Most of these models deal with basic thermodynamic processes and physical water properties that affect water temperature. The basic aim of several models was to predict water temperature through the relationship of energy balance components, water properties, flow rate, depth, and area of water exposed.

All of the models rendered predict what happens in downstream reaches of a stream given the inputs to the reaches and upstream or tributary inflows. None of the models evaluated predicted water temperature of first order streams or the temperature of water inputs to these streams from surface or subsurface flow.

Many of the models available were developed for predicting the effects of point discharges of warm water into a larger body of water or a stream. Such models should have applicability to the wildland situation when a small stream affected by forest cover manipulation is tributary to another stream.

The models presented by Brown (1969, 1970, and 1972), DeWalle and Kapple (1975), and Pluhowski (1972) provide a means of predicting the effects of forest cover manipulations in the riparian zone on stream temperature in a downstream reach.

Brown's model, developed in the Pacific Northwest, was subsequently tested for eastern forest conditions in the Southern Appalachians. Resuts showed that it significantly overestimated the actual temperatures (unpublished data, Coweeta Hydrologic Laboratory, Southeastern Forest Experiment Station, USDA--Forest Service). Hence, these models should be applied to a variety of wildland situations across the United States to test their general validity.

Microorganisms--

Work by McSwain and Swank (n.d.), Lee (1970), Cunningham and others (1974), and Buller (1974) were the only references found on the effects of wildland management activities on microorganism pollution indicators and pollutants. Although potential sources of microorganisms in the wildland environment are numerous, their relationships to management activities are not well documented. Some models were located which dealt with the survival of coliforms (Mattloch, 1974; Canale and others, 1973; and Canale, 1973). Again, these dealt only with downstream reaches, but may be helpful in assessing the time factors associated with coliform contamination of wildland surface waters. Buller (1974) was the only reference located that treated the viral hazards associated with land disposal of human wastes.

The HSP-QUALITY (Lombardo and Franz, 1972; Lombardo and Ott, 1974) and WHTM (Patterson and others, 1974) models may have utility in predicting the movement of pathogens in a wildland environment. However, both require quantities and distributions of coliform as inputs, and their applicability to wildland situations was not determined in this review.

Dissolved Oxygen (Stream Models)--

Models for dissolved oxygen in streams fall into two principal categories: those that predict behavior of a single reach of stream and those that model multiple reaches of a stream as linked system. Multiple reach models can handle simple reaches as a special case and hence are more general. They are generally directed toward a more sophisticated user. Single reach models are generally disregarded for use by the water resource professional.

All models selected for evaluation have generally been developed and used to predict water quality in systems receiving discharge from one or more point sources such as treatment plants or tributary inflows. Most can also handle non-point sources such as lateral inflow along the reach provided as input. All have utility for predicting the downstream effects of non-point source pollution entering the system from upstream tributaries which are normally considered to be just routing modes. This leaves the problem of predicting what is actually happening in the upstream tributaries, in particular, the first order streams.

Of those found, only the HSP-QUALITY model (Lombardo and Franz, 1972; Lombardo and Ott, 1974) appears to have the capability for predicting non-point source pollution. However, this review did not determine that the model can be applied in a wildland situation. QUAL-II and DOSAG3 (Duke, 1974), and models of Yao (1970), Butts (1973), Yeh (1973), Orsborne and others (1973), Novotny and Krenkel (1975), Hoover (1970), and Lin (1973) may be able to predict behavior of streams immediately downstream from first order streams.

Dissolved Oxygen (Lake and Impoundment Models)--

The same models applied to streams are often applied to small lakes and impoundments. In these cases each reservoir is simply treated as another reach of the stream. However, difficulties are frequently encountered, particularly when the reservoir or lake is deep and stratified.

Numerous models were found which dealt with lake water quality. All of these were classified as lake ecosystem models and hence were not evaluated. Only two were specific with regard to dissolved oxygen (Newbold, 1974; Bella, 1970). Both basically apply simple lake ecosystem models to the specific problem of predicting dissoved oxygen profiles in lakes. These models do not appear usable at present in operational wildland situations.

In order to estimate non-point source pollution impact on a lake, one has to know the pollution load entering the lake from all sources and how this loading is affected by various upland activities. This problem is considered by Tenney (1971), Lombardo and Ott (1974), and Chen (1972). Only the HSP-QUALITY model (Lombardo and Ott, 1974) explicitly attempts to predict pollutant loading from non-point sources. As mentioned earlier, it remains to be determined if the model is applicable to the wildland situation.

Ground Water--

Models for biological aspects of groundwater were not found. Work is needed in this area, particularly with regard to pathogens, and should be directed towards describing biological contamination of ground water supplies by recharge with contaminated water.

## Chemical Model Review

Chemical models were considered to include those dealing with pH, acidity, alkalinity, conductivity, and various other chemical parameters. While many models were screened, only a few were selected for evaluation because most do not model the effects of land management on chemical parameters. The modeling efforts reviewed fall into three general classes: (1) downstream routing techniques for river systems, (2) empirical relationships derived from data bases for specific streams or rivers, and (3) forest ecosystem models based on abiotic and biotic processes, including both terrestrial and aquatic ecosystems. The downstreams routing techniques have little utility in evaluating the impact of forest activities on upstream characteristics. However, given upstream contributions these and other routing techniques will be useful in evaluating the importance or impact of these contributions on downstream reaches. Downstream routing techniques include HSP-QUALITY (Lombardo and Ott, 1974), QUAL-II and DOSAG3 (Duke, 1974; Orsborne and others, 1973), and WHTM (Patterson and others, 1974). These are generally simulation programming models. HSP-QUALITY, PTR (Crawford and Donigian, 1973), and WHTM all appear to have capabilities for predicting non-point source pollution, but their applicability to wildlands was not determined. Existing regression models have limited application for predicting chemical pollutant loads resulting from forest activities. These models are generally derived for a specific area of interest, and none appears to be broadly applicable because of the limited data bases used in their development. In addition, none of those reviewed is capable of predicting changes in water chemistry characteristics resulting from wildland management activities. Process simulation models are in various stages of development, but none has been documented in the open literature.

## STATE-OF-THE-ART

The following state-of-the-art assessment is based on a literature review of the models inventoried and did not involve actual model testing or in-depth comparative evaluation. The models were evaluated and the state-of-the-art was assessed subjectively from the perspective of the research or academic community. A "state-of-the-art" model is defined as one that incorporates advanced knowledge relevant to predicting a particular non-point source pollutant.

It is recognized that the state-of-the-art of models for use by field personnel lags that for the research and academic community in terms of sophistication. With few exceptions, the state-of-the-art for field-usable models is represented by local or regional regression models and similar analytical procedures.

Because of the inherent limitations of regression models vis-a-vis, the desirable characteristics for non-point models (previously discussed) the task group did not believe there were any that had widespread applicability. Thus this state-of-the-art assessment focuses on those simulation (process and programming) models that appear to represent the highest level of knowledge for each category of models (i.e., physical, chemical, and biological).

The review did not determine the wildland applicability of a number of the designated state-of-the-art models. The utility of several models for predicting the effect of wildland management on pollutant loads to receiving waters needs to be established. This, in the opinion of the reviewers, will require a program of model testing and comparative evaluation. This is especially true of the simulation programming models that are derivatives of the Stanford Model, such as HSP, HSP-QUALITY, and PTR.

## Runoff Models

The state-of-the-art for runoff models is represented by the process simulation models--the most advanced of all the non-point models. Models of this type that were developed for describing forest environments are represented by the Leaf (1975) and Rogers (1975a) models. For single storm events, the Simons and others (1975) model is representative. These models are just becoming available and have yet to be widely tested and refined for management use.

At the field professional level, the BURP (USDA, 1967) model and the model developed by Douglass and Swank (1972) have been used to predict changes in water yield from cover type manipulations. The Northern Region water yield guide (Silvey, 1974) is being used by non-water resource technicians for determining water yields.

Process simulation models developed specifically for evaluating management effects are represented by the USDAHL-70 (Holten and Lopez, 1971) for agricultural land. The state-of-the-art in simulation programming is represented by the HSP (Donigian and Waggy, 1974) model which was developed for urban and general flow determinations. It may be difficult to relate many of the input parameters required by these models to management activities occurring throughout the forest environment.

## Sediment Models

### Surface Erosion--

For surface erosion, the state-of-the-art is represented by process simulation models of which Simons and others (1975) is an example. This model, newly available, has not been extensively tested or used in management and is more sophisticated than the models currently used.

Almost all surface erosion models that have been used extensively in field applications for forest management were developed from the models developed for agricultural lands by

Musgrave (1947) and the Universal Soil Loss Equation (Wischmeier and Smith, 1965). The ONEROS model (USDA, 1972) and FASS model (Dissmeyer, 1973) represent the best of these two basic approaches for wildland situations. The FASS model has been used mainly in the southeast, and the ONEROS model (or variations of it) mainly in the west. Both models require routing coefficients and provide little physical basis for determining them. Both assume that all runoff occurs by overland flow, which is not a valid assumption in many forest cover types.

Channel Erosion--

The state-of-the-art for channel erosion is simulation programming represented by Negev (1967) and WHTM (Patterson and others, 1974). No process simulation models were reviewed which simulate channel bank and/or bottom erosion. There are several routing models that account for aggradation and degradation in stable channel systems. The Simons and others (1975) and Thomas (1974) approaches are examples of process simulation models that represent the state-of-the-art for stable channel systems. Neither has been used to predict the effects of management activities in upland watersheds as the Thomas model was not designed for such use and the Simons model has only recently become available. The state-of-the-art for modeling unstable channels is represented by regression models and analytical techniques.

Mass Movement--

No process simulation models for the mass movement component of erosion were reviewed. The state-of-the-art at present uses analytical procedures that will lead to some prediction that an area is unstable and has potential for failure (Dryness, 1967).

Total Erosion--

A working process simulation model containing all components of sediment output was not found. The only total sediment output models are of the regression and simulation programming types.

## Chemical and Biological Models

Temperature--

The process simulation models such as those of Brown (1972), DeWalle and Kappel (1975), and Pluhowski (1972), represent the state-of-the-art for predicting the effects of forest cover manipulations on water temperature in the riparian zone of a downstream reach, given the upstream or tributary inputs to the reach. No temperature models were found which predict temperature of first-order stream or the temperature of water inputs to these reaches from surface or subsurface flow.

Dissolved Oxygen--

For predicting downstream effects on dissolved oxygen, simulation programming models such as HSP-QUALITY (Lombardo and Ott, 1974) are potentially suitable; however, none has been tested or evaluated for use in wildland situations. Only the HSP-QUALITY model is potentially applicable for use on the first-order streams.

Chemical and Dissolved Solids--

Simulation programming models represent the state-of-the-art for nutrient and dissolved solids models. Examples are HSP-QUALITY (Lombardo, 1973) and WHTM (Patterson and others, 1974). In field use the state-of-the-art is represented by regression models that relate nutrient and dissolved solid parameters to flow volumes.

Pathogens, Heavy Metals, and Pesticides--

For pesticides the state-of-the-art is represented by the Pesticide Transport and Runoff (PTR) model for agricultural lands (Crawford and Donigian, 1973). The WHTM model was designed for trace contaminants such as heavy metals and pesticides, so it may also be suitable for simulating the effects of forest managment activities on pathogens. The HSP-QUALITY model may also be useful in simulating the effect of forest management situations on heavy metals and pathogens. All of the above models (PTR, WHTM, and HSP-QUALITY) are state-of-the-art models, but their utility in modeling the effects of wildland management activities on the wildland environment has not been adequately demonstrated. Until they are further tested and evaluated for wildland application, no conclusions can be drawn and little can be said regarding their potential utility for such purposes.

## NON-POINT WATER QUALITY MODELS

To design and develop a useful model it is necessary to understand the specific intended uses of the model and the environments in which the model is going to be utilized. To date, the specific environments in which non-point models will be used in the management of water quality from wildlands have not been defined in sufficient detail to adequately guide model development work. Nevertheless, some aspects of this environment can be outlined along with some of the characteristics that the task force believed non-point models needed so as to be useful in forest land management.

### Role in the Decision Process

Water quality is only one of the main factors in the natural resource area that must be evaluated in making land management decisions. Economic, social, political, and institutional, as well as natural processes must all be effectively considered in establishing water quality goals and criteria and in making land management decisions.

At least three roles need to be met by water quality models in this decision making process. Models need to:

1. Relate alternative land use allocation and activities to water quality goals and criteria in a manner that can be used by land managers.

2. Provide an insight and understanding of the effect of various water quality levels on the aquatic environment so that land managers will be able to identify the trade-offs involved and effectively participate in the process of establishing water quality goals.

3. Predict the water quality effects of the alternatives under consideration in on-the-ground project planning and design.

## Perspective of the User

Water quality models will be used to help assess the effects of proposed land management activities on selected water quality parameters in both the land use planning and project design phases of forest management. The highest priority need will be for models suitable for use by professional water resource personnel operating at the field level. In some cases achieving this type of model may require the prior development of more complex simulation models of basic ecosystem processes; but the end results must be models or techniques that are operational and usable in the field management environment. Thus the long-run goal is to have models available that water quality professionals at the field level can use in developing management prescriptions and guidelines for application by other professionals and technicians involved in general land use planning and on-the-ground project planning and design.

## Desirable Model Characteristics

Based on the above discussion and the information obtained in this review, some desirable characteristics for non-point water quality models have been compiled. In trying to describe desirable model characteristics, there is always the problem of where to stop, considering the time available or the resources that might be allocated to the actual model development. This section cannot specifically deal with these questions; instead the attempt here is to highlight those characteristics that are necessary for models to be useful to the land manager at the field level. It may often be necessary first to develop detailed process models which can then be simplified, generalized, and regionalized for field use. The necessary model characteristics that can be specified at this stage are outlined below:

Loading vs. Routing--

To be useful in wildland management, non-point water quality models must be able to predict parameter loads resulting from specified (alternative) management activities. Once such loads are determined, then routing becomes a desirable feature. Moreover, in some cases, prediction of loading requires prediction of routing. But routing models that do not include loading appear to have little use in wildland management.

Relative Differences vs. Total Amount--

Models suitable for predicting both relative differences and total amounts of pollution loading resulting from management alternatives are desirable. However, the accuracy of predicted relative differences resulting from management alternatives is more essential to effective decision-making than the accuracy related to total amounts.

Time Effects--

Since the effects of most forest management activities can be expected to change over time, it is important that time-dependent phenomena be represented in the model. This is one of the principal shortcomings of almost all regression models and a primary reason why process simulation and simulation programming models are emphasized in the preceding state-of-the-art assessments.

Spatial Effects--

The spatial distribution of management activities in a watershed, vis-a-vis the location of the channel system, often has enormous influence on the water quality effects of these activities. Therefore, models must be able to accept inputs which describe the spatial variability of the landscape itself, and represent the effects of altering the locations and patterns of activities being planned.

Data Availability--

The data required by non-point models must either be available in the area where such models are proposed for use or must not be too difficult for typical water resource staffs to collect. In many forested areas use of relatively extensive data will be necessary. These data must represent the differences in land and land activity combinations to the extent necessary to evaluate water quality.

Activity Oriented--

It must be possible to represent land management activities and evaluate their water quality effects in any model proposed for use. A management activity would be described in terms of model input parameters. The model would then output the predicted water quality for the specified set of management activities and land and climatic conditions.

Another modeling approach would be to develop parameter-oriented models. In this approach, a target or ceiling value for a water quality parameter would be entered into the model, and the model would output all or selected management activity combinations that would meet the desired water quality level. In the long run, both of these types of models may be helpful, but to develop such a parameter-oriented model, the activity-oriented process models must already be available for determining the water quality effects of specified management activities.

## MODEL DEVELOPMENT AND APPLICATION APPROACH

### Decision-Making Environment

Model development and application must take place in light of and in response to the decision-making processes and situations in which they are to be employed. The decision-making activity determines on a continuing basis what information will be needed, at what precision and cost, and when, where, how, and by whom it will be provided. Managers must be able to select specific tools and procedures in light of each decision need or situation. The tools to be used will depend on:

1. The nature of the alternative actions being considered.

2. The characteristics of the resources and people to be involved.

3. The possible effects of alternative actions on these resources and people.

4. The values and risks involved.

5. Other planning constraints such as the time, funds, and skills available.

Each land manager must be able to tailor organizational arrangements, operating procedures, data bases, and analytical systems to fit his own situation, in such a way that effective decisions are reached.

## Modularity

In many field units, most planning activities are still being done with the aid of common tools. For some units, these methods will suffice for decision-making in most situations. But other field-level managers now want and need to utilize information that can be efficiently generated and communicated only by using various computer-aided systems.

Some minimum standardization will be necessary among system components for two major reasons: (1) to hold down development and training costs; and (2) to improve the effectiveness of communications between organizational levels. On the other hand, it is clear that one standard, integrated system for planning and decision-making for all units is not practical because of the great variability in informational needs from location to location and from situation to situation.

If computer hardware and software and related tools are to become widely accessible and used cost-effectively and wisely in planning and decision-making, what is needed is a range of standarized (modular), mutually compatible component models having common interfaces where necessary. A manager could then choose from these modular components to assemble a planning/decision-making system tailored to his own particular information needs and could easily adjust the mix of components from one situation to the next. In non-point pollution studies, for example, the tools needed would depend on the characteristics of the particular land area being studied, as well as on the skills, data, time, and funds available.

One of the primary needs in the non-point area is for a coordinating mechanism for building a nucleus of standardized system components. This nucleus would be made up of modules that complement each other, offer alternative intensities of investigation in problem solving, and provide common interfaces for necessary information transfer between components, such as between various modules for storage and retrieval, analysis, and display. Once established, the nucleus would continue to grow over time, gradually expanding into a full complement of standardized components suitable and available for use as needed at all administrative levels.

Modularity also appears to be an important modeling concept to the extent that models must be kept simple to be feasibly used and gain acceptance. It appears that generalized all-purpose models are expensive to develop, difficult to use and control, and have large data requirements--all of which tend to detract from their field usability. Using a modular approach should help overcome some of these limitations.

User Participation--

For usable models to be designed and implemented, decision makers and modelers must be in effective communication throughout the development process. They must develop a mutual understanding of the problems the policy makers are facing so these problems can be highlighted and the model relegated to its proper status--as an aid to the decision maker. User involvement in model design also insures that the modeler has a full understanding of the perception of the situations being modeled from the user's view. Such interactions prove mutually beneficial and educational. The model thus developed will tend to be more relevant for the purpose for which it was devised, and the user will have more trust in its validity and capabilities. Quite often the ultimate user has very little involvement with the development phase, and consequently has to accept the final product on faith. Thus, it is not surprising that decision-makers do not rely heavily on models for evaluating alternatives.

Multi-Level Models--

To provide the full range of tools needed for non-point management, models at several levels of accuracy and resolution will undoubtedly be needed. As stated earlier, providing usable models and guidelines for field managers may require that comprehensive process models be developed and tested and then be regionalized and simplified.

Multi-Stage--

Multi-stage development is one process used to develop models. In this process the following steps are used:

1. Initial development--model ready for testing.

2. Development and parameter testing--model ready for use in research environment.

3. Model simplification, regionalization, and generalization--model ready for testing by water resource professionals.

4. Validation testing under operational field conditions--models ready for operational use by water resource professionals.

Modeling Approach--

Utilization of the process simulation approach to modeling, supported as needed by simulation programming and regression models, appears to provide the strongest foundation for non-point model development. This approach represents the physical-chemical processes involved in the most straightforward manner, and includes the time effects and spatial variability of forest landscapes and activities.

## Core Models

Core models for an operational set of non-point source pollution module components are those that represent water and sediment loading processes, as water and sediment (along with air) are the principal pollutant transport mechanisms.

An in-depth analysis of the impact of various pollutants upon beneficial water uses plus an area-by-area evaluation of the associated socio-economic consequences should precede the determination of specific priorities for developing operational modules. However, it appears that in most areas, operation modules for water yield, water routing, surface erosion, mass wasting, channel erosion, and sediment routing are high priority needs. Other module components, such as nutrient yield, pesticides, pathogens, or heavy metals could be designed for coupling to this basic set.

# CONCLUSIONS AND RECOMMENDATIONS

## Streamflow Models

Steamflow predictive models have received the most intensive study of all non-point loading predictive techniques. The ability of the majority of available streamflow models to relate wildland activities to their unique environment and to account for spatial diversity is not well demonstrated, even for those models that have been developed for that purpose.

An extensive program of testing, evaluating, refining, and validating the more promising exising models is needed. The possibilities of adapting and/or simplifying existing models for operational use should be exhausted prior to initiating any major new development in streamflow models. The program should evaluate abilities of the existing streamflow models to represent wildland activities and environments in a way that accounts for spatial diversity. Skills and data required to operate the models should be reasonably accessible to wildland managers.

## Sediment

Existing sediment models deal mainly with surface erosion. While two models handle aggradation and degradation in stable channels, no process models exist for in-channel erosion, nor are any models available for predicting mass wasting.

Almost all existing surface erosion models are based on either the Musgrave approach or the Universal Soil Loss Equation, although some recent work has been done on simulating the basic physical processes involved.

Managers currently must rely on regional regression models to estimate on-site erosion and translate it to downstream points. These models usually will not adequately represent specific management activities in terms of predicting their effects on on-site and downstream sediment.

In many areas channel erosion and/or mass wasting, rather than surface erosion, are the dominant sediment producing processes. Managers in such areas are very anxious to have better methods for predicting the effects of their activities on sediment from these sources.

A comprehensive sediment loading model that is comparative in nature and contains components representing surface, channel, and mass wasting erosion processes should be developed and tested. For wildland management, the model must provide a physical basis to evaluate the initial effects and trend in recovery time for massive site disturbance (road and trail construction and site preparation) as well as the direct and secondary effects of vegetation removal. The component models (surface, channel, and mass wasting) have provincial priorities; however, the ability to model site disturbance within a comprehensive model commands the highest priority.

## Biological and Chemical

### Water Temperature--

There are several process simulation models available for predicting the effects of forest cover manipulation in downstream riparian zones on stream temperature. These models should be tested in a variety of wildland situations across the United States to determine their potential for nation-wide application and usability in an operational environment.

### Dissolved Oxygen and Pathogens--

Loading models for dissolved oxygen and pathogens are virtually non-existent. Available simulation programming models need to be evaluated with respect to their ability to relate to wildland activities, both upstream and downstream.

### Chemicals--

Almost no chemical models applicable to wildland activities were found. There is a need to examine existing simulation programming models with respect to their capability to predict movement of chemicals within and from wildlands.

Heavy Metals--

Waste disposal is the most important wildland management activity that affects heavy metals. There are two models that should be evaluated for applicability to a wildland environment.

Dissolved Solids--

There appears to be no presently available model for predicting the effects of wildland management activities upon concentrations of dissolved solids with the possible exception of waste disposal. Waste disposal is unique as a wildland management activity since the amounts of material being loaded into the system are generally known. A model is available for routing known concentrations but requires field evaluation.

Pesticides--

No presently available model for predicting the effects of using pesticides in a wildland environment has been developed or tested in such an environment. The Pesticide Transport and Runoff Model for Agricultural Lands may be suitable or provide the basis for developing a wildland version. This model should be modified as needed and tested for applicability.

General--

Although some physical models may be adequate to account for sedimentation and water yield, there is a question as to how compatible they are with the processes that regulate chemical fluxes, pathogens, and factors affecting dissolved oxygen and temperature. For example, terrestrial and aquatic ecosystem processes such as primary and secondary production, decomposition, and consumption are integral functions of wildland systems that control the natural circulation of nutrients. Any attempt to predict or model chemical response due to wildland activities must couple biological and physical processes. Also, the time base of physical models must be examined with respect to the time resolution needed to model the biological and chemical constituent response.

LITERATURE CITED, SECTION 5

Anderson, David 1969. Guidelines for computing quantified soil erosion hazard and on-site soil erosion. USDA Forest Service, Southwestern Region, Albuquerque, N.M.

Anderson, Henry W. 1954. Suspended sediment discharge as related to streamflow, topography, soil, and land use. Trans. Amer. Geophys. Union 35(2): 268-281.

Bell, James M. 1968. General slope stability analysis. Proc. Amer. Soc. Civ. Eng., J. Soil Mech. Found. Div. 94(SM6): 1253-1270.

Bella, D. A. 1970. Dissolved oxygen variations in stratified lakes. J. Sanitary Eng., Div. ASCE 96(SA5): 1129-1146.

Bolton, Wilson, and Bowie. 1972. Runoff and sediment in large watersheds. USDA, ARS, Oxford, Miss.

Brown, G. W. 1972. An improved temperature prediction model for small streams. Nat. Tech. Inform. Serv. PB-212 385, Oregon Water Resources Res. Inst., Corvallis, Completion Rpt. 20 p.

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

Brown, George W. 1970. Predicting the effect of clearcutting on stream temperature. J. Soil and Water Conservation, 25(1): 11-12.

Buller, Richard S. 1974. Potential viral hazards of land disposal of human wastes. M.S. thesis, Michigan Technological Univ.

Butts, T. A., Kothandaraman, V., and Evans, R. L. 1973. Practical considerations for assessing the waste assimilative capacity of Illinois streams. Illinois State Water Survey Circular 110.

Canale, R. P., Patterson, R. L., Gannon, J. J., and Powers, W. F. 1973. Water quality models for total coliform. J. Water Poll. Control Fed. 45: 325-336.

Canale, Raymond P. 1973. Model of coliform bacterial in grand Traverse Bay. J. Water Poll. Control Fed. 45: 2358-2371.

Chen, C. W. and Orlob, G. T. 1972. Ecologic simulation for aquatic environments, final report. OWRR Project No. C-2044. Office of Water Resources Research, Dept. of Interior. NTIS PB-218 828.

Crawford, Norman H., and Donigian, Anthony S., Jr. 1973. Pesticide transport and runoff model for agricultural lands. Environmental Prot. Tech Series EPA-660/2-74-013 Office Res. and Devel. Environmental Prot.

Cunningham, Robert, Tluczek, Louis, and Urie, Dean H. 1974. Soil incorporation shows promise for low cost treatment of sanitary vault wastes. USDA Forest Serv. Res. Note NC-181, 3 p. North Central Exp. Sta., St. Paul, Minn.

Dewalle, David R., and Kappel, William M. 1975. Estimating effects of clearcutting on summer water temperatures of small streams. Manuscript, School of Forest Resources, Pennsylvania State Univ., University Park, Pa.

Dissmeyer, G. E. 1973. Evaluating the impact of individual forest management practices on suspended sediment. Proc. of Nat. Meet. of SCSA, Hot Springs, Arkansas.

Donigian, Anthony, Jr. and Waggy, W. Henry. 1974. Simulation--a tool for water resource management. Water Resource Bull. 10(2): 229-244.

Douglass, J. E., and Swank, W. T. 1975. Effects of management practices on water quality and quantity. USDA Forest Service Tech. Rept. SE-13. Southeastern Forest Exp. Sta., Asheville, N.C.

Duke, James H., Jr. 1974. Practical application of water quality models. 1974 Summer Computer Simulation Conference, pp. 606-617.

Dyrness, C. T. 1967. Mass soil movements in the H.J. Andrews Experimental Forest. USDA Forest Serv. Res. Pap. PNW-42, 12 pp., Illus. Pacific Northwest Forest and Range Exp. Sta., Portland, Ore.

Flaxman, Elliott M. 1972. Predicting sediment yield in western United States. J. Hydraluics Div., ASCE 98(12): 2073-2085.

Foster, G. R. and Meyer, L. D. 1972. Mathematical simulation of upland erosion using fundamental erosion mechanics. USDA, ARS, Sediment Yield Workshop, Oxford, Miss. Nov. 28-30, 1972.

Gray, Donald H. 1969. Effects of forest clear cutting on the stability of natural slopes. Progress Rpt. Univ. of Michigan, ORA Proj. 01939, 67 p.

Hewlett, John D. and Troendle, Charles A. 1975. Non-point and diffused water sources: A variable source area problem proceedings of symposium conducted by the irrigation and drainage division of ASCE, p. 21-46, Logan, Utah.

Holtan, H. N. and Lopez, N. C. 1971. USDAHL 70 model of watershed hydrology. Tech. Bull. No. 1435, 84 p.

Hoover, Thomas E. and Arnoldi, Robert A. 1970. Computer model of Connecticut river pollution. J. Water Poll. Cont. Fed. 42(2), Part 2: R67-R75.

Jones, F. O., Embody, D. R., Peterson, W. L., Hazlewood, R. M. 1961. Landslides along the Columbia River Valley, northeastern Washington. U.S. Geol. Surv. Prof. Pap. 367, 98 p.

Keller, Hans M. and G. E. Brink. 1975. Watershed simulation model for selected ion concentrations. USDA, Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colorado.

Leaf, Charles. 1974. A model for predicting erosion and sediment yield from secondary forest road construction. USDA Forest Serv. Research Note RM-274. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo.

Leaf, Charles F., and Brink, Glen E. 1975. Land use simulation model at the subalpine coniferous forest zone. USDA Forest Serv. Res. Paper RM-135, 15 p.

Leopold, L. and Maddock, T., Jr. 1953. The hydraulic geometry of stream channels and some physiographic implications. U.S. Geologic Survey Paper 252.

Lee, Roger D., Symons, James M., Roberts, Gordon G. 1970. Watershed human use level and water quality. J. Amer. Water Works Assoc. 62(7): 412-422.

Lin, S. H., Fan. L. T., and Hwang, C. L. 1973. Digital simulation of the effect of thermal discharge on stream water quality. Water Res. Bull. 9(4): 689-702.

Livesey, R. H., Anuambhotia, V.S.S., and Sayre, W. W. 1972. The statistical properties of Missouri River bedforms. ASCE. Vol. 98, No. WW4, Paper 9358, pp. 489-510.

Lombardo, P. S., and Franz, D. D. 1972. Mathematical model of water quality in rivers and impoundments. Hydrocomp, Inc., Palo Alto, California.

Lombardo, Pio S. 1973. Critical review of currently available water quality models. Hydrocomp, Inc. 91 p.

Lombardo, Pio S. and Ott, Ronald E. 1974. Water quality simulation and application. Water Resources Bull. 10(1): 1-9.

Mattlock, Jerome L. 1974. Comparative analysis of modeling techniques for coliform organisms in streams. Applied Microbiology 27(2): 340-345.

McSwain, Michael R. and Swank, Wayne T. N.D. Baseline values and short-term fluctuations of enteric bacteria in oligotrophic streams of western North Carolina. Manuscript in press at USDA, Southeastern Forest Exp. Sta., Asheville, N.C.

Megahan, W. F. 1974. Erosion over time on severely disturbed granitic soils: a model. USDA Forest Serv. Research Paper INT-156, 14 p., Intermountain Forest and Range Exp. Sta., Ogden, Utah.

Miller, C. R. 1951. Analysis of flow-duration--sediment rating curve method of computing sediment yield. USDI, Bureau of Reclamation.

Morrill, R. A. and Van Dok, F. 1974. Available computer programs for the prediction and evaluation of sediment erosion, transportation and deposition. EPA Contract 4-40-00672. Denver, Colorado, Region VIII.

Musgrave, G. W. 1947. The quantitative evaluation of factors in water erosion--a first approximation. J. Soil and Water Cons. 2: 133-138.

Negev, Moshe. 1967. A sediment model on a digital computer. Dept. of Civil Engineering, Stanford Univ. Tech. Rpt. No. 76, 109 p., illus.

Newbold, J. D. and Liggett, J. A. 1974. Oxygen depletion model for Cayuga Lake. J. Environ. Eng. Div. Proc. ASCE, 100(EE1): 41-59.

Novotny, Vladimir and Krenkel, Peter A. 1975. A waste assimilative capacity model for a shallow turbulent stream. Water Research 9: 233-241.

Orsborne, John F., Mar, Brian W., Crosby, James W. III, and Crutchfield, James. 1973. A summary of quantity, quality, and economic methodology for establishing minimum flows. State of Washington. Water Res. Ctr. Rep. No. 13, Vol. 1 and 2.

Patterson, M. R. and others. 1974. A user's manual for the FORTRAN IV version of the Wisconsin hydrologic transport model (WHTM). Oakridge Nat. Lab. Rpt. ORNL-NSF-EATC-7, EDFB-IBB-74-9. Contract No. W-7405-ENG.-26, 272 p.

Pluhowski, E. J. 1972. Clear-cutting and its effect on the water temperature of a small stream in northern Virginia U.S. Geol. Surv. Prof. Paper 800-C, pp. C-257 to C-262.

Rogers, James J. 1975a. Ecosystem analysis of forest watersheds: Documentation of a general water balance model. Manuscript in review, Coniferous Forest Biome, College Forest Resources, Seattle, Washington.

Rogers, James J. 1975b. Development of a general erosion model for terrestrial forest ecosystems. Draft study plan W-MD-8, USDA, Rocky Mountain Forest and Range Exp. Sta., Flagstaff, Arizona.

Rosgen, Dave. 1975. Preliminary report procedure for quantifying sediment production. North Zone Planning Unit, USDA, Forest Service, Sandpoint, Idaho, 13 p.

Silvey, H. L. 1974. Water yield increase analysis procedure. Forest Hydrology, Part II. USDA, Forest Service, Region 1, Missoula, Montana. 61 p.

Simons, D. B., Li, R. M. and Stevens, M. A. 1975. Development of models for predicting sediment yield from small watersheds. Civil Engr. Dept., Colo. State Univ. Rpt. CR 74-75, DBS-RML-MAS 24, Aug. 1975, 127 p.

Simons, Daryl B. and Li, Ruh-Ming. 1975. Development and documentation of a physical simulation model for routing water and sediment from small watersheds. Study Plan, CSC Project 31-1372-2126, CSU Dept. of Civil Engineering, June 15, 1975. Ft. Collins, Colo.

Strand, Robert I. 1972. PSAND (sediment model). Bureau of Reclamation, Denver, Colo.

Tenney, M. W., Echelberger, W. F. Jr., Singer, P. C., Verhoff, F. H. and Garvey, W. A. 1971. Biogeochemical modeling of eutrophic lakes for water quality improvement. In: Adv. In Water Pollution Research, Proc. 5th Int. Conf., San Francisco, 1970. III-21, pp. 1-12.

Thomas, W. A. 1974. Scour and deposition in reservoirs and rivers. Program 723-G2-L2470 Corp. of Engineers, Hydrologic Engineering Center, Davis, Calif.

USDA, Forest Service. 1967. BURP--a water balance program. Watershed Systems Development Unit, PSW Forest and Range Exp. Sta., Berkeley, Calif.

USDA, Forest Service. 1972. ONEROS. Watershed Systems Development Unit, Pacific Forest and Range Exp. Sta., Berkeley, Calif.

Wischmeier, W. H. and Smith, D. O. 1960. Universal soil loss equation. Seventh Int. Cong. Soil Sci., Madison, Wisc.

Woolhiser, D. A. and Todorovic, P. 1974. A stochastic model of sediment yield for ephermeral streams. Proc. of Symposium on Statistical Hydrology, Tucson, Ariz., USDA Misc. Pub. 1275, pp. 295-308.

Yao, K. M. 1970. Generalized equations for critical oxygen deficit. Water and Sewage Works 117(12): 426-429.

Yeh, Hsin H., Skelly, Michael J., and Lawler, John P. 1973. Generalized simulation models for Massachusetts streams. Journal of the Boston Soc. of Civil Engineers 60(3): 108-132.

## SECTION 6

## DATA BASE AVAILABLE FOR NON-POINT POLLUTION MODEL DEVELOPMENT AND TESTING

Part of the state-of-the-art documentation regarding non-point pollution is the identifying and characterizing of selected instrumented watersheds where a data base is available for predictive model development and testing.

### CRITERIA FOR SELECTING WATERSHEDS

Eight criteria were developed for selecting the watersheds to be surveyed and documented. The restrictive criteria were a combination of contractual direction, a search of published methodology, and the subjective reasoning of the evaluators. The criteria and a brief explanation of the reasoning behind each follow:

1. The watershed must represent activities typical of forest and range (wildland) areas.

2. The data must have been collected according to a plan and collection accomplished on a routine basis. The intent was to avoid the haphazard "nice to know" data bases. This insured that the available data base was collected in an orderly manner, was complete, and was representative of standard analysis methodology.

3. The data must be available. If an organization or agency had instrumented watersheds but was not prepared to release the base data for model development and/or testing, the watershed was not documented.

4. The available data must be reliable. To qualify, the data base must have potential usefulness for predictive model development and testing; therefore, precision and accuracy of the data was essential. The reliability of data was a subjective decision of the task group member based on his understanding of standard instrumentation, acceptable procedures and methods of data collection, and accepted analysis procedures.

5. The time span of data collection must be 1 year or greater. In general, it was put that the longer the period of record, the higher the probability of developing realistic characterization of the entity recorded. One year was selected as the minimum time needed to characterize seasonal fluctuations and to evaluate cyclic trends.

6. There must be a combination of several types of data; i.e., water quality, hydrometeorological, physical, etc., collected over a similar time frame. The majority of models require more than one type of data. To insure comparative capabilities among data, a common time frame is essential. Because a watershed did not have one of the indicated types of data, it was not necessarily eliminated from the survey. If sufficient types of data were believed to be available to warrant further supplemental instrumentation or monitoring to meet the model development or testing needs, it was included.

7. The watersheds should not have large-scale mining, agriculture, or urbanization activities within them.

8. The watersheds inventoried must be representative of accepted physiographic units.

It should be noted that it was not considered essential that the watershed be currently operational. Thus certain watersheds that were not operational but known to members of the task group to have an existing and useful data base were listed.

WATERSHED INVENTORY FORM

After various methods of presentation were evaluated, the conclusion was that identification and characterization could best be accomplished through the use of a survey form (note example). The form provided a uniform method of summarizing descriptive watershed information from numerous and diverse areas of the United States. Basically, the form was designed to answer four questions: Where is the watershed? What is the watershed like? Who is the administering agency? What type of data are available? The form resembles that used in "International Hydrologic Decade Representative and Experimental Basins in the United States." Although the form is essentially self-explanatory, the following discussion of some of the terms will assist the user:

Type--There were two acceptable designations for the type of watershed--either experimental or representative. An experimental watershed is one that has been instrumented to study hydrological phenomena; a representative watershed is one that has been instrumented to be indicative of a broad, homogeneous area.

WATERSHED INVENTORY FORM

| | |
|---|---|
| Watershed identification | Name: Thomas Creek Watersheds<br>Area: 421.9 ha (1,042 acres)<br>Type: Experimental |
| Administering organization | Name: Rocky Mountain Forest & Range Experiment Station<br>Address: Forest Hydrology Lab<br>Tempe, Arizona 85281 |
| Location | State: Arizona<br>Latitude: 33°40'28"<br>Longitude: 109°16'08" |
| Physiographic description | Geology: Basalt<br><br>Typography: Steep slopes near Weirs, relatively flat at upper ends.<br><br>Vegetation: Mixed conifer<br><br>Soil: Fine, fine loamy, basalt rock<br>soil depth .9 to 1.83 m (3 to 6 feet)<br><br>Climate: 63.5 cm (25 in.) precipitation |
| Use | Past: Virgin forest, grazing<br><br>Present: Virgin forest |
| Purpose of data collection | The watersheds are under calibration for a multiple use treatment on South Fork in 1976. Intent is to monitor multiple use. |
| Publications | None |

(EXAMPLE - SIDE 1)

| | |
|---|---|
| **Data availability**<br>To whom<br>When<br>Form | **Collected data:** All individuals as requested:<br>Daily summaries:<br>1. Runoff--computer printout<br>2. Precipitation--hand compilation<br><br>**Supporting data:** Apache-Sitgreaves National Forest, reports, surveys, and written reports. |
| **Date collection initiated** | Runoff - August 1960<br>Precipitation - November 1962<br>Temperature - July 1973<br>Solar and Net Radiation - July 1974 |
| **Date collection terminated** | Continuing |

**Types of Data Available (P = periodic; C = continuous)**

**Collected Data**

Runoff (C)
Precipitation (C)
Temperature (C)
Solar Radiation (P & C)
Sediment Sampling (P)
Relative Humidity (C)
Snow Survey (P)
Soil Moisture (P) (limited)
Transmissity (P)
Snow Density (P)
Water Quality (P)
Silica
Sodium
Orthophosphate
Iron
Flouride
Sulphate
pH
Total Dissolved Solids
Bicarbonate
Calcium
Chloride
Magnesium
Nitrate
Total Nitrogen

**Supporting Data**

Timber inventory
Esthetic evaluation
Soil inventory

**Remarks:** Paired watersheds control and treated:
North Fork 178.5 ha (441 acres)
South Fork 243.2 ha (601 acres)

(EXAMPLE - SIDE 2)

Latitude/Longitude--Unless otherwise specified, the given figures are those locating the most downstream portion or mouth of the watershed.

Publications--Up to three or four of the most prominent publications will be listed, if any exist. The word "other" at the end of the list indicates additional documents to those listed.

Data Availability--Identifies constraints on obtaining the data and establishes the status of the data. "Form" is an indication of condition of the data; i.e., on field form, edited, summarized, computer stored, etc.

Collected/Supporting--Identifies the two types of information that may be available: (1) collected data being that which is periodically or continuously collected, compiled, and analyzed; i.e., water quality, streamflow, precipitation, etc.; and (2) supporting data being the static information which is obtained and summarized generally only once; i.e., geologic surveys, soils inventories, vegetative inventories, etc.

Continuous Data--Collected essentially without interruption, usually by some mechanical recording device placed within the watershed.

Periodic Data--Collected routinely or by plan (e.g., once per month) but not "continuously" in the sense described above. Data usually collected by hand as compared to mechanical devices.

A completed set of the individual inventory forms appears in Appendix B.

SURVEY TECHNIQUES

The initial intent was to contact agencies administering the watersheds by telephone and verbally obtain the information necessary to complete the forms. Travel, personal contacts, and mailing of forms for completion were to be kept to a minimum. The short-comings of this approach became rapidly apparent. The individuals contacted generally did not have the necessary information at hand, which required contacting them again at a later date. Some persons had more than one or two instrumented watersheds and it involved an excessive investment of time to complete the survey by telephone.

Upon recognizing this problem, the technique was altered. The individual was contacted by phone and made aware of the intent of the survey. When it was ascertained that instrumented watersheds were available and that they met the survey criteria, one of the following procedures was used, based on the preference of the individual.

1. The individual was sent an explanatory letter, a completed sample form, and a request to have the same type of information available for a subsequent telephone call.

2. The individual was sent a completed sample form, a supply of blank forms, and requested to complete the forms and send them back to the team member.

Because some of the forms were filled out by different persons, some heterogeneity in the format of information on the forms was experienced.

The final survey method used to document instrumented watersheds was a literature review of selected publications.

SUMMARY

A total of 176 watersheds or groups of watersheds were inventoried that were judged to have data potentially useful for model development and testing. The survey covered an estimated 95 to 100 percent of the college or university watersheds, and an unknown percentage of other instrumented watersheds.

The purpose of this survey was to identify data bases suitable for model development and testing. Recognizing that any predictive model will have to be adjusted for regional differences the inventoried watersheds were summarized by region. The eight regions were selected based on similar physiographic and climatic conditions within each region (Figure 2).

Many of the 176 watersheds inventoried contained only baseline data on undisturbed areas. Overall, the general assessment is that the data base available for model development and testing is:

Good: for baseline conditions
Fair: for vegetative manipulation and timber harvest
Poor: for other forest management activities

It should be noted that one of the criteria for the inventory was that it was an instrumented watershed. Special project, well, and lake data were not included. There is considerable lake data collected by the Forest Service in the Lake States relating recreation to lake water quality. Likewise there is considerable data relating waste disposal to ground water quality.

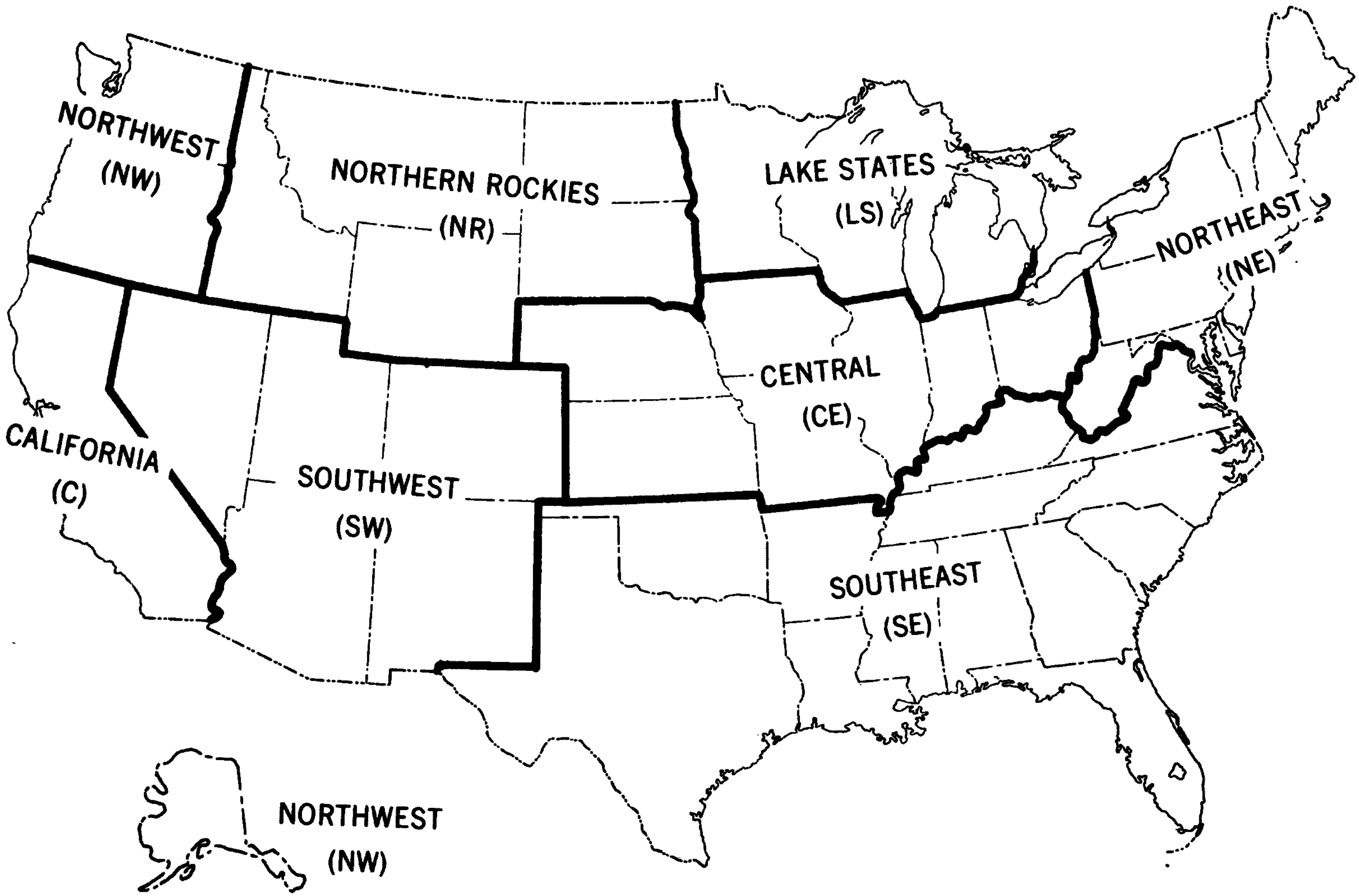


Figure 2. Watershed inventory subdivisions.

## CONCLUSIONS

Table 6, derived from the inventory forms, presents those watersheds with water quality data reported as the wildland management activities shown. The watersheds are listed by geographical area with no priority intended. This table is only a summary of information provided by the various administering organizations, and therefore should not be considered all inclusive. The user is cautioned not to disregard any watersheds which are unlisted.

The watersheds in each region were ranked in Tables 7-14 according to their overall suitability for modeling purposes--best first (see Appendix B). The criteria used to rank the watersheds were:

1. Number of parameters--the more diverse the data base, the more likelihood of having the input parameters necessary to use various models.

2. Frequency of sampling--the more frequent the sampling, the finer the model can be tuned.

3. Length of record--coupled with the frequency of sampling, it defines the data base available for modeling.

4. Type of parameters--emphasis was given to sediment and streamflow because of their relative importance to forest management practices.

5. Quality of data--watersheds known to have highly reliable sample analyses were ranked higher.

6. Supporting data--consideration was given to watersheds with well documented supportive data such as soils, geology, vegetation, aerial photos, topographic maps, etc.

7. Number of watersheds--some single entries on the summary forms are actually several watersheds combined under a single project name. Multiple watersheds have some obvious advantages to modeling and were considered for higher ranking.

TABLE 6. NUMBERS AND LOCATION OF WATERSHEDS HAVING DATA SPECIFICALLY RELATING WATER QUALITY TO WILDLAND MANAGEMENT ACTIVITIES*

| Vegetative manipulation | Roads and Trails | Fire | Grazing | Timber Harvest | Recreation | Forest fertilization | Waste disposal | Low head impoundments | Pesticides | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 8 | 2 | 2 | 22 | 4 | 2 | | 1 | | 57 |
| NE-2 | NE-4 | NW-4 | NR-23 | NE-1 | NR-4 | NE-4 | | LS-11 | | |
| SE-1 | SE-1 | SW-22 | SW-1 | NE-4 | NR-15 | SE-5 | | | | |
| CE-7 | SE-2 | | | NE-10 | SW-28 | | | | | |
| SE-20 | SW-2 | | | SE-1 | SW-39 | | | | | |
| SE-21 | SW-19 | | | SE-2 | | | | | | |
| SE-22 | NR-1 | | | SE-6 | | | | | | |
| SE-27 | NW-5 | | | SE-22 | | | | | | |
| NR-3 | NW-9 | | | SE-29 | | | | | | |
| SE-3 | | | | NR-1 | | | | | | |
| SW-10 | | | | NR-25 | | | | | | |
| SW-12 | | | | NR-26 | | | | | | |
| SW-16 | | | | SW-1 | | | | | | |
| SW-23 | | | | SW-2 | | | | | | |
| SW-31 | | | | SW-4 | | | | | | |
| NW-5 | | | | SW-18 | | | | | | |
| C-9 | | | | SW-20 | | | | | | |
| | | | | NW-8 | | | | | | |
| | | | | NW-9 | | | | | | |
| | | | | NW-11 | | | | | | |
| | | | | C-17 | | | | | | |
| | | | | C-18 | | | | | | |

* The numbers are keyed to Tables 7-14.

TABLE 7. WATERSHED SUITABILITY RANKING--NORTHEAST

| Priority no. for modeling | Watershed | State | Sediment: Reservoir sediment | Sediment: Suspended sediment | Sediment: Bed load | Sediment: Mass wasting | Water temperature | Dissolved oxygen | Pathogen | Nutrients | Dissolved solids | Pesticides | Heavy metals | Flow | Climate: Air temperature | Climate: Precip. | Climate: Radiation | Climate: Relative humidity | Climate: Wind | Color | Turbidity | Conductivity | pH | Biological oxygen demand | Nitrogen | Phosphates | Cations/Anions | Benthos | Total organic carbon | Collecting frequency[a] | Years recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Hubbard Brook | N.H. | | X | | | X | | | X | | | | X | X | X | X | | X | | | X | X | | X | | X | | | W | 20 |
| 2 | Leading Ridge | Pa. | | X | | | X | | | X | | | | X | X | X | | | | | | X | X | | X | | X | | | *M | 18 |
| 3 | Shale Hills | Pa. | | X | | | X | | | X | X | | | X | X | X | | | X | | | X | X | | X | | X | | | *M | 13 |
| 4 | Fernow | W.Va. | | X | | | X | | | | | | X | X | X | X | X | | | | | X | X | | | | X | | | *M | 20 |
| 5 | Wild River | Me. | | X | | | X | X | X | X | X | | | X | X | X | X | X | X | | | X | X | X | | X | X | | | M | 8 |
| 6 | Esophus Creek | N.Y. | | X | | | X | X | X | X | X | | | X | | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 7 | McDonald's Branch | N.J. | | X | | | | X | X | X | X | | | X | X | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 8 | Young Woman's Creek | Pa. | | X | | | X | X | X | X | X | | X | X | | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 9 | Little Black Fort | W.Va. | | | | | | | | X | | | X | X | | X | | | | | X | X | X | | X | | X | | | M | 2 |
| 10 | E. Branch Saco | N.H. | | | | | X | | | X | | | | X | | X | | | | X | | X | | | | X | X | | | M | 8 |
| 11 | Cranberry River | W.Va. | | | | | X | | | | | | | X | X | X | X | X | X | | X | X | X | | | | X | | | *M | 7 |

[a]M = Monthly
*M = Monthly with more frequent sampling of selected parameters
W = Weekly

# TABLE 8. WATERSHED SUITABILITY RANKING--CENTRAL

| Priority no. for modeling | Watershed | State | Sediment | | | | Water temperature | Dissolved oxygen | Pathogen | Nutrients | Dissolved solids | Pesticides | Heavy metals | Flow | Climate | | | | | Color | Turbidity | Conductivity | pH | Biological oxygen demand | Nitrogen | Phosphates | Cations/Anions | Benthos | Total organic carbon | Collecting frequency[a] | Years recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reservoir sediment | Suspended sediment | Bed load | Mass wasting | | | | | | | | | Air temperature | Precip. | Radiation | Relative humidity | Wind | | | | | | | | | | | | |
| 1 | Upper Twin Creek | Ohio | | X | | | X | X | X | X | X | X | | X | X | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 2 | Dismal River | Neb. | | X | | | X | X | X | X | X | | | X | | | | | | | | X | X | | X | X | X | | | M | 8 |
| 3 | Hurricane Creek | Mo. | | | | | X | X | X | X | | | X | X | X | X | X | | X | X | X | X | X | | X | X | X | X | | W | 3 |
| 4 | S. Hogan Creek | Ind. | | X | | | X | X | X | X | X | X | | X | | X | | | | | | X | X | | | X | X | | | M | 7 |
| 5 | Lusk Creek | Ill. | | | | | X | X | X | X | X | | X | X | | X | | | | | | | X | | X | X | X | | | M | 6 |
| 6 | University | Mo. | | | | | X | | X | X | | | | X | X | X | | X | | | X | X | X | | X | | X | | | M | 3 |
| 7 | Coshocton River | Ohio | | | | | | | | X | | | | X | X | X | X | | | | | | | | X | X | X | | | M | 33 |

[a]M = Monthly
W = Weekly

# TABLE 9. WATERSHED SUITABILITY RANKING--LAKE STATES

| Priority no. for modeling | Watershed | State | Sediment | | | | Water temperature | Dissolved oxygen | Pathogen | Nutrients | Dissolved solids | Pesticides | Heavy metals | Flow | Climate | | | | | Color | Turbidity | Conductivity | pH | Biological oxygen demand | Nitrogen | Phosphates | Cations/Anions | Benthos | Total organic carbon | Collection frequency[a] | Years recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reservoir sediment | Suspended sediment | Bed load | Mass wasting | | | | | | | | | Air temperature | Precip. | Radiation | Relative humidity | Wind | | | | | | | | | | | | |
| 1 | Marcell WS#2 | Minn. | | | | | X | | | X | | | X | X | X | X | X | X | | X | | X | X | | X | X | X | | | W | 15 |
| 2 | Pine River | Mich. | | X | | | X | X | X | X | X | | X | X | X | X | X | | X | X | X | X | X | | X | X | X | X | | M | 9 |
| 3 | Popple River | Wisc. | | X | | | X | X | X | X | X | X | X | X | | X | | | | | | X | X | X | X | X | X | | | M | 9 |
| 4 | Roseau River | Minn. | | X | | | X | X | X | X | X | | X | X | | X | | | | | X | X | X | X | X | X | X | | X | M | 8 |
| 5 | Washington Creek | Mich. | | X | | | X | X | X | X | X | | | X | X | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 6 | Kawishiwi River (GS) | Minn. | | | | | X | | | X | X | | | X | | X | X | | X | | | | X | | X | X | X | | | M | 8 |
| 7 | Kawishiwi River (FS) | Minn. | | | | | X | | X | X | | | X | X | | X | X | | X | X | | X | X | | X | X | X | | | M | 5 |
| 8 | Big Fork River | Minn. | | | | | X | X | X | X | X | | X | X | | X | | | | | X | X | X | X | X | X | X | | X | M | 4 |
| 9 | Md. Br. Ontonagon | Mich. | | | | | X | X | X | X | | | X | X | X | X | X | X | | X | X | X | | | X | X | X | | | M | 6 |
| 10 | E. Fk. Chippawa River | Wisc. | | | | | X | | | X | | | X | X | | X | | | | X | | X | X | | X | | X | | | M | 4 |
| 11 | Allen Creek | Wisc. | | | | | X | | | X | | | X | X | | X | X | | | X | X | X | | X | X | | | | | S | 6 |
| 12 | Baptism River | Minn. | | | | | X | X | X | X | | | X | X | | X | | | | | X | X | X | X | X | X | X | | X | M | 2 |
| 13 | O'Brian Brook | Minn. | | | | | X | X | X | X | X | | X | X | | X | | | | | X | X | X | X | X | X | X | | X | M | 1 |
| 14 | Brule River | Minn. | | X | | | X | X | | X | | | | | | | | | | | | X | | X | X | X | | | | M | 1 |

[a]M = Monthly
W = Weekly
S = Summer daily

## TABLE 10. WATERSHED SUITABILITY RANKING--SOUTHEAST

| Priority no. for modeling | Watershed | State | Sediment: Reservoir sediment | Sediment: Suspended sediment | Sediment: Bed load | Sediment: Mass wasting | Water temperature | Dissolved oxygen | Pathogen | Nutrients | Dissolved solids | Pesticides | Heavy metals | Flow | Climate: Air temperature | Climate: Precip. | Climate: Radiation | Climate: Relative humidity | Climate: Wind | Color | Turbidity | Conductivity | pH | Biological oxygen demand | Nitrogen | Phosphates | Cations/Anions | Benthos | Total organic carbon | Collection frequency[a] | Years recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Coweeta | N.C. | | X | | | | | | X | X | | | X | X | X | X | X | X | | | | X | | X | X | X | | | *M | 42 |
| 2 | Davidson River | N.C. | | X | | | X | X | X | X | | | | X | X | X | X | X | X | | X | | X | | X | X | | | | M | 8 |
| 3 | Sopchoppey River | Fla. | | X | | | X | X | X | X | X | X | | X | X | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 4 | Walker Branch | Tenn. | | X | | | | | | X | X | | | X | X | X | | X | | | | | X | | X | X | X | | | *M | 8 |
| 5 | Bear Creek Basin | Ala. | | X | | | | | | X | X | | | X | X | X | | | | | | | X | | X | X | X | | | W | 6 |
| 6 | Coffeeville | Miss. | | X | | | | | | X | X | | | X | | X | | | | | | | X | | X | X | X | | | W | 11 |
| 7 | Cataloochee Creek | N.C. | | X | | | X | X | X | X | X | X | | X | X | X | | | X | | | X | X | X | X | X | X | | | M | 8 |
| 8 | Sipsey Fork | Ala. | | X | | | X | X | X | X | X | X | X | X | | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 9 | Kiamichi River | Okla. | | X | | | X | X | X | X | X | X | X | X | | | | | | | | X | X | X | X | X | X | | | M | 8 |
| 10 | Holiday Creek | Vir. | | X | | | X | X | X | X | X | X | | X | | | | | | | | X | X | X | X | X | X | | | M | 8 |
| 11 | Cypress Creek | Miss. | | X | | | X | X | X | X | X | X | | X | X | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 12 | Falling Creek | Ga. | | X | | | X | X | X | X | X | X | | X | | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 13 | Buffalo River | Tenn. | | X | | | | X | X | X | X | X | | X | X | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 14 | Little River | Tenn. | | X | | | X | X | X | X | X | X | | X | | | | | | | | X | X | X | X | X | X | | | M | 8 |
| 15 | N. Sylamore | Ark. | | X | | | X | X | X | X | X | X | | X | | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 16 | Big Creek | La. | | | | | X | X | X | X | X | X | | X | | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 17 | S. Fk. Rocky Creek | Tex. | | X | | | | | | X | X | X | | X | | X | | | | | | X | X | | X | X | X | | | M | 8 |
| 18 | Blue Beaver | Okla. | | | | | | | | X | X | | X | X | | | | | | | | | X | | X | X | X | | | M | 8 |
| 19 | Tallulah River | Ga. | | | | | X | | | X | X | | | X | | X | | | | | | | X | | X | X | X | | | M | 8 |
| 20 | White Hollow | Tenn. | | X | | | | | | | | | | X | X | X | | X | | | | | | | | | | | | M | 40 |
| 21 | Oxford Exp. WS | Miss. | | X | | | | | | | | | | X | | X | | | | | | | | | | | | | | M | 18 |
| 22 | Citico Creek | Tenn. | | X | | | X | | | | X | | | X | X | X | | X | | X | | X | X | | | | | X | | M | 3 |
| 23 | Cossatot River | Ark. | | | | | | | | X | X | | | X | | | | | | | | | X | | X | X | X | | | M | 6 |
| 24 | Upper Bear Creek | Tenn. | | X | | | | | | | | | | X | | X | | | | | | | | | | | | | | M | 13 |
| 25 | Limpia Creek | Tex. | | | | | | | | X | X | | | X | | X | | | | | | | X | | X | X | X | | | M | 8 |
| 26 | Boston Mt. | Ark. | | | | | | | | X | X | | | X | X | X | | X | | | | | X | | X | X | X | | | W | 2 |
| 27 | Alum Creek | Ark. | | X | | | | | | X | X | | | X | X | X | | X | | | | | X | | X | X | X | | | M | 2 |
| 28 | Koen | Ark. | | X | | | | | | X | X | | | X | X | X | X | X | | | | | X | | X | X | X | | | *M | 2 |
| 29 | Pine Tree Branch | Tenn. | | X | | | | | | X | | | | X | X | X | | X | | | | | | | X | X | X | | | M | 34 |
| b | B.F. Grant Mem. Forest | Ga. | | X | | | X | | | | X | | | X | | X | | | | | | X | X | | X | X | X | | | W | 2 |
| b | Whitehall | Ga. | | | | | X | | | | | | | X | X | X | | X | | | | X | X | | X | X | X | | | M | 8 |

[a]M = Monthly
*M = Monthly with more frequent sampling of selected parameters
W = Weekly

[b]Received too late to rate.

TABLE 11. WATERSHED SUITABILITY RANKING--NORTHERN ROCKIES

| Priority no. for modeling | Watershed | State | Sediment | | | | Water temperature | Dissolved oxygen | Pathogen | Nutrients | Dissolved solids | Pesticides | Heavy metals | Flow | Climate | | | | | Color | Turbidity | Conductivity | pH | Biological oxygen demand | Nitrogen | Phosphates | Cations/Anions | Benthos | Total organic carbon | Collection frequency[a] | Years recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reservoir sediment | Suspended sediment | Bed load | Mass wasting | | | | | | | | | Air temperature | Precip. | Radiation | Relative humidity | Wind | | | | | | | | | | | | |
| 1 | Silver Creek | Ida. | X | X | X | | X | X | | X | X | | | X | | X | | | | | | X | | | X | X | X | | | W | 15 |
| 2 | Horse Creek | Ida. | | X | X | | X | | | X | X | | | X | X | X | | X | X | | X | X | X | | X | X | X | | | *M | 10 |
| 3 | Stratton | Wyo. | | X | X | | X | | | | | | | X | X | X | X | | X | | | | | | | | | | | *M | 7 |
| 4 | Upper Salmon River | Ida. | | X | | | | | | X | X | | | X | | X | | | | | X | X | X | X | X | X | X | | | W | 5 |
| 5 | Cashe Creek | Wyo. | | X | | | X | X | | X | X | X | X | X | | | | | | | | X | X | X | X | | X | | | M | 10 |
| 6 | Encampment BW | Wyo. | | | | | X | X | | X | X | | | X | X | X | X | X | X | | | X | X | X | X | X | X | | | M | 10 |
| 7 | Castle Creek | S.D. | | X | | | X | X | X | X | X | X | | X | X | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 8 | Hayden Creek | Ida. | | X | | | X | X | X | X | X | X | | X | X | | | | | | | X | X | X | X | X | X | | | M | 8 |
| 9 | Beauvais Creek | Mont. | | X | | | X | X | X | X | X | X | | X | X | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 10 | Rock Creek | Mont. | | X | | | X | X | X | X | | | | X | | | | | | | X | X | X | X | X | X | | | | M | 5 |
| 11 | E.F. Smith's Fork BW | Wyo. | | X | | | | | | X | X | | | X | X | X | X | | X | | | X | X | X | X | X | X | | | M | 2 |
| 12 | Wyman Creek | Mont. | | X | | | X | X | | X | | | | X | | | | | | | X | | X | X | X | X | X | | | M | 5 |
| 13 | Alder Creek | Mont. | | X | | | X | X | | X | | | | X | | | | | | | X | X | X | X | X | X | X | | | M | 5 |
| 14 | Encampment River | Wyo. | | | | | | | | X | X | | X | X | X | X | X | X | X | | | | X | | X | X | X | | | M | 8 |
| 15 | Big Wood River | Ida. | | X | | | | | | X | X | | | X | | X | | | | | X | X | X | X | X | X | X | | | M | 5 |
| 16 | Grizzly Creek | Mont. | | X | | | X | X | | X | | | | X | | | | | | | X | X | X | X | X | X | X | | | M | 5 |
| 17 | Swift Current Creek | Mont. | | | | | X | | | X | X | | | X | X | X | | | | | | | | | X | X | X | | | M | 8 |
| 18 | W. Br. Weiser | Ida. | | X | X | | X | | X | | | | | X | X | X | | | | | X | X | | | | | | | | M | 5 |
| 19 | Rapid River | Ida. | | X | | | X | | X | X | X | | | X | | X | | | | | X | X | X | | X | X | X | | | M | 4 |
| 20 | Bear Den Creek | N.D. | | | | | | | | X | X | | | X | | | | | | | | | X | | X | X | X | | | M | 8 |
| 21 | Wickhoney Creek | Ida. | | | | | | | | X | X | | | X | | | | | | | | | X | | X | | X | | | M | 8 |
| 22 | Logan Creek | Mont. | | X | | | X | | X | X | | | X | X | | | | | | | X | X | X | X | X | X | X | X | | M | 1 |
| 23 | Ruby River | Mont. | | X | | | X | | X | X | | | | X | | X | | | | | | | | | X | X | X | | | M | 2 |
| 24 | Worswick Creek | Ida. | | X | | | X | X | X | | | | | | | | | | | | X | X | X | | | | | | | M | 1 |
| 25 | N.F. Fisk Creek | Wyo. | | X | | | X | | | X | | | | X | | | | | | | X | | | | X | X | | | | M | 1 |
| 26 | Zena Creek | Ida. | X | | | | | | | | | | | X | X | X | | | | | | | | | | | | | | M | 16 |

[a]M = Monthly
W = Weekly
*M = Monthly with more frequent sampling of selected parameters.

# TABLE 12. WATERSHED SUITABILITY RANKING--SOUTHWEST

| Priority no. for modeling | Watershed | State | Sediment | | | | Water temperature | Dissolved oxygen | Pathogen | Nutrients | Dissolved solids | Pesticides | Heavy metals | Flow | Climate | | | | | Color | Turbidity | Conductivity | pH | Biological oxygen demand | Nitrogen | Phosphates | Cations/Anions | Benthos | Total organic carbon | Collection frequency[a] | Years recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reservoir sediment | Suspended sediment | Bed load | Mass wasting | | | | | | | | | Air temperature | Precip. | Radiation | Relative humidity | Wind | | | | | | | | | | | | |
| 1 | Beaver Creek | Ariz. | X | X | | | | | | X | X | | | X | | X | X | X | X | | | | X | | X | X | X | | | *M | 16 |
| 2 | Fraser Exp. Forest | Colo. | | | X | | X | | | X | | | | X | X | X | | X | X | | | | X | | X | X | X | | | M | 6 |
| 3 | Straight Canyon Baro.WS | Utah | | X | | | X | X | X | X | | | | X | X | X | X | X | X | X | X | X | X | | X | X | | | | M | 8 |
| 4 | Blk. River Baro. WS | Ariz. | | | | | X | X | X | X | X | | X | X | X | X | X | X | X | | X | | X | | X | X | X | | | M | 8 |
| 5 | Chicken Creek | Utah | | X | | | | | | X | | | | X | X | X | X | X | | | | X | X | | X | X | X | | | W | 10 |
| 6 | Seven Spring Creek | Ariz. | | X | | | | | | X | X | | | X | X | X | X | | X | | | | X | | X | X | X | | | *M | 11 |
| 7 | Vallecita Creek | Colo. | | X | | | X | | | X | X | | X | X | X | X | | | | | | X | X | | X | X | X | | | M | 13 |
| 8 | Halfmoon Creek | Colo. | | | | | | X | X | X | X | X | | X | X | X | | | | | | X | X | X | X | X | X | | | M | 9 |
| 9 | Lake Creek Baro. WS | Colo. | | | | | X | X | X | X | X | | X | X | X | X | X | X | | | | X | X | X | X | X | X | | | M | 11 |
| 10 | Mogollan Creek | N.M. | | X | | | | X | X | X | X | X | | X | | | | | | | | X | X | X | X | X | X | | | M | 7 |
| 11 | Three-Bar WS | Ariz. | | | | | | | | X | X | X | | X | X | X | | | | | | X | X | | X | X | X | | | *M | 7 |
| 12 | Wet Bottom Creek | Ariz. | | X | | | X | X | X | X | X | X | | X | | | | | | | | X | X | X | X | X | X | | | M | 8 |
| 13 | Rio Mora | N.M. | | X | | | X | X | X | X | X | X | | X | | | | | | | | X | X | X | X | X | X | | | M | 8 |
| 14 | Red Butte Creek | Utah | | X | | | X | | X | | X | X | | X | | X | | | | | | X | X | X | | | X | X | | M | 8 |
| 15 | S. Twin River | Nev. | | | | | X | X | X | X | X | X | | X | | | | | | | | X | X | X | X | X | X | | | M | 8 |
| 16 | Sheep Creek | Utah | | X | | | X | | | X | X | | X | X | X | X | | X | | | | X | X | | X | X | X | | | M | 5 |
| 17 | Steptoe Creek | Nev. | | | | | X | | | X | X | | | X | | | | | | | | | | | X | X | X | | | M | 8 |
| 18 | Castle Creek | Ariz. | | X | | | | | | X | X | | | X | X | X | X | | | | | | X | | X | X | X | | | *M | 10 |
| 19 | Tesuque | N.M. | | | | | | | | X | | | | X | X | X | | X | | | | | | | X | | X | | | M | 14 |
| 20 | Willow Creek | Ariz. | | | | | X | | | X | X | | | X | | X | | | | | | | X | | X | X | X | | | *M | 17 |
| 21 | Heber | Ariz. | | X | | | | | | X | X | | | X | | X | | | | | | | X | | X | X | X | | | *M | 3 |
| 22 | Rattleburn | Ariz. | | X | | | | | | X | X | | | X | | X | | | | | | | X | | X | X | X | | | *M | 3 |
| 23 | Whitespar | Ariz. | | | | | X | | | X | X | X | | X | | X | | | | | | X | X | | X | X | X | | | *M | 3 |
| 24 | Truckee | Nev. | | X | | | X | | | X | | | | X | | | | | | | | X | | | X | X | | | | M | 4 |
| 25 | Halfway Creek | Utah | | | | | | | X | X | | | | X | | | | | | | | X | X | X | X | X | X | | | W | 2 |
| 26 | Corduroy Creek | Utah | | X | | | | | X | X | | | | X | | | | | | | | X | X | | X | X | X | | | *M | 3 |
| 27 | North Creek | Utah | | | | | X | X | X | X | X | | | | | | | | | | X | X | X | | X | X | | | | M | 1 |
| 28 | Pleasant Creek | Utah | | | | | X | X | X | X | | | | | | | | | | | | X | X | | X | X | | X | | M | 1 |

(continued)

TABLE 12. Continued

| Priority no. for modeling | Watershed | State | Sediment: Reservoir sediment | Sediment: Suspended sediment | Sediment: Bed load | Sediment: Mass wasting | Water temperature | Dissolved oxygen | Pathogen | Nutrients | Dissolved solids | Pesticides | Heavy metals | Flow | Climate: Air temperature | Climate: Precip. | Climate: Radiation | Climate: Relative humidity | Climate: Wind | Color | Turbidity | Conductivity | pH | Biological oxygen demand | Nitrogen | Phosphates | Cations/Anions | Benthos | Total organic carbon | Collection frequency[a] | Years recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | Pine Creek | Utah | | | | | X | X | X | X | X | | | | | | | | | | X | X | X | | X | X | | | | M | 1 |
| 30 | Kingston | Nev. | | | | | X | X | X | X | X | | X | X | | X | | | | | | X | X | | X | X | X | X | | M | 1 |
| 31 | Mingus | Ariz. | | | | | X | | | X | X | X | | X | | | | | | | | X | X | | X | X | X | | | M | 1 |
| 32 | Whipple Creek | Utah | | X | | | | | X | X | X | | | X | | | | | | | | X | X | | X | X | X | | | *M | 2 |
| 33 | Thomas Creek | Ariz. | | X | | | | | | X | X | | | X | X | X | X | X | | | | | X | | X | X | X | | | M | 1 |
| 34 | San Luis | N.M. | X | | | | | | | | | | | X | | X | | | | | | | | | | | | | | *M | 23 |
| 35 | Watersheds A & B | Utah | | X | X | | | | | | | | | X | | X | | | | | | | | | | | | | | *M | 63 |
| 36 | Mammoth Creek | Utah | | | | | X | X | X | X | X | | X | X | | | | | | | X | X | X | | X | X | X | | | M | 1 |
| 37 | Antimony Creek | Utah | | X | | | | X | X | X | X | | X | X | | | | | | | X | X | X | | X | X | X | | | M | 1 |
| 38 | Blue Springs Creek | Utah | | | | | X | X | X | X | | | | | | | | | | | X | X | X | | X | X | | | | M | 1 |
| 39 | Coal Creek | Utah | | | | | X | X | X | | | | | | | | | | | | X | X | X | | | | | | | M | 1 |
| 40 | White Rocks | Utah | | | | | | | X | X | X | | X | X | | | | | | | X | | X | | X | X | X | | | M | 1 |
| 41 | Dry Fk. Ashley | Utah | | | | | | | X | X | X | | X | X | | | | | | | X | | X | | X | X | X | | | M | 1 |
| 42 | Yellow Stone | Utah | | | | | | | X | X | X | | X | X | | | | | | | X | | X | | X | X | X | | | M | 1 |
| 43 | Headwaters Uinta | Utah | | | | | | | X | X | X | | X | X | | | | | | | X | | X | | X | X | X | | | M | 1 |
| 44 | Sowers | Utah | | | | | | | X | X | X | | X | X | | | | | | | X | | X | | X | X | X | | | M | 1 |
| 45 | Rock Creek | Utah | | | | | | | X | X | X | | X | X | | | | | | | X | | X | | X | X | X | | | M | 1 |
| 46 | Ashley | Utah | | | | | | | X | X | X | | X | X | | | | | | | X | | X | | X | X | X | | | M | 1 |

[a]W = Weekly
M = Monthly
*M = Monthly with more frequent sampling of selected parameters.

# TABLE 13. WATERSHED SUITABILITY RANKING--NORTHWEST

| Priority no. for modeling | Watershed | State | Sediment | | | | Water temperature | Dissolved oxygen | Pathogen | Nutrients | Dissolved solids | Pesticides | Heavy metals | Flow | Climate | | | | | Color | Turbidity | Conductivity | pH | Biological oxygen demand | Nitrogen | Phosphates | Cations/Anions | Benthos | Total organic carbon | Collection frequency[a] | Years recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Reservoir sediment | Suspended sediment | Bed load | Mass wasting | | | | | | | | | Air temperature | Precip. | Radiation | Relative humidity | Wind | | | | | | | | | | | | |
| 1 | H.J. Andrews | Ore. | X | X | X | X | X | X | | X | | | X | X | X | X | X | X | X | | | X | X | | X | X | X | X | | W | 8 |
| 2 | Cedar River | Wash. | | X | | | X | X | X | X | X | X | X | X | X | X | | | | X | X | X | X | | X | X | X | | | M | 10 |
| 3 | Clackamas | Ore. | | X | | | X | X | X | X | X | X | X | X | X | X | | | | X | X | X | X | | X | X | X | | | M | 8 |
| 4 | Green River | Wash. | | X | | | X | X | X | X | X | | X | X | X | X | X | X | | X | X | X | X | | X | X | X | | | M | 8 |
| 5 | Entiat | Wash. | | X | | | X | | | X | | | | X | X | X | | | | | | | | | X | X | X | | | W | 16 |
| 6 | N. Fk. Quinault | Wash. | | X | | | X | X | X | X | X | X | | X | | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 7 | Minam River | Ore. | | X | | | X | X | X | X | X | X | | X | X | | | | | | | X | X | X | X | X | X | | | M | 8 |
| 8 | Coyote Creek | Ore. | X | X | | | X | | | X | | | | X | | X | | | | | | | | | X | X | X | | | *M | 12 |
| 9 | Alsea | Ore. | | X | | | X | X | | X | | | | X | X | X | X | | | | | | | X | | X | X | X | | M | 15 |
| 10 | HI-15 Basins | Ore. | | X | | | X | | | X | | | | X | X | X | | | | | | | | | X | X | X | | | *M | 11 |
| 11 | Fox Creek | Ore. | | | | | X | | | X | | | | X | | X | | | | | | | | | X | X | | | | *M | 18 |
| 12 | Umatille Baro. WS | Ore. | | | X | | X | | X | X | | | | X | X | X | | | X | | | X | X | | X | X | X | X | | M | 3 |
| 13 | Tonalite Creek | Alas. | | X | | | | | | X | X | | | X | X | X | | | | X | | X | X | | X | | X | | | M | 7 |
| 14 | Kadashan | Alas. | | X | | | | | | X | X | | | X | X | X | | | | X | | X | X | | X | | X | | | M | 7 |
| 15 | Hook Creek | Alas. | | X | | | | | | X | X | | | X | X | X | | | | X | | X | X | | X | | X | | | M | 7 |
| 16 | Stequaleho Creek | Wash. | | X | | | X | | | | | | | X | X | X | | X | | | | | | | | | | | | M | 3 |
| 17 | Clearwater River | Wash. | | X | | | X | | | | | | | X | X | X | | X | | | | | | | | | | | | M | 2 |
| 18 | Christmas Creek | Wash. | | X | | | X | | | | | | | X | X | X | | X | | | | | | | | | | | | M | 2 |
| 19 | Upper Salleks | Wash. | | X | | | X | | | | | | | X | X | X | | X | | | | | | | | | | | | M | 2 |

[a]M = Monthly
*M = Monthly with more frequent sampling of selected parameters
W = Weekly

TABLE 14. WATERSHED SUITABILITY RANKING--CALIFORNIA

| Priority no. for modeling | Watershed | Sediment | | | | Water temperature | Dissolved oxygen | Pathogen | Nutrients | Dissolved solids | Pesticides | Heavy metals | Flow | Climate | | | | | Color | Turbidity | Conductivity | pH | Biological oxygen demand | Nitrogen | Phosphates | Cations/Anions | Benthos | Total organic carbon | Collection frequency[a] | Years recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Reservoir sediment | Suspended sediment | Bed load | Mass wasting | | | | | | | | | Air temperature | Precip. | Radiation | Relative humidity | Wind | | | | | | | | | | | | |
| 1 | Elder Creek | | X | | | X | X | X | X | X | X | | X | | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 2 | Merced River | | X | | | X | X | X | X | X | X | | X | | X | | | | | | X | X | X | X | X | X | | | M | 8 |
| 3 | Mid. Fk. Feather River | | X | | | X | X | X | X | X | | | X | X | | | | | X | X | X | X | X | X | X | X | | | M | 5 |
| 4 | Putah Creek | | X | | | X | X | | X | | X | X | X | X | X | | X | X | | | X | X | | X | X | X | | | M | 5 |
| 5 | Hopland Watershed | X | X | | | | | | X | | | | X | | X | | | | | | | | | X | X | X | | | M | 23 |
| 6 | Ice Cream Creek | | | | | | X | X | X | | | | X | X | | | | | | X | X | X | | X | X | | | | M | 6 |
| 7 | Dry Creek | | | | | X | X | X | X | X | | X | X | | X | | | X | | | X | X | | X | X | | | | *M | 4 |
| 8 | Mineral King | | | | | | | | X | | | | X | X | X | | | X | | | | | | X | X | | | | M | 7 |
| 9 | Small Bell Watersheds | X | X | | X | | | | | | | | X | | X | | | | | | | | | | | | | | M | 37 |
| 10 | Indian Creek | X | X | | | X | X | | X | | | X | X | | X | | | | | X | | X | | X | X | X | | | M | 3 |
| 11 | Grass Valley Creek | X | X | | | X | X | | X | | | X | X | | | | | | | X | | X | | X | X | X | | | M | 3 |
| 12 | Aspen Quail | | X | X | | X | | | | | | | X | X | X | | | | | X | | | | | | | | | M | 1 |
| 13 | Cabin Creek | | | X | | | X | X | X | | | | X | X | X | | | | | X | X | X | | X | X | | | | M | 1 |
| 14 | Santa Ynez | | X | | | | | | | | | | X | X | X | X | X | | | | | | | | | | | | M | 10 |
| 15 | E. Fk. Russian River | | | | | X | | | X | | | X | X | | X | | | X | | X | X | X | | X | X | | | | *M | 2 |
| 16 | Lights Creek | | | | | X | | | | | | X | X | X | | | | | | X | X | X | | | | X | | | M | 4 |
| 17 | Casper Creek | X | X | | | | | | | | | | X | | X | | | | | | | | | | | | | | *M | 13 |
| 18 | Salmon Creek | X | X | | | X | | | | | | | X | X | X | | | | | | | | | | | | | | M | 14 |
| 19 | Bishop Creek | | | | | X | X | X | X | X | | | X | X | X | | | | | | | X | | X | X | X | X | | M | 1 |
| 20 | E. Fk. San Dimas | | | | X | | | | X | | | | X | | X | | | | | | | | | X | X | | | | *M | 19 |
| 21 | Teakettle Creek | | X | | | | | | | | | | X | X | X | | | X | | | | | | | | | | | *M | 30 |
| 22 | Onion Creek | | X | | | | | | | | | | X | | X | | | | | | | | | | | | | | *M | 18 |
| 23 | Indian Creek | | | | | | X | | | | | | X | | | | | | | | X | X | | | | X | | | M | 2 |
| 24 | Big Creek Barometer | | X | | | | | | | | | | X | X | X | | | X | | X | | | | | | | | | M | 10 |

[a]M = Monthly
*M = Monthly with more frequent sampling of selected parameters.

## SECTION 7

## GLOSSARY OF TERMS

Activity--an action or group of actions describing the kind of work of which various mixtures are required when managing forest and range lands.

Balloon Logging--a system of logging where logs are transported from a stump to landing by means of a balloon.

Bedload--the sediment in a stream channel that mainly moves by jumping, sliding, or rolling on or very near the bottom of the stream (American Geological Institute, 1962).

Beneficial Uses--includes those uses made of water by man. These uses include, but are not limited to, domestic, municipal, agricultural, and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and preservation and enhancement of fish, wildlife, and other aquatic resources.

Bloom (Algal Bloom)--a readily visible, concentrated growth or aggregation of plankton (plant and/or animal) (Geckler and others, 1963).

Buffer Strip--an undisturbed strip of vegetation that retards flow of runoff water, causing deposition of transported material, thereby reducing sediment flow (EPA-R2-72-015).

Chaining--an operation where two bulldozers are teamed to drag an anchor chain in order to knock down brush and small trees (Duerr and others, 1974).

Contour Furrowing/Trenching--a rangeland improvement technique whereby a tractor and plow construct trenches contouring rolling terrain in order to reduce erosion and encourage water infiltration.

Debris Basins--basins or depressions within or near streams designed to entrap material or organic origin such as slash, slabs, bark, leaves, or sawdust.

Dry Ravel--the downslope movement of rock and soil particles resulting from gravitational force.

Enteric--of or from intestinal origin.

Fire Retardant--chemicals used in the suppression of wildfires.

First-Order Streams--the smallest fingertip tributaries within a stream system (Chow, 1964).

Helicopter Logging--a system of logging where logs are transported from stump to landing by means of helicopter.

Impact--the effect, positive or negative, of land management activities on the environment.

Litter--the uppermost (soil) layer of the organic debris, composed of freshly fallen or slightly decomposed organic materials (Chow, 1964).

Loading (Loading Models)--the process where amounts of flow or pollutants are transported from land surfaces and delivered to streams or lakes.

Mass Movement--downslope, unit movement of a portion of the land's surface--i.e., a single landslide or the gradual simultaneous, downhill movement of the whole mass of loose earth material of a slope face (i.e., soil creep) (after American Geological Institute, 1962).

Mineral Nutrients--those inorganic substances which stimulate plant growth.

Modular Model Development--the development of a system of mutually compatible models having common interfaces where necessary.

Non-Point Source--generalized discharge of waste into a water body which cannot be located as to specific source, as outlined in Section 304(e) of the Act (PL 92-500).

Non-Point Source Pollution--a pollutant which enters a water body from diffuse origins on the watershed and does not result from discernible, confined, or discrete conveyances.

Nutrition--the nourishment of surface waters through nutrient addition or loading.

Operational Modules--components of a group of models which provide integral inputs to a final output.

Operational Watersheds--watersheds which are currently instrumented or monitored to gather various hydrometeorological or water quality data.

Parameter--a measurement or more generally an index used to evaluate water quality.

Point Source--"The term 'point source' means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or can be discharged." (Act, sec. 502(14)).

Point Source Pollution--pollution whose source is specific rather than general in location. For example, particulate matter emanating from a specific smoke stack is point source pollutant (Sesco and others, 1973).

Pollutant--any substance, natural or man-made, which upon entry to a watercourse can degrade water quality.

Prescribed Fires (Burns)--those fires deliberately planned to accomplish a management objective, e.g., burning for fuel reduction.

Process--those continuing physical, chemical, and biological functions which characterize a particular interaction or operation, e.g., the "process" of sedimentation involves erosion, soil particle transport, etc.

Range Improvement--those management practices undertaken to improve range condition for grazing animals, e.g., brush control, grass seeding, fertilization.

Reach--an uninterrupted length of stream channel.

Routing (Routing Coefficients, Routing Models)--the procedure whereby the timing and amount of water and its constituents (sediment, dissolved solids, etc.) at a point in a stream is determined from known or assumed data at one or more points upstream.

Simulation Programming--the development of a model which represents the general processes involved, but not the process mechanisms.

Site Preparation--those methods employed in order to prepare an area for a subsequent treatment, e.g., chaining might be used to prepare rangeland for grass seeding.

Skyline Logging--a system of logging where logs are transported from stump to landing by means of a cable stretched through the air between two elevated points. The logs travel within a sling and are raised entirely above the land surface during transport.

Slash--the residue or debris remaining from logging operations such as limbs, tree tops, chips, and small branches.

Soil Pitting--a rangeland improvement technique where a tractor pulling a toothed rotating drum (pitter) creates numerous shallow depressions in order to enhance infiltration and increase vegetative growth.

Soil Ripping--a rangeland improvement technique where a tractor pulling a toothed plow tears the soil up to a depth of 36" in order to increase vegetative growth and enhance infiltration.

Spray Irrigation--the final step of a tertiary waste water treatment process where the effluent is sprayed upon the land surface and the soils serve as the últimate treatment mechanism removing nutrients and pathogens.

Surfactant--chemicals used to promote infiltration and counteract water repellent layers which sometimes develop within upper soil layers following fires.

Terracing--the practice of constructing contour steps upon hillsides in order to encourage vegetation establishment and retard surface runoff of water.

Tractive Force--the drag of shear that is developed on the wettable area of the stream channel bed and acts in the direction of flow (Chow, 1964).

Tractor Logging--a system of logging where logs are transported from stump to landing by means of a tractor, bulldozer, or skidder.

Trade-offs--the combination of benefits and costs which are gained and lost in switching between alternative courses of action. "Trade-offs" include only those portions of benefits and costs which are not common to all alternative courses of action under consideration.

Trap Efficiency--a measure of the effectiveness of a buffer strip or debris dam to retard runoff and cause deposition of transported soil particles, e.g., a wide, well-vegetated buffer strip may effectively "trap" 100 percent of the transported soil while a narrower strip may only trap 80 percent.

Upland Watersheds--those watersheds on the upper reaches of a stream system, or those watersheds on first order streams.

Understory--lesser vegetation consisting of small trees and shrubs growing beneath the canopy of leaves created by larger, mature trees.

Water Chances--small diversions placed in live streams to impound water so that it may be pumped to water trucks for use elsewhere.

Wildfire--any fire of either natural (lightning) or man-caused origin burning uncontrolled across forest or range land.

Wildland--forest and range lands specifically excluding land encompassing urban, industrial, agricultural, and mining activities.

## SELECTED BIBLIOGRAPHY

Ackerman, W. C. and Corinth, R. L. 1962. An empirical equation for reservoir sedimentation. Publication de l'Association Internationale d'Hydrologie Scientifique (Gentrugge), No. 59, 359-366, In English.

Ahlert, Robert C. 1971. Mathematical description of biological and physical processes in heated streams. AICHE Symposium Series, 68(124): 191-201.

Aleksashenko, A. A. and Khublaryan, M. G. 1971. Mathematical models for water quality evaluation. In: Biswat, A. (Ed). Internat. Symp. on Mathematical Modeling Techniques in Water Resources Systems. Canadian Ministry of Environment. pp. 603-612.

American Geological Institute. 1962. Dictionary of geological terms. Dolphin Books, Doubleday and Co., Garden City, New York. 545 p.

Amorocho, J. and Espildora, B. 1966. Mathematical simulation of the snow melting process. Dept. of Water Sci. and Engr. University of Calif., Davis, Calif.

Anderson, H. W. 1951. Physical characteristics of soils related to erosion. J. Soils and Water Conserv. pp. 129-133.

Anderson, H. W. and Hobba, R. L. 1959. Forest and floods in the northwestern United States. Int. Assoc. Sci. Hydrol., Pub. No. 48, 30-39.

Anderson, H. W. and Trobitz, H. K. 1949. The influence of some watershed variables on a major flood. J. Forestry 47(5): 347-356.

Anderson, H. W. and Wallis, James R. 1965. Some interpretations of sediment sources and causes. USDA, ARS, Misc. Publ. 970, pp. 22-30.

Anderson, Henry W. 1975. The hydrologic potential of unit areas: the basis for managing water resources. Proc. 2nd World Congress of Water Res. Assn., Dec. 12-17, 1975, New Delhi, India.

Anderson, Henry W. 1949. Flood frequencies and sedimentation from forested watersheds. Trans. Amer. Geophys. Union 30(4): 567-584.

Anderson, Henry W. 1970. Principal components analysis of watershed variables affecting suspended sediment discharge after a major flood. Int. Assoc. Sci. Hydrol. Publ. No. 96: 404-416.

Anderson, Henry W. 1971. Relative contributions of sediment from source areas and transport processes. Proc. Symp.

Forest Land Use and Stream Environment. Oregon State Univ. Corvallis, Oct. 19-21, 1970, pp. 55-63.

Anderson, Harry W. 1973. The effects of clearcutting on stream temperature--a literature review. Wash. Dep. Natural Resources Rep. DNR 29, 24 p.

Annon. 1957. Operation outdoors, part 1, national forest recreation. U. S. Govt. Printing Off., Washington, D.C., 14 p.

Annon. 1972. Forest land erosion and sediment evaluation. FSH 3509.21 NA, USDA Forest Service.

Annon. 1973. Annual pesticide use report. USDA Forest Service.

Annon. 1973. The outlook for timber in the United States. Forest Resource Rept. No. 20, USDA Forest Service. 367 p., Illus.

Annon. 1973. Waste water management study summary report for Cleveland--a known metropolitan and three rivers watershed areas. Dept. of the Army, Buffalo District, Corps of Engineers. 207 p., attachments.

Annon. 1974. Final environmental statement cooperative gypsy moth suppression and regulatory program 1974 activities. USDA Forest Serv., Animal and Plant Health Insp. Service, 178 p., Appendix.

Annon. 1974. Final environmental statement cooperative spruce budworm suppression project Maine, 1974 activities. USDA Forest Serv., Animal and plant health insp. Service, 178 p., Appendix.

Annon. 1974. Final environmental statement cooperative spruce budworm suppression project Maine, 1974 activities. USDA Forest Serv. 55 p., Appendix.

Atlee, B. J. and Smith, M. N.D. Impact of forest management practices on the aquatic environment. P.B. 236-040, National Technical Information Service, U.S. Dept. Comm.

Baker, J. B., Jr. 1975. 'Testing of water quality and yield models on Thomas Creek.' USDA Forest Service, Forestry Sciences Lab., Flagstaff, Arizona.

Bard, H. and Krutchoff, R. G. 1974. Predicting pollution in the James River estuary, a stochastic model. Virginia Water Resources Center Bull. 70, NTIS PB-236 784.

Barrett, M. J. 1972. Predicting the effect of pollution in estuaries. Proc. Royal Soc. London B. 180: 511-520.

Beliveau, J. G. and Mattingly, G. 1974. Nonlinear least squares techniques for system identification in water quality. J. Environ. Systems. 4(1): 23-37.

Bella, D. A. 1972. Enviromental considerations for estuarine benthal systems. Water Research 6(11): 1409-1418.

Bennett, J. P. 1971. Convolution approach to the solution for the dissolved oxygen balance equation in a stream. Water Resources Research 7(3): 580-590.

Bennett, J. P. and Rathbun, R. E. 1972. Reaeration in open channel flow. Geological Survey Professional Paper 737. Printing Office.

Benson, M. A. 1964. Factors affecting the occurrence of floods in the southwest. U.S. Geol. Survey, Water-Supply Paper 1585-D. 72 p.

Betson, R. P. 1974. First generation models for water quantity and quality. Amer. Soc. Civ. Engr. Biloxi, Miss. Conference.

Betson, Roger P. and McMaster, William M. 1974. A first generation non-point source mineral water quality model. Proc. 47th Annual Conf. of the Water Poll. Cont. Federation, Denver, Colo.

Bhagat, S. K., Funk, W. H., Johnstone, D. L. 1972. Correlated studies of Vancouver Lake--water quality prediction study. EPA Tech. Series Report, EPA-R2-72-111.

Bloomfield, J. A., Park, R. A., Scavia, D., and Zahorcak, C. S. 1973. Aquatic modeling in the eastern deciduous forest biome. U. S. International Biological Program. Reprinted from Modeling the Eutrophication Process--Workshop Proceedings, (E. Joe Middlebrooks, Donna H. Flakenborg, and Thomas E. Maloney, eds.) Utah Water Research Lab., Logan, Utah, pp. 139-158.

Bormann, F.H., Likens, G.E., Fisher, D.W., and Pierce, R.S. 1968. Nutrient loss accelerated by clearcutting of a forest ecosystem. Science, 159: 882-884, illus.

Boster, R. S. and Davis, L. R. 1972. Soil-loss considerations in chaparral-to-grass conversions. Nat. Symp. on Watersheds in Transition, AWRA Proc.

Boughton, W. C. 1966. A mathematical model for relating runoff to rainfall with daily data. Civ. Eng. Trans. Inst. Engrs. Australia, CE8(1): 83-97.

Brakensiek, D.L. and Onstad, C.A. 1968. The synthesis of distributed inputs for hydrograph predictions. Water Resources Res. 4(1): 79-85.

Branson, F.A. and Owen, J.B. 1970. Plant cover, runoff, and sediment yield relationships on mancos shale in western Colorado. Water Resources Res. 6(3): 783-790.

Brett, J. R. 1952. Temperature tolerance of young Pacific salmon. J. Fisheries Research Board of Canada, 9(6): 265-323.

Brown, Harry E. 1970. The status of pilot watershed studies in Arizona. Amer. Soc. Civ. Eng. IR1, 96: 11-13.

Brown, Harry E., Baker, M. B. Jr., Rogers, J. J., and others. 1974. Opportunities for increasing water yield and other multiple-use values on ponderosa pine forest lands. USDA Forest Serv. Res. Paper RM-129, 36 p. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo.

Brown, Linfield C. 1974. Statistical evaluation of reaeration prediction equations. J. Environ. Engin. Div. ASCE 100(E55): 1051-1068.

Bullard, W. E. 1965. Effect of highway construction and maintenance on stream sediment loads. Proc. Fed. Inter-Agency Sedimentation Conf. 1963. Pap. No. 7. USDI, ARS Misc. Publ. 970, pp. 52-58.

Bungay, H. R. 3rd and Paynter, M. J. B. 1971. Models for multicomponent microbial ecosystems. Water - 1971. AIChE Symp. Series. 68(124): 220-225.

Burges, S. J. and Lettenmaier, D. P. 1975. Probabilistic methods in stream quality management. Water Resour. Bull. 11(1): 115-130.

Burnash, Robert J. C. and Ferrall, R. Larry. 1971. The generalized stream simulation system. Paper 6/6, Int. Symposium on Mathematical Models in Hydrology, Warsaw, Poland, July 26-31, 1971. Int. Assoc. Sci. Hydrology Pub. No. 100-102.

Burt, Wayne V. 1974. Verification of water temperature forecasts for deep stratified reservoirs. Water Resources Res. 10: 93-97.

Busby, M.W. and Hirashima, G.T. 1972. Generalized streamflow relations of the San Bernardino and eastern San Gabriel Mountains, California. Geol. Surv. Open File Rpt. 75 p.

Butz, Brian P., Fishchl, Robert, and Harper, Thurmon R. 1973. Computer-aided analysis of estuarine dynamics simulated by a distributed parameter model. IEEE Transactions on Systems, Man and Cybernetics, SMC-3(4): 318-327.

Canale, R. P. 1974. Effects of temperature on phytoplankton growth. J. Environ. Engr. Div. ASCE 100(EEI): 231-241.

Canale, R. P. 1974. Oxygen utilization in bacterial-protozoan community. J. Environ. Engr. Div. ASCE 100(EEI): 171-185.

Canale, R. P., Hineman, D. F., Nachiappan, S. 1974. A biological production model for grand tranverse bay. Univ. of Mich., Sea Grant Tech. Rept. No. 37.

Carnegie, D. M. 1965. Herbage growth of four California annual range plants in response to freouency and time of clipping. University of California, Berkeley, MS Thesis.

Chen, C. W. and Orlob, G. T. 1972. Predicting quality effects of pumped storage. J. Power Viv. ASCE 98(P01): 65-75.

Chow, Ven Te. 1964. Handbook of applied hydrology. McGraw-Hill Book Co., New York. 29 chapters.

Cleary, Robert W., McAvy, Thomas J., and Short, W. Leigh. 1972. Unsteady state, three-dimensional model of thermal pollution in rivers. Water - 1972, AICHE Symposium Series No. 129, Vol. 69: 422-431.

Cluis, Daniel A. 1972. Relationship between stream water temperature and ambient air temperature, Nordic Hydrology 3: 65-71.

Cobb, Ernest D. and Biesecker, J. E. 1971. The national hydrologic benchmark network. Geological Survey Circular 460-D.

Cooper, Alfred J., and Snyder, Willard M. 1956. Evaluating effects of land use changes on sediment load. J. Hydrolics Div. Proc. ASCE HY 1, Pap. 83.

Cordeiro, C. F. and Verhoff, F. H. 1974. Mathematical model of the surface microbial populations of a freshwater lake. Water - 1973, AICHE Symp. Series, 70(136): 50-65.

Coutart, E. C. 1971. Effect on organisms of entrainment in cooling water - steps toward predictability. Nuclear Safety 12(6): 600-607.

Coweeta Hydrologic Laboratory. 1968. Models of nutrient circulation in forested watershed ecosystems at Coweeta. USDA, Forest Service, Franklin, N. C.--Institute of Ecology, University of Georgia, Athens, Ga.

Crawford, Norman H. and Linsley, R. K. 1966. Digital simulation in hydrology: Stanford watershed model 4. Dept. Civil Engineering, Tech. Rpt. No. 39.

Crippen, J. R. 1974. Basin-characteristics indexes as flow estimators. Am. Soc. Civil Eng. Nat'l Mtg. Water Resources Eng., Los Angeles, Ca. Mtg. Preprint 2117, 23 p.

Dailey, James E. and Harleman, Donald R. F. 1972. Numerical model for the prediction of transient water quality in estuary networks. Mit. Sea Grant Proj. Office, Report No. MITSG 72-15.

Dawdy, David R. and Lichty, R. W. 1968. Methodology of hydrologic model building. Int. Assoc. of Sci. Hydrology, 2(81): 347-355.

Debano, L. F., and Conrad, C. E. 1974. The effect of a wetting agent and nitrogen fertilizer on the establishment of ryegrass and mustard on a burned watershed. Jour. Range Mgt. 27(7): 57-60.

DeWalle, David R. 1974. Effect of partial vegetation and topographic shade on radiant energy exchange of streams--with applications to thermal loading problems. Res. Pub. No. 82, Pennsylvania State Univ., University Park, Pa.

Dillon, P. J., and Rigler F. H. 1974. A test of simple nutrient budget model predicting the phosphorous concentration in lake water. J. Fish. Res. Board Can. 31: 1771-1778.

Dissmeyer, G. E. 1971. Estimating the impact of forest management on water quality. Coop. Watershed Manag. Workshop, USDA Forest Service, Memphis, Tenn., 14 p.

Dixon, N. and Hendricks, D. W. 1971. Simulation of spatial and temporal changes in water quality within a hydrologic unit. Water Resources Bull. 6(4): 483-497.

Douglass, James E. and Swank, Wayne T. 1972. Streamflow modification through management of eastern forests.

USDA Forest Serv. Res. Pap. SE-94, 15 p. Southeastern Forest Exp. Sta., Asheville, N.C.

Dugdale, R. C., and Goering, J. J. 1971. A model of nutrient-limited phytoplankton growth. In: Hood, D. W. (Ed) Impingement of Man on the Oceans, p. 589-600.

Eichelberger, James W., and Lichtenberg, James. 1971. Persistence of pesticides in river water. Environ. Sci. Tech. 5(6): 541-544.

Einstein, H. A. 1950. The bedload function for sediment transportation in open channel flows. USDA, Soil Conservation Service Tech. Bull. 1026.

Espey, W. H., and Ward, G. H. 1972. Estuarine water quality models. Water Research 6: 1117-1131.

Everett, L. G. 1972. A mathematical model of primary productivity and limnological patterns in Lake Mead. Ph.D. Thesis, Univ. of Arizona, Tucson.

Fair, J. F. and Morrison, S. M. 1967. Recovery of bacterial pathogens from high quality surface waters. Water Resources Research 3(3): 799-803.

Fan, L. T., Nadkarni, R. S., and Erickson, L. E. 1971. Dispersion model for a stream with several waste inputs and water intakes. Water Resources Bull. 7(6): 1210-1220.

Fanenf, Arthur G., and Healy, William A. 1952. Misuse of watershed caused pollution at Concord, N. H. Waterworks Eng. 105: 131-153.

Farnham, C. W., Beer, C. E., Heinemann, H. G. 1966. Evaluation of the factors affecting reservoir sediment deposition. Int. Ass. Sci. Hydrol. Publ. No. 71, 747-758.

Fee, Everett J. 1973. A numerical model for determining integral primary production and its application to Lake Michigan. J. Fish. Res. Bd. Canada 30(10): 1447-1468.

Feigner, Kenneth D. and Jaworski, Norbert A. 1972. Mathematical model applications for water quality management in the Potomac estuary. In: A. Biswat (ed.) Proc. International Symp. on Mathematical Modeling Techniques in Water Resources Syst., pp. 129-138.

Flaxman, E. M. 1972. The use of suspended sediment load measurements and equations for evaluations of sediment yield in the west. Sediment Yield Workshop, Nov. 28-30, 1972. Oxford, Miss.

Flaxman, Elliott and Hobba, Robert L. 1955. Some factors affecting rates of sedimentation in the Columbia River Basin. Trans. Amer. Geophys. Union 39(2): 293-303.

Fleming, George. 1971. Simulation of water yield from devegetated basins. J. of the Irrig. and Drainage Div. ASCE, 97(IR 2): 249-262, illus. Proc. Pap. 8175.

Fogel, M. M., Duckstein, L., and Kisiel, C. C. 1974. Modeling the hydrologic effects resulting from land modification. Trans. Amer. Soc. Agr. Engineers 17(6): 1006-1010.

Forcier, L. K., and others. 1971. Lubrecht ecosystem project. Lubrecht Ecosystem Project, 2nd Prog. Rep., Mr. Hedley Bond, Univ. of Utah, 1971 to present.

Foster, G. R., and Meyer, L. D. 1972. A closed form soil erosion equation for upland areas. In: Proc. Sedimentation Symp. to honor Professor H. A. Einstein, Chapter 12, H. W. Shen, editor and publisher, Ft. Collins, Colo.

Frazier, M. 1974. Bow creek watershed - stream temperature effects of a harvest proposal. Administrative Release, Zigzag Ranger District, Mt. Hood Nation Forest, 11 p.

Fuhs, G. W. 1974. Nutrients and aquatic vegetation effects J. Environ. Engr. Div. ASCE. 100(EE2): 269-278.

Fujiwara, Koichiro. 1970. A study of the landslides by aerial photographs. Hokkaido Univ., College Experiment Forests, Res. Bull. 27(2): 343-345.

Galloway, F. M. 1974. On the space/time scale questions in limnological systems analysis. Water-1973. AIChE Symp. Series No. 136, Vol. 70, p. 40-49.

Garrison, G.A. and Rummell, R.S. 1951. First year effects of logging on ponderosa pine forest rangelands of Oregon and Washington. J. Forestry, 49: 708-713.

Geckler, Jack R., Mackenthun, Kenneth M., and Ingram, William Marcus. 1963. Glossary of commonly used biological and related terms in water and waste water control. U.S. Public Health Service, Cincinnati, Ohio. 22 p.

Gessel, S. P. (Univ. of Wash.), Waring, R. H. (Oregon St. Univ)--in Coop. with USFS. 1970. Western coniferous forest biome. 1974 Proposal: Western Coniferous Forest Biome, obtainable from above authors.

Goldstein, R. A., Mankin, J. B. and Luxmoore, R. J. 1974. Documentation of prosper--a model of atmosphere, soil, plant, water flow. EDFB-IBP-73-9 Oak Ridge Nat'l Lab. Oakridge, Tenn.

Gooding, J. S., and Arnold, T. G. 1972. Deep reservoir thermal stratification model. Water Resources Bull. 8: 745-749.

Goodman, Alvin S. and Tucker, Richard J. 1971. Time varying mathematical model for water quality. Water Research, 5:227-241.

Gottschalk, L. C. 1947. A method of estimating sediment accumulation in stock ponds. Trans. Amer. Geophys. Union 28(4): 621-625.

Grenney, W. J., Bella, D. A., and Curl, H. C., Jr. 1973. A theoretical approach to interspecific competition in phytoplankton communities. American Naturalist 107(955): 405-425.

Grenney, W. J., Bella, D. A., and Curl, H. C., Jr. 1973. A mathematical model of the nutrient dynamics of phytoplankton in a nitrate-limited environment. Biotech and Bioengineering 15(2): 331-358.

Hall, Francis R. 1970. Dissolved solids--discharge relationships: 1. Mixing models. Water Resources Res. 6(3).

Hall, J. D. and Lantz, R. L. 1969. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. Proceedings, a Symposium on Salmon and Trout in Streams, T. G. Northcote, ed., University of British Columbia, Vancouver, p. 353-375.

Hannaford, J. F. 1964. Development of a digital river basin model. Proc. WSC, 32 Ann. Meeting, Nelson, British Columbia, Canada pp. 20-26.

Hansen, E.A. 1966. Suspended sediment concentration as related to watershed variables in central Arizona. USDA Forest Service, Rocky Mountain Forest and Range Exp. Sta., 14 p.

Hansen, Edward A. 1975. Some effects of groundwater on brown trout redds. Trans. Amer. Fish. Soc. 104(1): 100-110.

Harder, J. A., and Zand, S. M. 1969. A non-linear mathematical model for the identification of hydrologic systems. Amer. Geophy. Union, San Francisco Meeting, Dec. 15, 1969, 9 p.

Harrison, E. A. 1975. Ecosystem models (a bibliography with abstract). Rept. for 1964--Oct. 74. NTIS/PS-75/088/5ST. 149 p.

Hawkins, Richard H. 1969. Effect of changes of streamflow regimen on reservoir yield. Water Resources Res. 5(5): 1115-1119.

Hedrick, D. W. 1951. Studies on the succession and manipulation of chamise brushlands in California. Texas A and M College, College Station. Unpublished Ph.D. Thesis.

Helvey, J. D. 1967. Interception by eastern white pine. Water Resources Res. 3(3): 723-729.

Helvey, J.D. 1972. First year effects of wildfire on water yield and stream temperature in north central Washington. Nat. Symp. on Watersheds in Transition, AWRA, Proc. Series No. 14, 308-312, illus.

Hess, Lloyd J. 1969. The effects or logging road construction on insect drop into a small coastal stream. Partial fulfillment of the requirements for the degree Master of Science, a thesis presented to the Faculty of Humboldt State College.

Hornberg, George M. and Kelly, Mahlon G. 1972. The determination of primary production in a stream using an exact solution to the oxygen balance equation. Water Resources Bull. Amer. Water Resources Assoc. 8(4): 795-801.

Huck, P. M., and Farquhar, G. J. 1974. Water quality models using the box-jenkins method. J. Environ. Engr. Div. ASCE. 100(EE3): 733-752.

Huff, D. D., Koonce, J. F., Ivarson, W. R., Weiler, P.R., Dettmenn, E.H. 1973. Simulation of urban runoff, nutrient loading, and biotic response of a shallow eutrophic lake. In: Modeling the Eutrophication Process--Workshop Proc. (E. Joe Middlebrooks, Donna H. Falkenborg and Thomas E. Maloney, eds.) Utah Water Research Lab., Logan, Utah, Nov. 1973, 228 p.

Huff, Dale D., and Kruger, Paul. 1974. Simulation of the hydrologic transport of radioactive aerosols. Redionuclides in the Env. Amer. Chem. Soc. Pub., p. 487-505.

Huggins, L. F., Burney, J. R., Kundu, P. S., and Monke, E. J. 1973. Simulation of the hydrology of ungaged watersheds. Purdue Univ. Water Res. Center, West Lafayette, Ind. Tech. Rept. No. 38, 70 p.

Imboden, D. M. 1974. Phosphorous model of lake eutrophication. Limnol. and Oceanography 19(2): 297-304.

International Hydrologic Decade. 1974. Representative and experimental basins in the United States: Catalog of available data and results, 1965-1972. National Academy of Sciences.

Jobson, Harvey M. 1973. The dissipation of excess heat from water systems. J. of the Power Div., ASCE, 99(PO1): 89-103.

Johnson, F.A. 1971. Stream temperatures in an alpine area. J. Hydrol. Amst. 14(3/4): 322-336.

Johnson, N.M., Likens, G. E., and others. 1969. A working model for the variation in stream water chemistry at the Hubbard Brook Experimental Forest, New Hampshire. Water Resources Res.

Johnson, R. W. 1974. A simulation model for studying effects of pollution and freshwater inflow on secondary productivity in an ecosystem. Ph.D. Thesis, North Carolina State Univ., 123 p.

Kardos, Louis T., and Sopper, William E. 1973. Renovation of municipal wastewater through land disposal by spray irrigation. Proceedings, Symposium Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland. pp. 148-163.

Khono, Y., Namba, S., Takiguchi, K., Kitamura, Y., Jurotori, T., Armitsu, K., Miyagawa, K., and Kobayashi, C. 1968. Roles of topography, soil and forest in the landslides of a weathered granite area. Rpt. of Coop. Res. for Disaster Prev. (Tokyo), No. 14, in Japanese, with English abstract, pp. 77-112.

King, Gerald F. and Olson, Gerald W. 1974. Modeling sediment and phosphorus yields to Canadrago Lake. New York's Food and Life Science 7(4): 7-10.

Kitchen, J. H. and Thames, J. L. 1969. Application of a computer model to a desert watershed. Progressive Agriculture in Arizona 21(6): 12-13, illus.

Kohler, M. A. and Richards, M. M. 1962. Multicapacity basin accounting for predicting runoff from storm precipitation. J. of Geophys. Res. 67(13): 5187-5197.

Kohlu, B. S. and Palmer, M. D. 1972. Lake water quality predictions. J. Water Poll. Cont. Fed. 44(8): 1580-1595.

Kothandaraman, V. and Ewing, B. B. 1970. A probabalistic analysis of dissolved oxygen--biochemical oxygen demand relationship in streams. J. of Water Poll. Control Fed. 41(2), Part 2: R73-R90.

Kramer, G. R. 1974. Predicting reaeration coefficients for polluted estuary. J. Environ. Engr. Div. ASCE 100(EE1): 77-92.

Kunkle, Samuel H. and Meiman, James R. 1968. Sampling bacterial in a mountain stream. Hydrology Papers, Colorado State University, Ft. Collins, Colo. No. 28, 27 p.

Lambert, A. O. 1969. A comprehensive rainfall runoff model for an upland catchment area. J. Inst. Water Eng. 23(4): 231-238, illus.

Landine, Robert C. 1971. Prediction of dissolved oxygen levels in the south Saskatchewan River in winter. Int. Symp. on Water Poll. Control in Cold Climates, EPA Water Poll. Comt. Res. Series 16100EXH, Nov. 1971.

Laursen, E. M. 1958. The total sediment load of streams. J. Hydraulics Div. ASCE, Vol 85.

Leaf, Charles F. 1966. Sediment yields from high mountain watersheds, central Colorado. USDA Forest Serv. Res. Pap. RM-23. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo. 15 p.

Leaf, C. F. and Brink, G. E. 1973. Hydrologic simulation model of Colorado subalpine forest. USDA Forest Serv. Res. Pap. RM-107. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo.

Leaf, C. F. and Brink, G. E. 1973. Computer simulation of snowmelt within a Colorado subalpine watershed. USDA Forest Serv. Res. Pap. RM-99. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo.

Ledbetter, J. E. and Gloyna, E. F. 1964. Predictive techniques for water qualiy inorganics. J. ASCE, Sanitary Engineering Division 90.

Lee, E. S. and Hwang, I. 1971. Stream quality modeling by quasilinearization. J. Water Poll. Control Fed. 43(2): 306-317.

Leibscher, H. 1970. Results of research on some experimental basins in the upper Harz Mountains (Federal Republic of Germany). J. Hydrol., New Zealand, Wellington Symp. 9(2): 163-176.

Leopold, L. B. and Emmett, W. W. 1975. Bedload measurements, East Fork River, Wyoming. Unpublished manuscript.

Lindahl, Robert and others. 1974. The effects of forestry activities on the water quality of the Great Lakes. USDA Forest Service. (Prepared for the Great Lakes Basin Commission Task A-10.) 55 p.

Liou, Earnest Y. 1970. OPSET--program for computerized selection of watershed parameter values for the Stanford watershed model. Water Res. Inst. Res. Rpt. No. 34, 299 p.

Liu, Kannson T. H. and Copp, Howard D. 1971. Warming of small impoundments through natural heat exchange. Report No. 3A, Study C, Washington Water Research Center, Pullman, Wash.

Long, G. E. 1974. Model stability, resilence, and management of an aquatic community. Oecologia (Berl.) 17: 65-85.

Lorenzen, M. and Mitchell, R. 1973. Theoretical effects of artificial destratification on algal production in impoundments. Environ. Sci. and Tech. 7(10): 939-944.

Loziuk, Larry A., Anderson, James C., and Belytschko, Ted. 1972. Hydrothermal analysis by finite element method. J. Hydraulics Div., ASCE 98(HY 11): 1983-1998.

Lull, Howard W. and Reinhart, Kenneth G. 1972. Forests and floods in the eastern United States. USDA Forest Serv. Res. Paper NE-226, 94 p., Northeastern Forest Exp. Sta., Upper Darby, Pa.

Lull, Howard W. and Sopper, William E. 1967. Prediction of average annual and seasonal streamflow of physiographic units in the northeast. Int. Symp. Forest Hydrol. Penn. State Univ., Pergammon Press, N.Y., pp. 507-521.

Lumb, Alan M., Currie, F. Leslie, Hassett, Timothy D. and Zorich, John. 1975. Georgia Tech watershed simulation model. School of Civil Engineering, Env. Res. Center, Georgia Institute of Tech., ERC-0175, 153 p., 7 appendices.

Luxmoore, R. J. 1973. Application of the Green and Corey method for computing hydraulic conductivity in hydrologic modeling. Oak Ridge Nat'l Lab. USARC. EDFB-IBP-73-4.

Mandeville, A. N., O'Connell, P. E., Sulcliffe, J. V., and Nash, J. E. 1970. River flow forecasting through conceptual models. Part III--the Ray Catchment of Greudon Underwood. J. Hydrol. 11(2): 109-128.

Marks, P. L. and Bormann, F. H. 1972. Revegetation following forest cutting: mechanisms for return to steady-state nutrient cycling. Science, Vol. 176, March 1972, pp. 914-915.

Masch, Fred D. and Associates. 1971. Simulation of water quality in streams and canals. Texas Water Development Board Rep. No. 128, May 1971, Austin, Tex., 13 p.

McCarthy, M. M. and others. 1974. Regional systems and systems analysis, an approach for management. In: Proc. of the First Int. Cong. of Ecology. The Hague, Netherlands. Sept. 1974.

McIntire, C. David. 1973. Periphyton dynamics in laboratory streams, a simulation model and its implications. Ecol. Mono. 43(3): 399-419.

McQuivey, R. S. and Keefer, T. N. 1974. Simple method for predicting dispersion in streams. J. Environ. Eng. Div. ASCE 100(EE4): 997-1011.

Meeuwig, Richard O. 1971. Soil stability on high elevation rangeland in the intermountain area. USDA Forest Serv. Res. Pap. INT-94, 10 p. Intermountain Forest and Range Exp. Sta., Ogden, Utah.

Meyer, L. D. and Wischmeier, W. H. 1969. Mathematical simulation of the process of soil erosion by water. Trans. ASAE 12(6): 754-758.

Murano, Y. 1968. Statistical studies on the landslides near the boundary between Gifu and Fukui prefectures. Reports of Cooperative Research for Disaster Prevention (Tokyo), No. 15, pp. 19-31, in Japanese, with English abstract.

Muratori, Alex, Jr. 1961. How outboards contribute to water pollution. N. Y. Conservationist 22(6): 6-8,34, illus.

Nece, E. Ronald. 1968. Stream temperature study, north fork Snoqualmie River, Washington. State of Washington Water Res. Center, Completion Rpt. Jan. 1968, 49 p., Techn. Rpt. No. 23.

Nelson, Jack C., Rauschuber, Donald G., Tischler, Lial F. 1973. The effects of water resources development on estuarine environments. Water Res. Bull. 9(6): 1249-1258.

Norris, L. A. 1975. Personal communications.

Nour, A. and Razek, A. 1972. Statistical methodology for predicting the pollutants in a river. Water Res. Bull. 8(1): 15-23.

Novotny, Vladimir, and Krenkel, Peter A. 1973. Simplified mathematical model of temperature changes in rivers. J. Water Poll. Control Fed. 45(2): 239-248.

O'Brien, W. J. 1974. The dynamics of nutrient limitation of phytoplankton algae, a model reconsidered. Ecology 55: 135-141.

O'Melia, Charles R. 1972. An approach to the modeling of lakes. Swiss Journal of Hydology 1: 1-33.

Orlob, Gerald T. 1972. Mathematical modeling of estuarial systems. In: A. Biswat (ed.) Proc. Int. Symp. on Mathematical Modeling Techniques in Water Resources Systems. Vol. 3. Canadian Ministry of Environment, pp. 78-126.

Overland, J. E. 1972. A review of estuarine modeling. In: Proc. 18th Annual Technical Meeting. Institute of Environmental Sciences, pp. 178-185.

Pacific Southwest Inter-Agency Committee. 1968. Factors affecting sediment yield and measures for the reduction of erosion and sediment yield. Rpt. of the Water Management Subcommittee, 13 p.

Palmer, M. D. and Ralston, J. G. 1972. Mathematical models for water management in Ontario, state of the art. Biswat, A. (ed.) Int. Symp. on Mathematical Modeling Techniques in Water Resources Systems. 1971. Canadian Ministry the Environment.

Park, Gordon C. and Schmidt, Philip S. 1973. Numerical modeling of thermal stratfication in a reservoir with large discharge to volume ratio. Water Resources Bull. 9(5): 932-941.

Park, Richard A. and others. 1974. A generalized model for simulating lake ecosystems. Simulation, August 1974, pp. 33-50.

Parker, R. A. 1968. Simulation of an aquatic ecosystem. Biometrics 24(4): 803-821.

Parnas, H. 1975. Model for decomposition of organic material by microorganisms. Soil Biol. Biochem. 7: 161-169.

Patterson, M. R. and others. 1974. Development and application of the unified transport model. In: Ecology and Analysis of Trace Contaminants. N. Fulkerson, W. D. Shults, and R. I. Van Hook, eds. Progress Report Oct. 1973-Sept. 1974, Oak Ridge Nat. Lab.

Pentland, R. L. and Cuthbert, D. R. 1971. Operational hydrology for ungaged streams by the grid square technique. Water Res. Res. 7(2): 283-291.

Petersen, Robert C. and Cummins, Kenneth W. 1974. Leaf processing in a woodland stream. Freshwater Biol. 14(4): 343-368.

Pfankuch, D. J. 1974. A stream channel stability procedure--Part II. Forest Hydrology. USDA, Forest Service Region 1, Missoula, Montana.

Piest, R. F., Bradford, J. M., and Spomer, R. G. 1972. Mechanisms of erosion and sediment movement from gullies. Sediment Yield Workshop, Oxford, Miss.

Ponce, Stanley L. 1974. The biochemical oxygen demand of finely divided logging debris in stream water. Water Res. Res. 10: 983-988.

Prober, Richard, Haimes, Yacov Y., Teraguchi, Mitsuo, and Moss, William, H. 1971. An ecosystem model of lake algae blooms. AICHE Symp. Series, Water-1971 68(124): 402-412.

Renard, K. G. 1972. Dynamic structure of ephemeral streams. Ph.D. Disser., Dept. of Civil Eng. and Eng. Mech., Univ. of Arizona, Tucson, Arizona.

Renard, Kenneth G. 1969. Sediment rating curves in ephemeral streams. Trans. Amer. Soc. Agric. Eng. 12(1): 80-85.

Renfro, E. W. 1972. Use of erosion equations and sediment delivery ratios for predicting sediment yield. Sediment Yield Workshop, Oxford, Miss., USDA Agricultural Research Service, S-40.

Rice, R. M. 1961. Hydrologic effects of logging in a snow zone watershed of the Sierra Nevada. M.S. thesis on file, University of California, Berkeley, Calif.

Rice, Raymond M. 1968. An estimate of the role of soil slips in erosion from the San Gabriel mountains. Trans. Amer. Geo. Union 49(4): 678.

Robert, Ruth. 1967. Silvicultural effects of skyline crane and high-lead yarding. J. Forestry 65: 251-255, illus.

Rockwood, David M. 1968. Application of streamflow synthesis and reservoir regulation, 'SSARR,' program to the lower Mekong River. Int. Assoc. of Sci. Hydrology 81(1): 329-343.

Roehl, J. W. 1962. Sediment source areas, delivery ratios and influencing morphological factors. Comm. of Land Erosion, IASH, Belgium., No. 59, pp. 202-213, in English.

Rogers, James J. 1973. Design of a system for predicting the effects of vegetation manipulation on water yields in the Salt Verde Basin. Ph.D. Dissertation, Univ. of Arizona, Tucson, 444 p.

Rogers, James J., Waring, R. H. and Swank, W. 1975. Water relations and hydrologic cycles. In: Reichle, D. E. (ed) International Biological Programme Synthesis Volumes. Woodlands: Their Structure and Function, Vol. 1 ad 2. Cambridge Univ. Press.

Rosa, J. M. and Tigerman, M. H. 1951. Some methods for relating sediment production to watershed conditions. USDA Forest Service, Intermountain Forest and Range Exp. Sta., Ogden, Utah.

Rosgen, D. L. 1975. Bedload measurements from forty streams plotting sediment transport rate over stream power. Unpublished report, USDA, Forest Service, North Zone Planning, Sandpoint, Idaho.

Rosgen, D., Matz, D., and Kenops, D. 1974. Water yield model I--Part II. Forest Hydrology, Region 1, Missoula, Montana.

Roth, C. B., Nelson, D. W. and Romkens, M. J. M. 1974. Predictions of subsoil erodibility using chemical, mineralogical and physical parameters. Office of Research and Development, EPA. Nat. Environ. Res. Center, Cinncinnati, Ohio.

Rowe, P. B. 1943. A method of hydrologic analysis in watershed management. Tran. Amer. Geophys. Union 24(II): 632-649.

Rutherford, J. Christopher and O'Sullivan, Michael J. 1974. Simulation of water quality in Tarawera River. J. Eniron. Eng., Div. ASCE, April 1974. pp. 369-390.

Ryan, James A., Morrison, I. G., and Bethel, J. S. 1974. Ecosystem modeling of a forested river basin. Water Res. Bull. AWRA 10(4): 703-709.

Sakhan, K. S., Riley, J. P., and Renard, K. E. 1971. Hybrid computer simulation of sediment transport with stochastic transfer at the streambed. Sedimentation Editor, H. W. Shen.

Scavia, Don, Bloomfield, Jary A., Fisher, John S., Nagy, James, and Park, Richard A. 1974. Documentation of CLEANX, a generalized model for simulating the open-water ecosystems of lakes simulation. August 1974, pp. 51-56.

Schofield, William R. and Krutchkoff, Richard G. 1972. Stochastic model of BOD and DO in segmented estuary. J. Sanitary Eng. Div., Proc. Amer. Soc. Civil Eng. 98(SA5): 745-762.

Schofield, William R. and Krutchkoff, Richard G. 1974. Deterministic model of dynamic eutrophic estuary. J. of the Environ. Engin. Div., ASCE 100(EE4): 979-995.

Schofield, William R. and Krutchkoff, Richard G. 1974. Stochastic model of dynamic eutrophic estuary. J. Environ. Eng. Div., ASCE 100(EE0): 613-629.

Schultz, A. M., Launchbaugh, J. L. and Biswell, H. H. 1955. Relationship between grass density and brush seedling survival. Ecology 36(2): 226-238.

Sedell, James R., Hall, James D., and Triska, Frank J. 1973. Stream ecology in relation to land use. Internal Report 138, IBP Interagency Coordination Committee, July 26, 1973, Washington, D. C.

Sesco, Jerry A., Lindmark, Ronald D., and Baumgartner, David C. 1973. An environmental glossary and dictionary of selected agencies and organizations with environmental interests. USDA Forest Service, North Central Forest Exp. Sta., St. Paul, Minn. 113 p.

Shastry, J. S., Fan, L. T., and Erickson, L. E. 1973. Nonlinear parameter estimation in water quality modeling. J. Environ. Engr. Div. ASCE 99(EE3): 315-331.

Shih, C. C., Bowles, D. S., and Riley, J. P. 1973. An application of the Utah State University watershed simulation model to the Entiat experimental watershed, Washington State. USDA Forest Service, Pacific Northwest Forest and Range Exp. Sta., 48 p.

Shulits, Sam, and Hill, Ralph D., Jr. 1968. Bedload formulas--Part A, selection of bedload formulas. Dept. Civil Eng. Hydraul. Lab. Bull., Pennsylvania State Univ., College of Engineering, University Park, Penn., p. 137.

Sopper, William E. 1973. Crop selection and management alternatives--perennials. Proc. Joint Conf. Recycling Municipal Sludges and Effluents on Land. EPA, USDA, Nat. Assoc. State Universities and Land Grant Colleges. pp. 143-153.

Sornberger, G. Clinton, and Keshavan, Krishnaswamiengar. 1973. Simulation of dissolved oxygen profile. J. Environ. Eng. Div., ASCE 99(EE4): 479-488.

Stall, John B. and Bartelli, L. J. 1959. Correlation of reservoir sedimentation and watershed factors. Illinois Water Survey Rpt. 37, 21 p.

Steele, T. D. 1971. A study of the chemical quality of streamflow in Arkansas. U.S. Geological Survey Open File Report, Oct. 1971. 8 p.

Steele, T. D. and Jennings, M. E. 1972. Regional analysis of streamflow chemical quality in Texas. Water Resources Res. 8(2): 460-477.

Striffler, W. D. 1973. Part II. Users manual for the Colorado State University Version of the Kentucky Watershed Model. NASA Contract NAS 9-13142, Sept. 1973, 165 p.

Striffer, W. David. 1965. Suspended sediment concentrations in a Michigan trout stream as related to watershed characteristics. USDA, ARS Misc. Pub. 970, Pap. No. 22, pp. 144-147.

Swank, W. T., Goebel, N. B. and Helvey, J. D. 1972. Interception loss in loblolly pine stands of the S. Carolina Piedmont. J. Soil and Water Conserv., July-Aug.

Swanston, D., and Fredrikson, R. 1975. Comprehensive studies on mass erosion and stream sedimentation as part of the northern coniferous biome study. USDA, Forest Service and Oregon State University, Corvallis, Oregon. Personal communication.

Swift, L. W. Jr. and others. 1973. Simulation of evapotranspiration from mature and clearcut deciduous forest and young pine plantations. Eastern Deciduous Forest Biome Memo Report No. 73-79.

Swift, L. W., Jr., and Luxmoore, R. J. 1973. Computational algorithm for solar radiation on mountain slopes. Eastern Deciduous Forest Biome Memo Report No. 73-10.

Swift, Lloyd W., Jr., and Baker, Samuel E. 1973. Lower water temperatures within a streamside buffer strip. USDA Forest Serv. Res. Note SE-193. 7 p. Southeastern Forest Exp. Sta.

Swift, Lloyd W., Jr., and Messer, James B. 1971. Forest cuttings raise temperatures of small streams in the southern Appalachians. J. Soil and Water Conserv. 26(3): 111-116.

Tasker, Gary D., and Burns, Alan W. 1974. Mathematical generalization of stream temperature in central New England. Water Res. Bull. 10: 1133-1142.

Tatum, Fred E. 1965. A new method of estimating debris-storage requirements for debris basins. USDA, ARS Misc. Pub. 970, pp. 886-888.

Tennessee Valley Authority, Hydrologic Research, and Analysis Staff. 1972. Upper Bear Creek experimental project, a continuous, daily streamflow model. TVA Res. Pap. No. 8, 99 p.

Tew, Ronald K. 1973. Estimating soil erosion losses from Utah watersheds. USDA Forest Service, Intermountain Region, Ogden, Utah.

Texas Water Development Board. 1970. QUAL-1, Simulation of water quality in streams and canals. Texas Water Dev. Board.

Thayer, Richard P. and Krutchkoff, Richard G. 1967. Stochastic model for BOD and DO in streams. J. Sanitary Eng., Div. ASCE 90 (SA3): 59-72.

Thomann, R. V., Ditoro, D. M., O'Connor, D. J. and Winfield, R. P. 1973. Mathematical modeling of the eutrophication of large lakes. Annual Rpt. Year 1, Manhattan College, Bronx, Environ. Engr. and Sci., Program.

Thomann, R. V., O'Connor, D. J., and Ditoro, D. M. 1970. Modeling of the nitrogen and algal cycles in estuaries. Adv. in Water Pollution Research Proc. 5th Int. Conf., San Francisco.

Thomann, Robert V. 1963. Mathematical model for dissolved oxygen. J. Sanitary Eng., Div. ASCE, 89(SA5): 1-30.

Tirabassi, Michael A. 1975. A statistically based mathematical water quality model for a non-estuarine river system. Water Res. Bull. 7(6): 1221-1237.

Tluczek, Louis J. M. 1974. Public health consideration of the soil incorporation of campground sanitary wastes. M.S. Thesis, Michigan Technological Univ.

Todini, E. and Wallis, J. R. 1974. Using CSL for daily or longer period rainfall-runoff modeling workshop on mathematical models in hydrology, Pisa, Italy, Dec. 9-12, 1974, Centro Scientifico IBM Italia, Pisa.

U.S. Army Corps of Engineers. 1958. Long-duration runoff volumes. Tech. Bull. No. 5., 20 p., illus.

U.S. Department of Agriculture, Soil Conservation Service. 1957. Soil Conservation Service. Hydrology, Supp. A., Sec. 4, Engineering Handbook.

U.S. Department of Agriculture, Forest Service. 1975. Hydrologic effects of vegetation manipulation. Forest Hydrology, Part II. USDA Forest Service, Missoula, Mont.

U.S. Department of Agriculture, Forest Service. 1975. Draft environmental statement. Triangle Ranch Wetlands Land Exchange, Modoc National Forest, 49 p.

U.S. Department of Agriculture, Forest Service. 1953. Formulas developed for estimating sediment yield in southern California. Report of Survey--Santa Clara-Ventura Rivers and Calleguas Creek Watersheds, California, Berkeley, Calif., 34 p. 5 appendices. (Hydrology Appendix by H. W. Anderson.)

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Staff Hydrologic Research Laboratory. 1972. National weather service river forecast system forecast procedures. NOAA Tech. Memo. NWS HYDRO-14, Solar Springs, Md.

U.S. Environmental Protection Agency. 1974. Water quality protection guides. Logging Roads, Draft Edition, Part I, 66 p.

U.S. Environmental Protection Agency. 1973. Methods for identifying and evaluating the nature and extent of non-point sources of pollutants. EPA-430/9-73-014, Oct. 1973, 261 p.

Umnov, A. A. 1971. Application of the mathematical simulation method to the study of the role of photosynthetic aeration of lakes. Soviet Journal of Ecology 2(6): 489-494.

Verry, E. S. 1975. Estimating water yield differences between hardwood and pine forests. Unpublished paper to be submitted as a USDA Forest Serv. Res. Pap, North Central Forest Exp. Sta., St. Paul, Minn.

Vogel, Allan H. and Canale, Raymond P. 1974. A food web model for Lake Michigan, Part 1, justification and development of the model. University of Michigan Sea Grant Program, Sea Grant Tech. Report No. 40.

Waggy, Henry W. 1973. HSP quantity-quality simulation. Simulation Network Newletter, Hydrocomp, 1502 Page Mill Road, Palo Alto, Calif.

Wallace, D. A. and Dague, R. R. 1973. Modelling of land runoff effects on dissolved oxygen. J. Water Poll. Cont. Fed. 45(8): 1795-1809.

Wallis, J. R. 1963. Logging for water quality in northern California. 116.28(794.)--31. USDA Forest Serv. Res. Note PSW-N23, 7 p. Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif.

Wallis, James R. and Anderson, Henry W. 1965. An application of multivariate analysis to sediment network design. Int. Assoc. Sci. Hydrol. Pub. 67, pp. 357-378.

Wallis, J. R. 1965. A factor analysis of soil erosion and stream sedimentation in northern California. Ph.D. Dissertation, 141 p. Univ. Microfilms, Ann Arbor, Mich., Pap. No. 65-8113.

Walter, W. G. and Jezeski, J. J. 1973. Microbial and chemical studies in a watershed used for municipal supply and waste disposal. Montana Water Resources Research Center. Rept. No. 41, (NTIS PB-226 240). 27 p.

Ward, G. H., Jr. and Espey, W. H., Jr. 1971. Estuarine modeling: an assessment. Tracor, Inc., Austin, Texas. (GPO stock No. 5501-0129). 517 p.

Warner, M. M. 1966. Sedimentational analysis of the Duchesne River formation, Uinta Basin, Utah. Geol. Soc. Amer. Bull, Vol. 77, pp. 945-958.

West, J. R. and Williams, D. J. A. 1970. The use of a simple mathematical model to account for the variation of coliform density, salinity, and temperature with tidal state. In: Adv. in Water Pollution Research, Proc. 5th Int. Conf.

Wiegert, R. G. and Wetzel, R. L. 1974. The effect of numerical integration technique on the simulation of carbon flow in a Georgia salt marsh. Proc. 1974 Summer Computer Simulation Conf., pp. 575-577.

Willen, Donald W., Shumway, Clyde A., and Reid, James E. 1971. Simulation of daily snow water equivalent and melt. Proc. 39th Western Snow Conf., Billings, Montana, April 20-22, pp. 1-8.

Williams, J. R. 1975. Sediment yield prediction with universal equation using runoff energy factor. Sediment Yield Workshop, USDA, ARS, Nov. 28-30, 1972, Oxford, Miss.

Williams, J. R. and Hann, R. W. 1972. HYMO, a problem oriented computer landguage for building hydrologic models. Water Resources Res. 8(1): 79-86.

Wilson, D., and Bennett, M. 1975. Landtype analysis procedure. USDA Forest Service, Clear-Water National Foret, Orofino, Idaho, Personal communication.

Wischmeier, W. H. 1974. New developments in estimating water erosion. SCSA. 29th Ann. meeting, Aug. 11-14, 1974, Syracuse, N.Y.

Wischmeier, W. H. 1972. Estimating the cover and management factor for undisturbed areas. Sediment Yield Workshop, ARS, Oxford, Miss.

Witherspoon, D. F., and Poulin, R. Y. 1970. A study of the heat loss of the St. Lawrence River between Kingston and Cornwall. Poc. 13th Conf. Great Lakes Research, pp. 990-996.

Woolhiser, D. A. and Blinco, P. H. 1972. Watershed sediment yield--a stochastic approach. Sediment Yield Workshop, Oxford, Miss.

Woolridge, David D. 1960. Water disturbance from tractor and skyline crane logging. J. Forestry 58: 369-372, illus.

Yang, C. T. ad Stall, J. B. 1974. Unit stream power for sediment transport in natural rivers. University of Illinois Water Resources Center, Urbana, Ill., UILU-WRC-71-0088.

Yang, Jeff T. T. and Johnson, A. I. 1974. A mathematical simulation of land ecology and control of its balance. Water-1973. AIChE Symp. Series 70(136): 66-82.

Young, G. K., Tseng, M. T., and Taylor, R. S. 1971. Estuary water temperature sensitivity to meteorological conditions. Water Resources Res. 7(5): 1173-1181.

Young, G. K. and Pisano, W. C. 1968. Operational hydrology using residuals. J. of Hydraul. Div. Proc. of Amer. Soc. of Civil Eng. 94(HY4): 909-923.

Ziemer, Robert R. 1964. Summer evapotranspiration trends as related to time after logging of forests in Sierra Nevada. J. Geophys. Res. 69: 615-620.

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

1. REPORT NO.
EPA-600/3-77-036

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
Non-Point Water Quality Modeling in Wildland Management: A State-of-the-Art Assessment (Volume I--Text)

5. REPORT DATE
April 1977 issuing date

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
US Forest Service

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Forest Service
United States Department of Agriculture
Washington, DC 20250

10. PROGRAM ELEMENT NO.
1HB617

11. [redacted]
Interagency Agreement
EPA-IAG-D5-0660

12. SPONSORING AGENCY NAME AND ADDRESS
Environmental Research Laboratory - Athens, GA
Office of Research and Development
United States Environmental Protection Agency
Athens, Georgia 30601

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/600/01

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Predicting non-point pollution from wildland environments is evaluated in three main areas: management activity/pollutant relationship, predictive model review and state-of-the-art assessment, and an inventory of 176 wildland watersheds suitable for model validation and development.

Non-point pollution is directly related to the time and space variability of the hydrologic cycle and existing terrain, and the relationship is site dependent. Impact of sedimentation from site disturbance is the most common problem.

Predictive models for non-point pollutant loading relating spatial variability and diversity of terrain to management activities are the most important in evaluating the potential on-site impact of planned wildland management activities. Few non-point loading models exist.

The state-of-the-art is represented by process similation models, not yet extensively used for field application. Their use will require validation and simplification. The state-of-the-art at the field level lags that of research and is represented by regional regression models and analytical procedures.

Watersheds available for non-point model validation and testing do not have long data records (less than 10 years) except on streamflow and to a lesser extend sediment.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Simulation, Runoff, Forestery, Water Quality, Hydrology, Erosion, Planning | Nonpoint pollution, forestry, runoff, model studies, watershed studies | 02F/08H |

18. DISTRIBUTION STATEMENT
RELEASE TO PUBLIC

19. SECURITY CLASS *(This Report)*
UNCLASSIFIED

20. SECURITY CLASS *(This page)*
UNCLASSIFIED

21. NO. OF PAGES
156

22. PRICE

EPA Form 2220-1 (9-73)



☆U.S. GOVERNMENT PRINTING OFFICE: 1977—757-056/5610