DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
UNITED STATES FOREST SERVICE
AND THE
WASHINGTON DEPARTMENT OF GAME

WATER RESOURCES INVESTIGATION
OPEN-FILE REPORT 80-1124

Base from U.S. Geological Survey
Snoqualmie Pass, Skykomish River,
Chelan, Wenatchee, 1:100,000, 1976

Hydrologic data compiled 1979

EXPLANATION

Pollutant-Loading Likelihood

L — Low: 0-10 percent of shoreline area is wet area

M — Moderate: 10-30 percent of shoreline area is wet area and less than 10 percent of the basin area is wet area

H — High: greater than 30 percent of the shoreline area is wet area, or 10-30 percent of shoreline area is wet area and greater than 10 percent of basin area is wet area

Alpine Lakes Wilderness Area boundary

Drainage basin boundary

Lake not shown at 1:100,000 map scale

SCALE 1:100 000

CONTOUR INTERVAL 50 METERS
WITH SUPPLEMENTARY CONTOURS AT 25-METER INTERVALS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Index map of the State of Washington showing Alpine Lakes Wilderness Area

PRELIMINARY EVALUATION OF LAKE SUSCEPTIBILITY TO WATER-QUALITY DEGRADATION BY RECREATIONAL USE, ALPINE LAKES WILDERNESS AREA, WASHINGTON

By

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1980

INTRODUCTION

The Alpine Lakes Wilderness Area contains more than 700 lakes (see map), many of which provide exceptional recreational opportunities. The lakes are receiving an increasing number of visitors and the resulting heavy use of trails and campsites near these lakes could result in degradation of lake-water quality. Reliable predictions of water-quality impacts caused by specific levels of recreational activity at each lake would greatly aid in managing the Wilderness Area. However, extensive data are necessary for making this type of prediction, and such data are not presently available. In the absence of extensive data, identification of those lakes that are most susceptible to water-quality degradation, and identification of natural features in the Wilderness Area that affect the susceptibility of lakes, is needed to help guide current management of recreation.

In this report, the inherent susceptibility of a lake to degradation is considered from two perspectives as determined by its natural features: (1) water-quality sensitivity, which is the tendency of a lake's water quality to degrade in response to pollutant loading, and (2) the likelihood of pollutant loading, which is determined by the presence of drainage-basin features that enhance the transport of pollutants to a lake. Water-quality sensitivity and pollutant-loading likelihood combine to determine the relative susceptibility of a lake to degradation of water quality at a given level of recreational use. Such an evaluation of susceptibility can be combined with a planner's assessment of lake-recreation potential, which should consider such factors as historical use, accessibility, and lake attractiveness, to judge the overall potential for water-quality degradation.

This study was designed to make optimal use of existing data in a short period of time to fulfill an immediate need of the U.S. Forest Service for use in legislatively mandated wilderness-area planning. Available data allowed limited assessment, for 298 lakes in the ALWA (Alpine Lakes Wilderness Area), of the relative likelihood that each lake would receive pollutants under conditions of intense recreational activity in the lake's drainage basin. Water-quality sensitivity was numerically evaluated for 60 of the 298 lakes, and those evaluations for the 60 lakes were used as the basis for general conclusions about the sensitivity of the other lakes in the ALWA.

AVAILABLE DATA

In an earlier, related study, Dethier (1978) evaluated the extent of areas with seasonally saturated, poorly drained soils near the lakeshores and in drainage basins for 298 of the larger and most accessible lakes in the ALWA. That study was conducted during July to September 1978 by the Geological Survey in cooperation with the U.S. Forest Service and the Washington Department of Game. These "wet areas", as referred to in this report, were delineated for the 298 lakes by interpretation of aerial photos and, for selected lake drainage basins, from reconnaissance mapping of surficial deposits. Drainage-basin boundaries were determined from topographic divides shown on 1:24,000- or 1:62,500-scale U.S. Geological Survey topographic maps.

Data are also available on volume, area, depth, other selected physical parameters, and water quality for 60 of the 298 lakes. These data were reported by Dethier and others (1979), who selected the 60 lakes with the purpose of collecting a sample representative of the range of environmental conditions present in the Wilderness Area. Therefore, data for these 60 lakes are useful for making general evaluations concerning all lakes in the ALWA.

GENERAL WATER QUALITY

The water quality of the 60 lakes studied by Dethier and others (1979) provides a good indication of the general water quality of most lakes in the ALWA. Thirty-five of these 60 lakes are west of the crest of the Cascade Range, which approximately bisects the ALWA in a north to south direction (see map). This part of the area has a cool, wet climate characterized by annual precipitation in the range of 3-5 meters. Twenty-five of the lakes are east of the crest of the Cascades, where there is a drier but still moist climate characterized by annual precipitation in the range of 1-3 meters. Despite the different climatic conditions, no statistically significant differences were observed between water quality of the east-side and west-side lakes. Both groups had excellent water quality as indicated by high water clarity and low concentrations of dissolved solids (Dethier and others, 1979). In comparison to other Washington lakes studied by Bortleson and Dion (1979), the Alpine Lakes are among the most pristine in the State. An example is the overall high water clarity of the Alpine Lakes, as shown in figure 1.

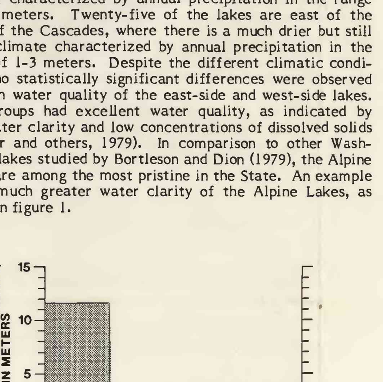

FIGURE 1.—Median Secchi-disc visibility for selected groups of Washington lakes. Secchi-disc visibility is a measure of water clarity and is statistically correlated with the amount of algal growth (Dillon and Rigler, 1975). Low readings (< 2 meters) are characteristic of highly productive lakes, while high readings (> 6 meters) are usually found in lakes with a low algal productivity. Data for the Alpine lakes is from Dethier and others (1979); the data for the other lakes is from Bortleson and Dion (1979).

The excellent water quality of lakes in the ALWA seems to result mainly from the following factors:

(1) The lakes are remote and inaccessible by any means other than horseback or foot travel; this has resulted in limited use of the lakes and, along with federal ownership of most of the land, has prevented permanent development.

(2) The abundant annual precipitation in the area, even in the east-side localities, causes large volumes of water to flow through the lakes each year. This rapid flushing tends to dilute and "flush" any pollutants that may enter a lake.

The present high quality of lakes in the Wilderness Area, however, does not necessarily indicate that these lakes will resist degradation of water quality in the future if recreational use increases.

WATER-QUALITY SENSITIVITY

General Considerations

The sensitivity of a lake to water-quality degradation by pollutant loadings depends mainly on the capability of the lake to dilute and "flush" pollutants with water flowing through the lake, and to "trap" pollutants in the bottom sediments if they settle along with particulate matter. These factors are important on both a whole-lake (average conditions throughout a lake) and a localized scale, and on both a long-term and short-term time basis.

On a long-term, whole-lake scale, a lake that has a large volume of water flow through it each year has a high capability to dilute and flush pollutants. Conversely, a lake with a small amount of water flowing through it may have a relatively low capacity to dilute and flush pollutants. In addition, pollutants that reach the bottom sediments of a deep lake are less likely to be "recycled" to near-surface waters, as compared to a shallow lake, because the mixing of waters throughout the lake is less frequent and often incomplete. If other factors are equal, lakes that are shallow and have a small inflow are the most sensitive to pollutant loadings; lakes that are deep and have a large inflow are the least sensitive.

Water-quality sensitivity is not only a whole-lake characteristic; features that make an entire lake sensitive also can be present in isolated parts of an otherwise relatively insensitive lake, especially during dry periods. For example, a large lake with a large inflow may have a small embayment that is shallow and receives little inflow during late summer, and exchanges little water with the rest of the lake. Consequently, the small embayment may be extremely sensitive to localized but temporary degradation during dry periods, while the main lake remains relatively unaffected. Therefore, evaluations of water-quality sensitivity based on average conditions for an entire lake must be used with caution, and decisions based on such evaluations should include consideration of environmental features of individual recreation sites as well (discussed further in "Management Applications").

The main types of pollutants that could enter the ALWA lakes and degrade lake-water quality as a result of recreational activity are (1) nutrients (primarily nitrogen and phosphorus), (2) pathogens (such as disease-producing bacteria, protozoa, and viruses), and (3) sediment from erosion. Adverse impacts of sediment, such as deposition in lakes and increased water turbidity, are not addressed in this report because of insufficient data. For some small lakes with large stream inflows, sediment loading could be a significant problem. The second type of potential pollutants, pathogens, probably will be the most important cause of localized and temporary water-quality problems; but they are not common whole-lake pollutants because they tend to be relatively short-lived in a lake environment (Mancini, 1978; Zanoni and others, 1978). Nutrients, in contrast to pathogens, are soluble and actively involved in chemical and biological cycles. Nutrients are relatively persistent in lakes and would be the most likely cause of long-term whole-lake degradation of water quality for lakes in the ALWA.

Excessive nutrient enrichment, causing nuisance growth of algae and rooted aquatic plants, has been observed in many lowland lakes that have residential and other land development within their drainage basins. Although symptoms of nutrient enrichment were not observed in any of the ALWA lakes, the potential for excessive nutrient loadings due to increased recreational activity in the future is important to evaluate. Of the two major nutrients (nitrogen and phosphorus), phosphorus is usually the growth-limiting nutrient in lakes; more phosphorus will cause more plant growth. Thus, lakes were assessed according to their predicted response to increases in phosphorus loading. This evaluation is useful as a general indication of lake sensitivity to other pollutants as well, because some of the same basic physical processes (dilution and sedimentation) control the effects of most pollutants on lakes.

Evaluation by Modeling Sensitivity to Phosphorus Loading

A simple mathematical model that simulates steady-state (constant annual average) phosphorus concentration in a lake, and which utilizes relatively few data, can be used to predict whole-lake sensitivity to increased phosphorus loading. This is the best method presently available to evaluate the response of lakes in the ALWA to increases in phosphorus loading. However, the method is not suitable for predicting localized and short-term responses to pollutants.

The phosphorus model used in this study is a mass-balance model, developed and refined mainly by Vollenweider (1968) and Dillon and Rigler (1975). It has been found to work well for a wide variety of lake types (Larsen and Mercier, 1976; Rast and Lee, 1978). The model relates the steady-state concentration of phosphorus in a lake to the annual loading of phosphorus to the lake, the volume of the lake, the rate of water flow through the lake, and the loss of phosphorus trapped in lake-bottom sediments. Appropriate data for use in the model were available for the 60 lakes studied by Dethier and others (1979). Because these lakes were selected as being representative of the range of lake types and climate found in the ALWA, they serve as a basis for general conclusions about other lakes as well.

For each of the 60 lakes, model predictions were made of the response to a hypothetical increase in phosphorus loading of 5 kg/yr (kilograms per year). This was considered a large, but potentially foreseeable, loading relative to what seems likely for any of the alpine lakes, especially the smaller ones that have few recreation sites. Results thus represent a type of "worst-case" test of lake sensitivity.

The results of this analysis indicated that all of the lakes evaluated were relatively insensitive to potential increases in phosphorus loading on a steady-state whole-lake basis. Some small lakes, such as Tank Lakes, Toehn Lake, and Enchantment "F" Lake, were predicted to be highly sensitive compared to the other lakes. However, for these lakes, the hypothetical 5 kg/yr increase in phosphorus loading is far greater than what is likely because they are small and have few potential recreation sites within their basins. This conclusion concerning the 60 lakes should not be interpreted to mean that any of the lakes in the ALWA can withstand unlimited levels of use without water-quality degradation.

The most serious potential water-quality problem for ALWA lakes is the localized transient type of pollution that can occur in particularly susceptible parts of a lake, adjacent to intensively used shoreline areas, and during the times of greatest use. The most significant pollutants related to this type of water-quality degradation are probably pathogens. The bodies of water that are most sensitive to transient and localized water-quality degradation are small, shallow lakes and small, shallow embayments that are poorly flushed during a time when recreational use is intense. On a relative basis, the lakes with the greatest local or temporary sensitivity probably are in the eastern part of the Wilderness Area where runoff, and thus lake flushing, is least.

POLLUTANT-LOADING LIKELIHOOD

General Considerations

A lake may be susceptible to water-quality degradation if the soil, geologic, and(or) hydrologic characteristics of its drainage basin (the area that potentially contributes surface runoff to the lake) favor the transport of pollutants to the lake from trails and campsites. Surface runoff is the primary means by which pollutants are transported to a lake. Generation of pollutants within, or disturbance of, any part of a lake drainage basin could result in adverse impacts on the lake. The most likely pollutants from recreational activity, as discussed earlier, are nutrients and pathogens derived from human (or livestock) waste, and sediment. Although lakes in the ALWA were generally found not to be sensitive to long-term and whole-lake degradation, the presence of certain land types in lake basins makes some lakes more susceptible than others to temporary, but potentially serious, localized pollution.

Three major land types in the ALWA tend to increase the likelihood of pollutant loading to lakes: (1) steep, soil-covered slopes, (2) exposed bedrock, and (3) wet areas. Steep, soil-covered slopes are vulnerable to erosion associated with trail construction and heavy visitor traffic. Such erosion can result in sediment entering a nearby lake or stream. Erosion is a potential problem throughout much of the ALWA because slopes are steep. In bedrock areas, where there is little or no soil available to allow infiltration of water and filtering of pollutants, wastes deposited near a lake or its inflowing streams may be rapidly carried to the lake by surface runoff. This situation may pose a problem for a few lakes, but exposed bedrock near most lakes is too steep to be used for camping or trails and, therefore, recreational use of these areas is not likely to be a major source of pollution.

Wet areas are probably the most important single land type that affect the transport of pollutants to lakes in the ALWA. Extensive wet areas occur near many lakes, they often attract high rates of recreational use, and their soils generally afford poor treatment of human wastes. Wet areas in the ALWA are generally alpine meadows or sparsely forested, brush-covered land. Parts of these areas are often dry enough for use as campsites and trails during the summer season. When these areas are near lakes, they usually attract recreational use because they are flat to gently sloping and often afford open views. Unfortunately, the physical and hydrologic characteristics of wet areas are such that intense recreational use is likely to result in pollutant loading of adjacent bodies of water.

The wet areas in the ALWA are predominantly underlain by silt and fine sand, with minor amounts of clay and medium sand. The soil and rock materials in these areas are saturated at very shallow depths (water lies within about one half meter of the land surface during most of the year). When disturbed, these areas are highly vulnerable to erosion by surface runoff, which occurs readily on gentle slopes because water cannot infiltrate the saturated ground. Moreover, saturated conditions reduce the retention of pollutants by the soil because (1) surface runoff, which can carry wastes directly from the land to a lake or stream, is rejected by the saturated soil (Dunne and Leopold, 1978) and thus is not filtered by the soil; and (2) pollutants that do get underground are generally more mobile in saturated than in unsaturated soils and can more readily move to adjacent surface-water bodies by subsurface flow (Otis, 1976). The closer these wet areas are to a lake or inflow stream, the more likely that pollutants will reach the lake and affect the water quality.

Evaluation by Drainage-Basin Wet Areas

The likelihood that a Wilderness Area lake will receive pollutant loadings because of increased recreational use was evaluated according to the extent of wet areas near the lakeshore and, to a lesser extent, in more remote parts of the basin. Though it clearly would be desirable to also include steep slopes and bedrock areas in this analysis, the necessary data were not available. Field inspection of about 50 lakes was used to assign general criteria for judging whether an alpine lake has a high, moderate, or low likelihood of receiving pollutant loadings according to the extent of wet areas that affect the lake. The criteria are given in the map explanation. These criteria are subjective, but they are based on extensive field experience in the Alpine Lakes Wilderness Area. They are proposed for planning guidance pending the availability of additional data.

Results of the evaluation of pollutant-loading likelihood are shown on the accompanying map. Of the 298 lakes evaluated, 224 were rated low, 22 moderate, and 52 as having a relatively high pollutant-loading likelihood.

EVALUATION OF LAKE SUSCEPTIBILITY

Evaluation of the susceptibility of lakes to water-quality degradation must include consideration of water-quality sensitivity and pollutant-loading likelihood from two perspectives: long-term whole-lake degradation and temporary local degradation. Findings of this study are sufficient for evaluating the susceptibiity of lakes in the ALWA to long-term whole-lake degradation of water quality, and they permit a partial evaluation of susceptibility to temporary local degradation.

Most lakes in the ALWA appear to have a low susceptibility to long-term whole-lake degradation of water quality, even though many lakes have a moderate or high rating of pollutant-loading likelihood. This is because the low sensitivity of the lakes would tend to negate the effects of even a relatively high rate of pollutant loading.

A number of the lakes, however, probably are susceptible to temporary and local water-quality degradation. This conclusion is based mainly on the finding that a large number of lakes have a moderate or high rating of pollutant-loading likelihood. Though seasonal or local occurrences of high sensitivity in these lakes were not evaluated, it is probable that because of the large number of lakes with adjacent wet areas, some of these lakes or their parts also have a high water-quality sensitivity on a temporary basis. Such local occurrences of high susceptibility to degradation of water quality are likely to result in serious problems only at heavily used sites. More detailed lake-by-lake evaluations of water-quality sensitivity and the distribution of drainage-basin features that increase the likelihood of pollutant loadings is therefore warranted for lakes that receive especially high levels of use.

MANAGEMENT APPLICATIONS

For application to water-quality management, the most important findings of this study are:

(1) The type of water-quality degradation likely to occur in the ALWA is temporary and local. The most serious pollutants related to this type of degradation are pathogens. Long-term whole-lake degradation is not likely to be a significant problem at pollutant-loading rates potentially associated with wilderness-area recreation.

(2) A preliminary identification of lakes most susceptible to localized short-term degradation is possible by using the ratings of pollutant-loading likelihood shown on the map. Such an assessment does not include consideration of water-quality sensitivity, however, and further studies would be necessary to assess both sensitivity and pollutant-loading likelihood on a more detailed lake-by-lake basis.

(3) The general physical principles and environmental characteristics of the ALWA that govern the transport of pollutants and the assimilative capability of lakes provide practical guidance for both current recreation management and further studies.

Current recreation management can be effectively guided by some general criteria that are based on discussions included in this report. Lakes often may be protected from pollutants simply by directing intense recreational activity to sites outside the drainage basin of the lake, or to parts of the basin that are remote from the lake. For example, a waste-disposal unit near a lake may only need to be moved a short distance to remove it from the drainage basin of the lake. Drainage-basin boundaries are shown where possible on the accompanying map, but the scale is too small to guide specific decisions of this kind. For site analysis or planning recreational use for an individual lake, drainage basins should be delineated on large-scale topographic maps, with appropriate field-checking.

Recreation in the drainage basin of a lake should be planned according to the following general criteria:

(1) Intense recreational activity should be directed away from areas that have seasonally saturated, poorly drained soils.

(2) Disposal of human wastes in areas of exposed bedrock near lakes should be avoided.

(3) Trail development on steep hillsides near lakes or their inflowing streams should be minimized.

(4) Because of the generally thin alpine soils in the ALWA, and the high rates of precipitation and runoff, privies, or campsites not served by privies, should be located at a conservatively safe distance (greater than 50 meters) from a lake. Where possible, a level site with relatively deep, unsaturated soil should be chosen for these facilities.

(5) Because localized pollution is the most serious potential problem in the ALWA, campsites and privies should be evenly distributed among the suitable locations around a lake; concentration of these facilities should be avoided.

(6) All the above guidelines are especially important for areas adjacent to shallow lakes or embayments that are likely to be poorly flushed during the high use season.

Further studies should include two main efforts: (1) detailed, lake-by-lake evaluations of the distribution and location of basin and lake characteristics that increase susceptibility to water-quality degradation, and (2) ongoing monitoring of water quality. Such a study should be limited, however, to a few selected lakes in high-use areas. Evaluations of these lakes should include identification of wet areas, bedrock areas, and steep slopes in the drainage basin; identification of shallow and poorly flushed embayments; and an assessment of the location of heavily used recreation sites relative to the location of these basin and lake features. These findings would provide guidance for current management and for designing the water-quality monitoring program so that it incorporates the most effective sample-site locations, and the most effective timing and frequency of sample collection.

Lake-water samples should be analyzed for specific conductance (an indicator of dissolved-solids concentration) in the field and, if values are found to be high, samples should be analyzed for pathogens (based on analyses of appropriate indicator bacteria), and possibly chlorides in the laboratory. Specific conductance alone should not be relied upon because high values may occasionally result from natural conditions. All three parameters are generally good indicators of the presence of human wastes, however, and specific conductance can be easily measured with a portable field meter. Samples should also be periodically analyzed for the possible presence of pathogens, regardless of specific conductance values, as these may sometimes be present in the absence of detectable chemical indicators. Phosphorus analyses are not recommended because, based on the findings of this study, nutrient enrichment is not expected to be an important problem in the ALWA.

Such a monitoring program would provide early warning of potentially serious problems, and aid in developing criteria for effective management of recreation. Results of the monitoring could be combined with the lake-by-lake inventories of factors that increase susceptibility to water-quality degradation to test for correlations between the recreation use of specific land types and the presence of water-quality problems.

CONVERSION TABLE

Multiply	By	To obtain
Meters (m)	3.281	feet (ft)
Kilograms (kg)	2.205	pounds (lbs)

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