WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

1994 Statewide Water Quality Assessment Lakes Chapter

Companion Document to Washington State's 305(b) Report

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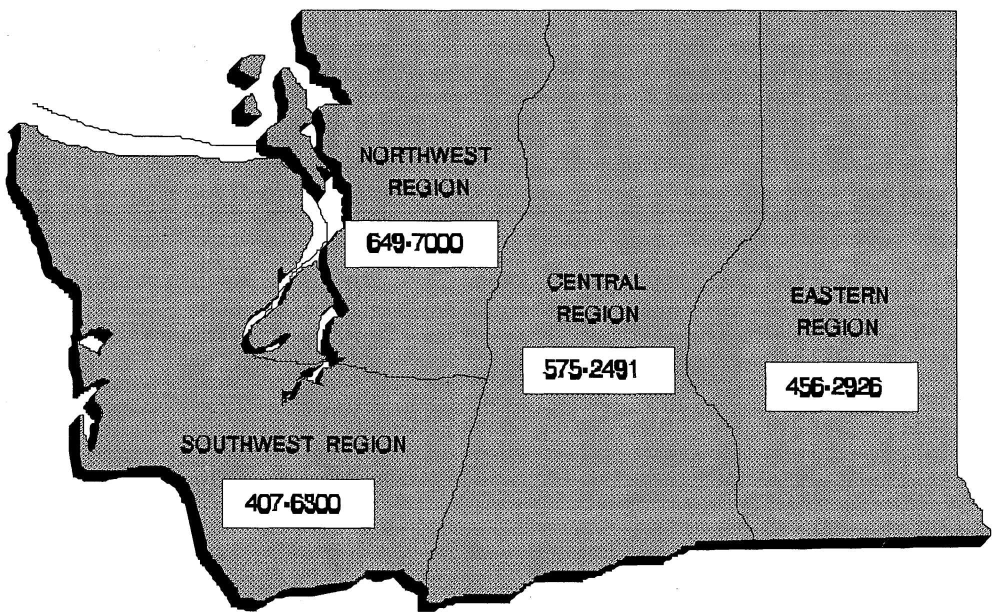

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Companion Document to Washington State's 305(b) Report

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This report has been prepared to partially fulfill the state of Washington's obligations under Sections 305(b) and 314 of the Federal Clean Water Act.

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ACKNOWLEDGEMENTS

The success of Ecology's Lake Water Quality Assessment Program is attributed to the participation of volunteers who have collected data for the program. Without volunteer participation, there would be not be a statewide lake water quality assessment program in Washington. The following people volunteered their time to collect lake data during 1992-1993.

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Sections in this report on lake restoration techniques, acid deposition, lake restoration, and Ecology's aquatic plant management program are updated from Ecology's 1992 Surface Water Quality Assessment 305(b) Report (Ecology, 1992a). These sections were originally written by Steve Butkus and Kim McKee.

This document was reviewed by the following people who provided valuable comments: Ken Dzinbal, Allen Moore, Steve Saunders, and John Glynn. Kim Douglas assisted with word processing of this document.

In 1992 and 1993, Ecology's Lake Water Quality Assessment Program cost approximately $140,000 annually, of which 32% was provided through Federal 314 grants, 27% from a Federal 205(j) grant, and 41% from matching state monies.

EXECUTIVE SUMMARY

This report comprises the "Lake Chapter" of Washington's 1994 305(b) report, and completion of this report partially fulfills Washington's obligations under sections 305 and 314 of the Federal Clean Water Act.

Ecology's Lake Water Quality Assessment (LWQA) Program was established in 1989 to gather water quality information from significant, publicly-owned lakes, to assess the trophic status of monitored lakes, and to educate the public about lake processes and lake protection. Monitoring is conducted by Ecology staff and by a corps of volunteers. Ecology staff collect water samples and profile data in May and August. Water samples are analyzed for total phosphorus, total nitrogen, and chlorophyll *a*. Profiles include temperature, pH, dissolved oxygen, and conductivity. Volunteers measure Secchi depth and surface water temperature at one lake station every two weeks from May through October. During 1992 and 1993, a total of 100 lakes were monitored for Ecology's LWQA program. Of these lakes, 78 were monitored by volunteers and Ecology staff, and 22 were sampled by Ecology staff only. Most lakes sampled only by Ecology staff were selected to support Ecology's watershed approach to water quality management.

There are approximately 1,000 significant, publicly-owned lakes in Washington that could be assessed for Ecology's LWQA Program. In addition to assessments from Ecology's LWQA program, assessments from other sources were included in this report if the information was published and the data were collected within 1989-1993. In all, trophic state assessments for 174 significant, publicly-owned lakes are listed in this report. Of the assessed lakes, 34 were oligotrophic, 80 were oligo-mesotrophic or mesotrophic, 58 were meso-eutrophic or eutrophic, and 2 were hyper-eutrophic. Of 17 lakes which had five consecutive years of Secchi depth data, two lakes had statistically significant improving trends in water clarity, and one lake had a statistically significant decreasing trend in water clarity.

Lakes monitored for Ecology's LWQA Program from 1989 to 1994 were ranked in order of their need for eutrophication management based on the ranks of variables descriptive of susceptibility to eutrophication, water quality, public value, and change in phosphorus concentration. Fifteen lakes were identified as high priority lakes for eutrophication management. An additional 12 lakes with good water quality were identified as high priority lakes for protective management.

As required, this report also includes descriptions of programs which control pollution into lakes, descriptions of lake restoration techniques, and a discussion of acid deposition in Washington lakes. Aquatic plant management in Washington lakes is also discussed.

PURPOSE OF REPORT

This report comprises the Lakes Chapter of Washington's 1994 305(b) report, and is written to partially fulfill Washington's obligations under Sections 305(b) and 314 of the Federal Clean Water Act. This section describes Washington's obligations, and lists the requirements which are fulfilled in this report.

Requirements Fulfilled in this Report

This report is a companion document to Washington's 1994 305(b) report. Included in this report are descriptions and discussions of trophic states, water quality trends, and eutrophication management needs for lakes which were monitored for Ecology's lake water quality assessment program. This report also includes a description of Washington's lake restoration program, aquatic plant management programs, and former acid deposition program, as well as a list of Washington state lakes which have received funding for lake management or restoration.

A list of impaired lakes, their sources of pollution, and extent of impairment, is included in the 1994 305(b) report. The 1994 305(b) report is prepared and published separately from this report. Additional detailed information about Ecology's LWQA Program and specific lakes is published in annual LWQA Program reports (e.g., Rector, 1994).

Requirements for Lake Water Quality Assessments

To be eligible for Federal Clean Lakes Program funding, Washington State must complete the following requirements listed under Section 314(a)(1) of the Federal Clean Water Act (as amended by the Water Quality Act of 1987):

- An identification and classification according to eutrophic condition of all publicly-owned lakes in such state.

- A description of the procedures, processes, and methods (including land use requirements), to control sources of pollution in such lakes.

- A description of methods and procedures, in conjunction with appropriate Federal agencies, to restore the quality of such lakes.

- Methods and procedures to mitigate the harmful effects of high acidity, including innovative methods of neutralizing and restoring buffering capacity of lakes and methods of removing from lakes toxic metals and other toxic substances mobilized by high acidity.

- A list and description of those publicly-owned lakes in such state for which uses are known to be impaired, including those lakes which are known not to meet applicable water quality standards or which require implementation of control programs to maintain compliance with applicable standards and those lakes in which water quality has deteriorated as a result of high acidity that may reasonably be due to acid deposition.

- An assessment of the status and trends of water quality in lakes in such state, including but not limited to, the nature and extent of pollution loading from point and nonpoint sources and the extent to which the use of lakes is impaired as a result of such pollution, particularly with respect to toxic pollution (EPA, 1993).

SCHEDULE FOR LAKE ASSESSMENTS

Although a schedule for assessing significant publicly-owned lakes is required, it is very difficult to develop an assessment schedule because of the large number of lakes in Washington and Ecology's reliance on volunteers to collect data for the lake water quality assessment program. As a result, no formal schedule has been developed for assessing lakes.

Lakes monitored for the program are selected by recruiting a volunteer (through press releases or word of mouth). About five to ten new volunteer-monitored lakes are added to the program each year. Some volunteers leave the program after their 6-month monitoring commitment is completed, and the dropout rate varies each year. An additional 10 to 15 lakes may be sampled by Ecology staff two times per year, as part of the data collection effort for Washington's watershed approach to water quality management.

As a result, each year of monitoring includes a group of lakes which have been monitored by volunteers over a long period (which allows for trend analysis), a group of lakes relatively new to the program whose volunteers may or may not continue over a long period, and a group of lakes monitored by Ecology staff for watershed-based permitting and planning purposes. Only the latter group of lakes are selected primarily because of a lack of data and geographical considerations.

DEFINITION OF LAKES ELIGIBLE FOR WATER QUALITY ASSESSMENTS

A lake must be significant and publicly-owned to be eligible for 305(b) water quality assessments. For the purposes of 305(b) reporting, significant, publicly-owned lakes are defined as:

"those lakes, including impoundments which meet the definition of Lake Class in the State Water Quality Standards (a mean detention time of greater than fifteen days), which have an area of 20 acres or greater within the bounds of their ordinary high water mark, support or have the potential to support the fishable-swimmable goals of the federal Clean Water Act, and are publicly owned or have a public access point; in addition to any other lakes specifically identified as significant by the Department of Ecology (Washington State Department of Ecology, 1992a)"

Wolcott (1973a, 1973b) lists 7,938 lakes, ponds and reservoirs in Washington, but only 15% of these lakes (574 lakes in eastern Washington, and 590 lakes in western Washington; these include high mountain lakes) cover at least 20 acres. In addition, not all lakes that cover at least 20 acres also have public access. The Department of Fish and Wildlife maintains public boat launches at about 400 lakes, but current information on other forms of public access, such as lakeshore parks or beaches, is not available. Because of lack of information on public access other than boat launches, the number of significant, publicly-owned lakes in Washington is not known. However, the actual number will be fewer than 1,164 lakes, which is the number of lakes which cover at least 20 acres. For the purposes of this report, an estimate of 1,000 significant, publicly-owned lakes will be used until more information on public access is available.

HISTORY OF LAKE WATER QUALITY ASSESSMENT PROGRAM

Ecology's lake water quality assessment (LWQA) program was established in 1989 as a two-year pilot project which was funded by a Federal 314 Water Quality Assessment grant. The goal of the program is to assess the current water quality of significant publicly-owned lakes in Washington, and to build a relationship with volunteers to foster data exchange, education, and technical assistance. Specific objectives are to

1) Determine the trophic status of monitored lakes
2) Assess water quality in lakes not evaluated in the last five years and determine the degree to which beneficial uses are supported
3) Promote public awareness of lake processes and lake protection measures and foster a conservation ethic
4) Determine trends once a sufficiently long period of record is established
5) Establish a dataset for analysis and dissemination

Ecology is committed to maintaining the LWQA program as part of its statewide ambient monitoring program. However, the LWQA program changes each year because of annual variations in funding levels. Short-term projects for adding more detailed data to the lake monitoring database are conducted as funding allows. Descriptions of lake water quality assessment activities for each year of the program are described below.

1989 - Volunteers measured Secchi disk transparency and surface water temperature on 48 lakes. Ecology staff conducted a supplemental water quality survey on 25 lakes (Brower and Kendra, 1990), and a toxics survey on fish tissues and sediments from 10 lakes (Johnson and Norton, 1990). Establishment and implementation of the program through 1990 was funded from Federal 314 and 205(j) funds.

1990 - The volunteer monitoring network was expanded to include additional lakes (for a total of 73 lakes), and in May and August volunteers transported Ecology staff to their monitoring sites. Quality assurance of volunteer-collected data was evaluated during these sampling visits, and Ecology staff collected water samples and profile data. A supplementary water quality survey was conducted on 15 lakes (Coots, 1991). There was no toxics component in the 1990 program.

1991 - The program was reduced because of insecure funding. A Federal 314 grant maintained the program through 1991. Volunteers collected data from 41 lakes, and Ecology staff collected one set of water samples and vertical profile data from each of the volunteer-monitored lakes. No supplemental surveys were conducted.

1992 - Additional 314 and 205(j) grants were obtained. In 1992 volunteers collected data from 41 lakes, and two sets of water samples and profile data were collected from these lakes. Monitoring methods used in 1992 are described in Rector (1994). In a separate monitoring effort, five lakes were surveyed for various contaminants in sediment and fish tissue, and five additional lakes were surveyed for copper in sediments (Serdar *et al.*, 1994).

1993 - Volunteers collected data from 65 lakes, and Ecology staff collected two sets of water samples and profile data from most of the volunteer-monitored lakes. Ecology staff collected water samples and profile data from 15 additional lakes, to support the monitoring phase of Ecology's watershed approach to water quality management. In 1993, watershed approach monitoring focused on the Kitsap, Lower Columbia, Upper Yakima, and Mid-Columbia basins.

1994 - The 1994 program is in progress. Volunteers are monitoring approximately 60 lakes. Ecology staff collected water samples and profile data from 73 lakes, which included 6 lakes which were sampled in support of the watershed approach to water quality management, as well as other lakes of interest to Ecology's regional permit writers and inspectors. In 1994, watershed approach monitoring focused on the Eastern Olympics, Cedar/Green, Spokane, and Lower Yakima basins.

Since 1989, a total of 126 lakes have been monitored for Ecology's LWQA Program. Locations of the monitored lakes are shown in Figure 1.

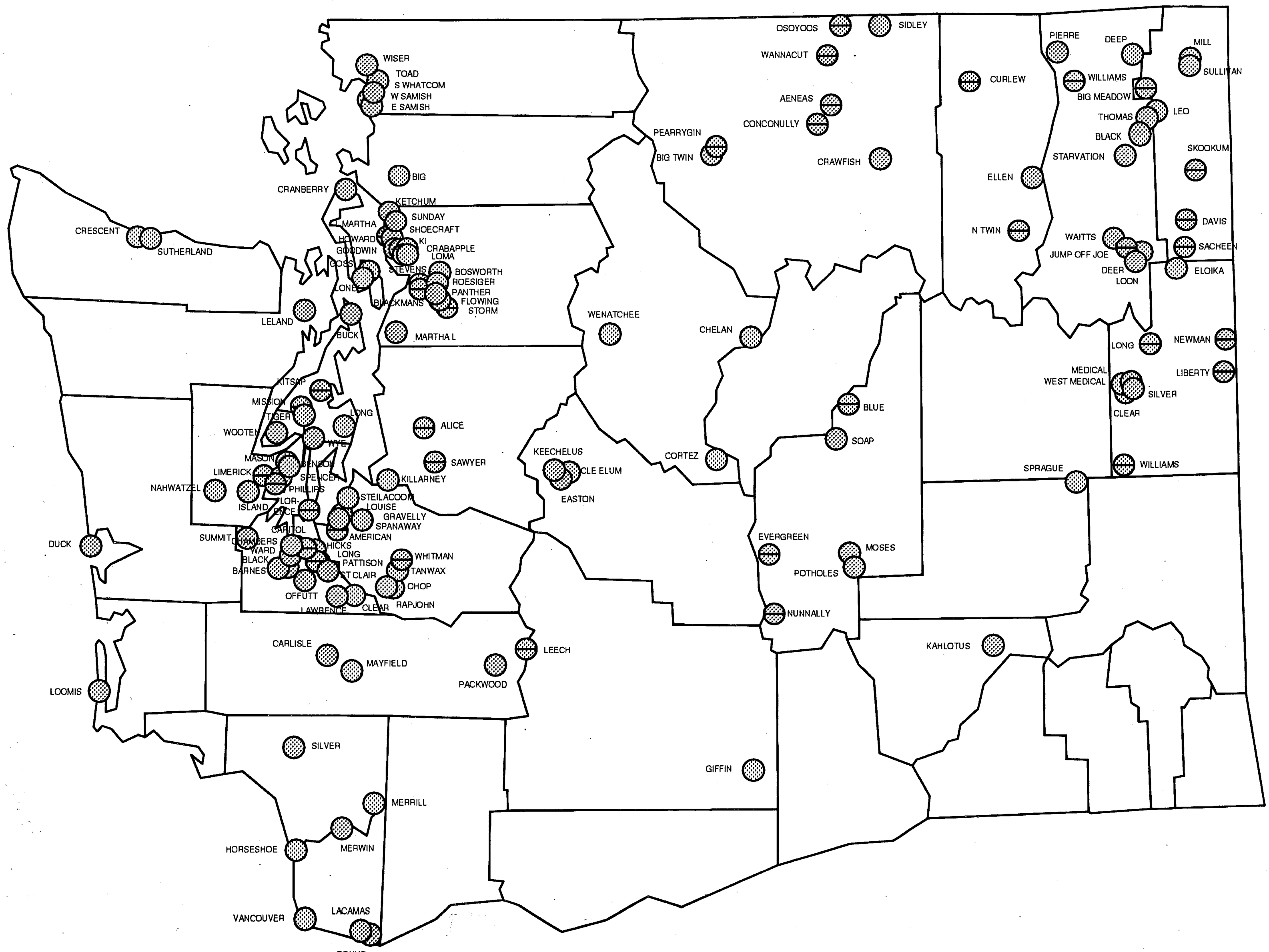

Figure 1. Lakes monitored for Ecology's LWQA Program 1989-1994.

TROPHIC STATE ASSESSMENTS

Trophic state assessments are summarized in Table 1, and assessments for individual lakes are listed in Table 2. These lakes represent approximately 18% of Washington's significant, publicly-owned lakes.

Table 1. Summary of trophic status of significant publicly-owned lakes.

	Number of Lakes
Total	~1,000
Assessed	174
Oligotrophic	34
Oligo-mesotrophic or Mesotrophic	80
Meso-eutrophic or Eutrophic	58
Hypereutrophic	2
Unknown	~826

The numbers of lakes in each trophic state category should not be used to infer the general quality of Washington's lakes, primarily because lakes are not randomly selected for monitoring. The majority of lakes monitored for lake restoration projects have moderate to severe water quality problems. In addition, lakes monitored for Ecology's LWQA program are biased towards lakes with moderate to heavy residential development and recreational use. Geographical distribution of trophic states for assessed lakes (listed in Table 2) is shown in Figure 2.

Sources of monitoring and assessment information used in this report are:

- Ecology's LWQA program (119 lakes),
- METRO (26 assessments used),
- research for state or federally-funded lake restoration projects (18 assessments used), and
- Snohomish County's 1992 citizen lake monitoring program (11 assessments used).

For lakes monitored by more than one source, the most recent assessment was used, or the assessment from the most comprehensive survey was used for lakes which were monitored by two sources during the same year.

Table 2. Trophic state assessments for lakes monitored within 1989-1994.

Lake (County)	Source of Assessment	Most Recent Assessment (yr)
Aeneas (Okanogan)	Ecology LWQA	Mesotrophic (90)
Alice (King)	Ecology LWQA	Mesotrophic (93)
American (Pierce)	Ecology LWQA	Mesotrophic (92)
	KCM, Inc. (1993)	Mesotrophic (92)*
Angle (King)	METRO (1994)	Oligotrophic (93)
Barnes (Thurston)	Ecology LWQA	Eutrophic (90)
Beaver (King)	METRO (1994)	Mesotrophic (93)
Benson (Mason)	Ecology LWQA	Oligotrophic (90)
Big (Skagit)	Ecology LWQA	Eutrophic (90)
Big Meadow (Pend Oreille)	Ecology LWQA	Mesotrophic (93)
Bitter (King)	METRO (1994)	Mesotrophic (93)
Black (Stevens)	Ecology LWQA	Oligo-mesotrophic (93)
Black (Thurston)	Ecology LWQA	Eutrophic (93)
Blackmans (Snohomish)	KCM, Inc. (1994)	Mesotrophic (93)*
	Ecology LWQA	Mesotrophic (93)
Blue (Grant)	Ecology LWQA	Mesotrophic (90)
Boren (King)	METRO (1994)	Mesotrophic (93)
Bosworth (Snohomish)	Ecology LWQA	Oligo-mesotrophic (93)
Buck (Kitsap)	Ecology LWQA	Meso-eutrophic (93)
Carlisle (Lewis)	Moore (1990)	Eutrophic (89)
Cassidy (Snohomish)	Macguire and Williams (1993)	Eutrophic (92)
Chambers (Thurston)	Ecology LWQA	Eutrophic (93)
Chelan (Chelan)	Ecology LWQA	Oligotrophic (90)
Cle Elum (Kittitas)	Ecology LWQA	Oligotrophic (89)
Clear (Pierce)	Tacoma-Pierce County Health Department (1994)	Mesotrophic (92)
Clear (Spokane)	Ecology LWQA	Eutrophic (90)
Clear (Thurston)	Ecology LWQA	Eutrophic (90)
Cochran (Snohomish)	Macguire and Williams (1993)	Mesotrophic (92)
Conconully (Okanogan)	Ecology LWQA	Mesotrophic (93)
Cortez (Grant)	Ecology LWQA	Eutrophic (90)
Cottage (King)	METRO (1994)	Eutrophic (93)
Crabapple (Snohomish)	Macguire and Williams (1993)	Oligo-mesotrophic (92)
Cranberry (Island)	Ecology LWQA	Eutrophic (93)
Crawfish (Okanogan)	Ecology LWQA	Oligo-mesotrophic (91)
Deep (King)	METRO (1994)	Mesotrophic (93)
Deep (Stevens)	Ecology LWQA	Oligo-mesotrophic (93)

* This trophic state was used for the summary in Table 1.

Table 2. Continued.

Lake (County)	Source of Assessment	Most Recent Assessment (yr)
Deer (Stevens)	Soltero *et al.* (1991)	Oligo-mesotrophic (90)
	Ecology LWQA	Oligotrophic (93)*
Desire (King)	METRO (1994)	Eutrophic (93)
Dolloff (King)	METRO (1990)	Eutrophic (89)
Duck (Grays Harbor)	KCM, Inc. (1994)	Hyper-eutrophic (92)*
	Ecology LWQA	Eutrophic (90)
Easton (Kittitas)	Ecology LWQA	Oligotrophic (93)
Echo (Snohomish)	Macguire and Williams (1993)	Meso-eutrophic (92)
Ellen (Ferry)	Ecology LWQA	Oligotrophic (93)
Eloika (Spokane)	Ecology LWQA	Meso-eutrophic (93)
Evergreen (Grant)	Ecology LWQA	Mesotrophic (93)
Fenwick (King)	METRO (1994)	Mesotrophic (93)
Fivemile (King)	METRO (1990)	Eutrophic (89)
Florence (Pierce)	Ecology LWQA	Mesotrophic (93)
Flowing (Snohomish)	Macguire and Williams (1993)	Oligo-mesotrophic (92)
	Ecology LWQA	Oligo-mesotrophic (93)*
Geneva (King)	METRO (1994)	Mesotrophic (93)
Giffin (Yakima)	Moore *et al.* (1992)	Eutrophic (91)
Goodwin (Snohomish)	Macguire and Williams (1993)	Oligo-mesotrophic (92)*
	Ecology LWQA	Oligotrophic (90)
Goss (Island)	Ecology LWQA	Oligotrophic (93)
Gravelly (Pierce)	Ecology LWQA	Oligo-mesotrophic (93)
Green (King)	URS Consultant (1990)	Eutrophic (no date)
Hicks (King)	Gendron and Pedersen (1987)	Eutrophic (86)
Hicks (Thurston)	Ecology LWQA	Mesotrophic (93)
Horseshoe (Cowlitz)	Welch *et al.* (1992)	Eutrophic (92)*
	Ecology LWQA	Eutrophic (92)
Howard (Snohomish)	Ecology LWQA	Oligo-mesotrophic (93)
Island (Mason)	Ecology LWQA	Oligotrophic (93)
Jump Off Joe (Stevens)	Ecology LWQA	Mesotrophic (93)
Kahlotus (Franklin)	Ecology LWQA	Eutrophic (92)
Keechelus (Kittitas)	Ecology LWQA	Oligotrophic (93)
Ketchum (Snohomish)	Ecology LWQA	Hyper-eutrophic (93)
Ki (Snohomish)	Macguire and Williams (1993)	Oligotrophic (92)
	Ecology LWQA	Oligotrophic (93)*
Killarney (King)	METRO (1994)	Mesotrophic (93)
	Ecology LWQA	Eutrophic (93)*
Kitsap (Kitsap)	Ecology LWQA	Mesotrophic (93)

* This trophic state was used for the summary in Table 1.

Table 2. Continued.

Lake (County)	Source of Assessment	Most Recent Assessment (yr)
Lacamas (Clark)	Ecology LWQA	Eutrophic (93)
Larsen (King)	KCM, Inc. (1993)	Eutrophic (92)
Lawrence (Thurston)	KCM, Inc. (1991)	Eutrophic (90)
Leech (Yakima)	Ecology LWQA	Mesotrophic (93)
Leland (Jefferson)	Ecology LWQA	Eutrophic (93)
Leo (Pend Oreille)	Ecology LWQA	Oligo-mesotrophic (93)
Liberty (Spokane)	Ecology LWQA	Mesotrophic (90)
Limerick (Mason)	Ecology LWQA	Mesotrophic (93)
Loma (Snohomish)	Macguire and Williams (1993)	Meso-eutrophic (92)
	Ecology LWQA	Eutrophic (93)
Lone (Island)	Ecology LWQA	Meso-eutrophic (93)
Long (Kitsap)	Ecology LWQA	Eutrophic (93)
Long (Spokane)	Soltero *et al.* (1992)	Mestrophic (92)
	Ecology LWQA	Meso-eutrophic (90)
Long (Thurston)	Ecology LWQA	Meso-eutrophic (93)
Loomis (Pacific)	Coots (1991)	Eutrophic (90)
Loon (Stevens)	Ecology LWQA	Oligotrophic (89)
Lost (Mason)	Ecology LWQA	Oligotrophic (93)
Lost (Snohomish)	Macguire and Williams (1993)	Meso-eutrophic (92)
Louise (Pierce)	Ecology LWQA	Oligo-mesotrophic (93)
Lucerne (King)	METRO (1994)	Oligotrophic (93)
Lake Martha (Snohomish)	Ecology LWQA	Mesotrophic (93)
Martha Lake (Snohomish)	Entranco (1991)	Oligo-mesotrophic (90)
	Ecology LWQA	Oligo-mesotrophic (93)*
Mason (Mason)	Ecology LWQA	Oligotrophic (93)
Mayfield (Lewis)	Ecology LWQA	Oligo-mesotrophic (93)
Medical (Spokane)	Soltero *et al.* (1989)	Eutrophic (88)
Meridian (King)	METRO (1994)	Oligotrophic (93)
Merrill (Cowlitz)	Ecology LWQA	Oligotrophic (90)
Merwin (Clark)	Ecology LWQA	Oligotrophic (93)
Mill (Pend Oreille)	Ecology LWQA	Oligotrophic (91)
Mission (Kitsap)	Ecology LWQA	Mesotrophic (93)
Morton (King)	METRO (1994)	Mesotrophic (93)
Moses (Grant)	Ecology LWQA	Eutrophic (93)
Nahwatzel (Mason)	Ecology LWQA	Oligotrophic (93)
Newman (Spokane)	Ecology LWQA	Mesotrophic (90)
North (King)	METRO (1990)	Mesotrophic (89)
Nunnally (Grant)	Coots (1991)	Mesotrophic (90)

* This trophic state was used for the summary in Table 1.

Table 2. Continued.

Lake (County)	Source of Assessment	Most Recent Assessment (yr)
Offutt (Thurston)	Ecology LWQA	Eutrophic (93)
Ohop (Pierce)	Ecology LWQA	Eutrophic (93)
Osoyoos (Okanogan)	Ecology LWQA	Mesotrophic (93)
Packwood (Lewis)	Brower and Kendra (1990)	Oligotrophic (89)
Panther (King)	METRO (1994)	Mesotrophic (93)
Panther (Snohomish)	Ecology LWQA	Oligotrophic (93)
N Pattison (Thurston)	Ecology LWQA	Mesotrophic (92)
S Pattison (Thurston)	Ecology LWQA	Meso-eutrophic (93)
Pearrygin (Okanogan)	Ecology LWQA	Mesotrophic (93)
Phantom (King)	KCM, Inc. (1993)	Mesotrophic (92)
Phillips (Mason)	Ecology LWQA	Mesotrophic (93)
Pierre (Stevens)	Ecology LWQA	Oligo-mesotrophic (93)
Pine (King)	METRO (1994)	Mesotrophic (93)
Pipe (King)	METRO (1994)	Oligotrophic (93)
Potholes (Grant)	Ecology LWQA	Eutrophic (93)
Rapjohn (Pierce)	Ecology LWQA	Meso-eutrophic (93)
Roesiger (Snohomish)	KCM, Inc (1989)	Mesotrophic (89)
	Ecology LWQA	Oligo-mesotrophic (93)*
Round (Clark)	Ecology LWQA	Eutrophic (90)
Sacheen (Pend Oreille)	Kennedy Engineers (1991)	Meso-eutrophic (91)*
	Ecology LWQA	Mesotrophic (90)
E Samish (Whatcom)	Ecology LWQA	Oligo-mesotrophic (93)
W Samish	Ecology LWQA	Oligo-mesotrophic (93)
Sammamish (King)	METRO (no date)	Mesotrophic (90)
Sawyer (King)	METRO (1994)	Mesotrophic (93)
	Ecology LWQA	Mesotrophic (93)*
Serene (Snohomish)	Macguire and Williams (1993)	Oligo-mesotrophic (92)
Shadow (King)	METRO (1994)	Mesotrophic (93)
Shady (King)	METRO (1994)	Oligotrophic (93)
Shoecraft (Snohomish)	Macguire and Williams (1993)	Oligo-mesotrophic (92)*
	Ecology LWQA	Oligo-mesotrophic (90)
Sidley (Okanogan)	Coots (1991)	Meso-eutrophic (91)
Silver (Cowlitz)	Moore (1990)	Eutrophic
Silver (Spokane)	Ecology LWQA	Meso-eutrophic (93)
Skookum (Pend Oreille)	Ecology LWQA	Mesotrophic (93)
Snake (Pierce)	Entraco (1989)	Eutrophic (87)
Spanaway (Pierce)	Ecology LWQA	Meso-eutrophic (93)
Spencer (Mason)	Ecology LWQA	Oligo-mesotrophic (93)

* This trophic state was used for the summary in Table 1.

Table 2. Continued.

Lake (County)	Source of Assessment	Most Recent Assessment (yr)
Sprague (Adams)	Brower and Kendra (1989)	Eutrophic (89)
Spring (King)	METRO (1994)	Mesotrophic (93)
Star (King)	METRO (1994)	Oligotrophic (93)
Starvation (Stevens)	Ecology LWQA	Eutrophic (90)
St. Clair (Thurston)	Ecology LWQA	Meso-eutrophic (93)
Steel (King)	METRO (1990)	Mesotrophic (89)
Steilacoom (Pierce)	Ecology LWQA	Eutrophic (90)
Stevens (Snohomish)	Ecology LWQA	Oligo-mesotrophic (93)
Storm (Snohomish)	Ecology LWQA	Mesotrophic (90)
Sullivan (Pend Oreille)	Ecology LWQA	Oligotrophic (93)
Summit (Thurston)	Ecology LWQA	Oligotrophic (93)
Sunday (Snohomish)	Ecology LWQA	Eutrophic (93)
Sutherland (Clallam)	Brower and Kendra (1990)	Oligotrophic (89)
Swartz (Snohomish)	Macguire and Williams (1993)	Oligo-mesotrophic (92)
Tanwax (Pierce)	Ecology LWQA	Meso-eutrophic (92)
Thomas (Stevens)	Ecology LWQA	Oligo-mesotrophic (93)
Tiger (Kitsap/Mason)	Ecology LWQA	Oligotrophic (93)
Twelve (King)	Welch *et al.* (1993)	Oligotrophic (93)
N Twin (Ferry)	Ecology LWQA	Mesotrophic (90)
Twin, Big (Okanogan)	Ecology LWQA	Oligo-mesotrophic (93)
Vancouver (Clark)	Ecology LWQA	Eutrophic (90)
Waitts (Stevens)	Ecology LWQA	Oligo-mesotrophic (93)
Wannacut (Okanogan)	Ecology LWQA	Mesotrophic (90)
Wapato (Pierce)	Entranco Engineers, Inc. (1986)	Eutrophic (85)
Ward (Thurston)	Ecology LWQA	Oligo-mesotrophic (93)
Washington (King)	METRO (no date)	Mesotrophic (90)
Wenatchee (Chelan)	Ecology LWQA	Oligotrophic (93)
West Medical (Spokane)	Ecology LWQA	Eutrophic (90)
S Whatcom (Whatcom)	Ecology LWQA	Oligotrophic (91)
Whitman (Pierce)	Ecology LWQA	Mesotrophic (93)
Wilderness (King)	METRO (1994)	Mesotrophic (93)
Williams (Spokane)	Ecology LWQA	Mesotrophic (93)
Williams (Stevens)	Ecology LWQA	Mesotrophic (93)
Wiser (Whatcom)	Ecology LWQA	Eutrophic (93)
Wooten (Mason)	Ecology LWQA	Oligotrophic (93)
Wye (Kitsap)	Ecology LWQA	Meso-eutrophic (93)

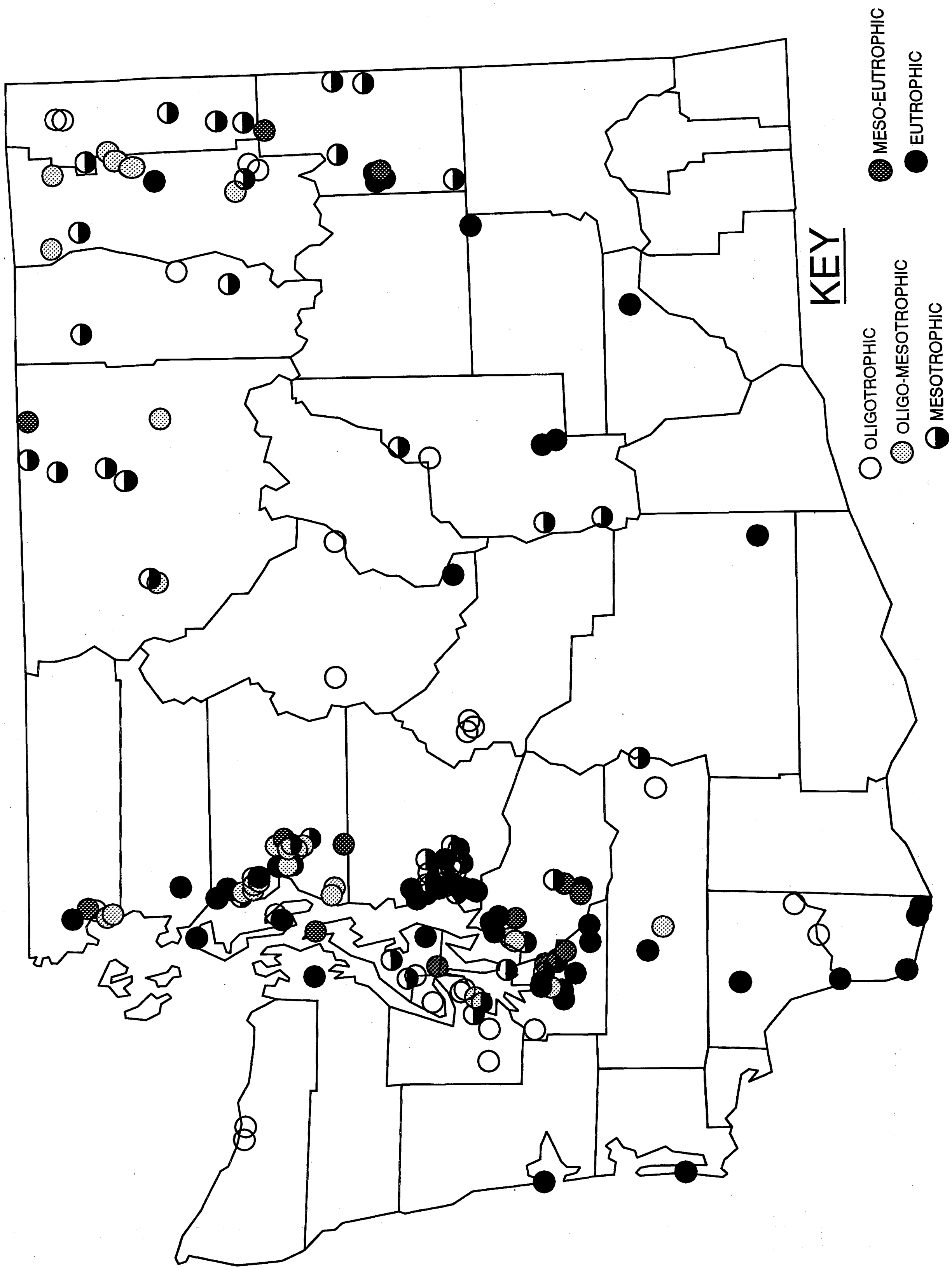

Figure 2. Geographical distribution of trophic states for assessed lakes.

Assessments by Ecology's Lake Water Quality Assessment Program

Trophic states are used to describe the supply of organic matter that is produced in a lake, or introduced from the watershed, and the effects of organic matter on lake water quality (Wetzel, 1983). The three major trophic state categories are oligotrophy, mesotrophy, and eutrophy. Oligotrophy refers to low amounts of organic matter, mesotrophy refers to moderate amounts of organic matter, and eutrophy refers to high amounts of organic matter. Variables which may be monitored to assess a lake's trophic state include nutrients (in-lake concentrations and loading), Secchi depth, dissolved oxygen (reported as concentrations, percent saturation, or anoxic factors), color, turbidity, suspended solids, macrophyte coverage and diversity, quantitative or qualitative expressions of primary productivity, and algal standing crop.

It is not practical, given current funding, for a statewide assessment program to routinely measure all the above parameters in all monitored lakes. As a result, parameters are chosen which are cost-effective and provide useful information about trophic status. Parameters used by Ecology to assess Washington lakes are Secchi depth, total phosphorus, total nitrogen, chlorophyll *a,* vertical profiles of temperature, dissolved oxygen, pH, conductivity, and qualitative evaluations of algae and macrophytes.

To establish cutoff points between trophic states, and to simplify comparisons among and between lakes based on trophic state parameters, the trophic status of monitored lakes is estimated using Carlson's (1977) trophic state indices (TSI; Table 3) for Secchi depth (TSI_{SD}), total phosphorus (TSI_{TP}), and chlorophyll *a* (TSI_{CHL}), tempered with some professional judgment.

The TSIs convert raw data to a scale from 1 to 100. The higher the TSI, the more eutrophic the value. In general, TSIs of 40 or less indicate oligotrophy, TSIs between 40 and 50 indicate mesotrophy, and TSIs greater than 50 indicate eutrophy (Carlson, 1977; 1979). Ranges of water clarity, total phosphorus, and chlorophyll values associated with each trophic state are listed below.

Table 3. Trophic states and ranges of values for trophic state parameters.

Trophic State	Trophic State Index	Secchi Depth (m)	Total Phosphorus (μg/L)	Chlorophyll *a* (μg/L)
Oligotrophic	1-40	> 4	0-12	0-2.6
Mesotrophic	41-50	2 - 4	12-24	2.6 - 6.4
Eutrophic	51 +	< 2	24 +	6.4 +

Information source: Carlson (1977)

Not all of Ecology's trophic state classifications were based on TSI alone. When there were discrepancies between TSI_{SD}, TSI_{TP}, and/or TSI_{Chl}, when water clarity was affected by algicide use or natural water color, or when localized water quality problems were not apparent from data which were collected at the deepest open-water site, the trophic state estimation was tempered using profile data, information on macrophyte species and surface coverage, and field notes (such as noting the smell of hydrogen sulfide in hypolimnion samples). Because there is generally a lot of natural and analytical variability in chlorophyll *a* results, the TSI_{TP} usually took precedence over the TSI_{CHL}.

The basis for each trophic state assessment is discussed in the individual data summaries written for each lake. Individual summaries for lakes monitored in 1992 are compiled in Lake Water Quality Assessment Program, 1991-1992 (Rector, 1994); 1993 data will be compiled in Lake Water Quality Assessment Program, 1993 (Rector, in prep.).

Assessments From Sources Other than Ecology's LWQA Program

Lake assessments from sources outside of Ecology's program are also listed in Table 2. Other sources of lake assessments include consultant reports prepared for Ecology's lake restoration program, reports from the Small Lakes Program coordinated by the former Municipality of Metropolitan Seattle (METRO; now part of the King County Department of Metropolitan Services), and reports from the Washington Water Research Center, Eastern Washington University, Western Washington University, and University of Washington. Trophic status information was also used from the citizen lake monitoring program that is coordinated by Snohomish County Public Works Department. Although King County Surface Water Management also has a volunteer lake monitoring program, and Thurston County Environmental Health is involved in lake monitoring, published data and data interpretation from these program were not available when this publication was written.

Monitoring methods, trophic state assessment methods, and data quality requirements vary between sources. Despite the occasionally subjective nature of trophic state assessments, different surveyors usually arrived at similar conclusions. For example, of the 16 lakes that were monitored by Ecology as well as by another source within the last five years, assessments were very similar for 15 lakes (Table 2). The minor differences between trophic state assessments (e.g., oligotrophic versus oligo-mesotrophic) were mostly for assessments that occurred during different years. Only one lake, Lake Killarney, was assigned different trophic states by different surveyors for data collected during the same year. This can probably be attributed to differences in data interpretation methods; Ecology uses mean values during the growing season to calculate trophic state indices based on Carlson (1977), whereas METRO uses mean values for the whole year and compares several different trophic state indices.

WATER QUALITY TRENDS

A long period of record (generally, at least five years) is needed for meaningful statistical trend analysis. Prior to the fifth year of Ecology's lake water quality assessment program, Ecology made subjective trend evaluations--basically, comparisons of trophic states between years. In 1993, there were sufficient Secchi depth data available to statistically evaluate trends in water clarity at 17 lakes.

The following sections discuss the statistical evaluation of Secchi depth data, as well as a subjective comparison of trophic states between years.

Statistical Analysis of Secchi Depth Data

Seventeen lakes were monitored by volunteers every year from 1989 to 1993. Secchi depth data from these lakes were analyzed using the seasonal Kendall test for trend. Slopes were also calculated to determine annual changes in Secchi depths from 1989 to 1993 (Table 4). WQHYDRO (Aroner, 1990) was used for data analysis.

Table 4. Seasonal slopes, percent annual change of Secchi depths, and probability of trend for lakes monitored by volunteers during 1989-1993.

Lake	Seasonal Slope*	Average Percent Annual Change	Probability
Big Meadow (Pend Oreille)	1.2691	12.9	0.0001***
Black (Stevens)	0.3083	1.8	0.6663
Curlew (Ferry)	0.1667	0.9	0.6427
Eloika (Spokane)	0.3056	4.1	0.2418
Killarney (King)	-0.2475	3.1	0.4395
Lacamas (Clark)	0.2486	4.3	0.7861
Long (Thurston)	-0.4982	6.2	0.1824**
Mason (Mason)	-0.1241	0.5	0.8197
Osoyoos (Okanogan)	0.1673	1.9	0.7105
Phillips (Mason)	-0.4762	3.8	0.4884
E Samish (Whatcom)	-0.2492	1.9	0.4785
W Samish (Whatcom)	-0.0418	1.3	0.8166
St. Clair (Thurston)	-0.0313	0.4	1.000
Thomas (Stevens)	0.4786	3.2	0.1378**
Wenatchee (Chelan)	-0.0376	0.2	0.8844
Williams (Spokane)	-0.7921	6.7	0.2998
Wooten (Mason)	-0.5192	2.4	0.3631

* Positive slope values (using Sen's slope estimator, Aroner, 1990) indicate increasing Secchi depths, and negative values indicate decreasing Secchi depths.

** Significant at 80% level

*** Significant at 99% level

Secchi depths increased at seven lakes over the five year monitoring period, suggesting an increase in water clarity (Table 4). However, only three lakes exhibited statistically significant trends. Big Meadow Lake and Lake Thomas exhibited statistically significant improving trends in water clarity from 1989 to 1993 (significant at the 99% and 80% levels, respectively). Long Lake in Thurston County exhibited a statistically significant decreasing trend in water clarity (significant at the 80% level).

Because there are gaps in the period of record for total phosphorus data (there are no total phosphorus data for the program in 1991), and because water samples are collected from lakes only two times per year, trend analysis of nutrient data will not have sufficient power to be meaningful until 1996 at the earliest.

Subjective Comparisons of Trophic States

Changes in assigned trophic states between two or three years do not necessarily reflect a long term change in a lake's water quality. Trophic state assignments can change with changes in monitoring methods and data interpretation methods, as well as changes in the nutrient budget, water budget, and weather conditions. For example, many lakes assessed by Ecology in 1989 were given different assessments after the 1990 monitoring season. This resulted because assessments in 1990 were based on Secchi depth, nutrient, chlorophyll *a*, and profile data, whereas most of the 1989 assessments were based on Secchi depth data alone.

From 1990 to 1991, trophic state assessments changed for two lakes (out of 28 assessed during both years). One of these lakes was Big Meadow Lake (see discussion above on statistical trends), and the other, Lake Wooten, had a severe blue-green algae bloom in 1990 that affected its trophic state assessment. Both lakes were less eutrophic in 1991.

From 1991 to 1992, trophic state assessments changed for five lakes (out of 38 lakes assessed during both years). All five lakes were less eutrophic in 1992 than in 1991. Two of the lakes, Deer Lake in Stevens County, and Lake Eloika in Spokane County, implemented lake protection projects during these years. The remaining three lakes, Lake Alice, Black Lake in Stevens County, and Lake Tanwax, exhibited characteristics of more than one trophic state, and the assessments were refined based on professional judgment.

Although there were no changes in the methods used to collect or analyze samples for Ecology's 1993 monitoring program, 10 lakes were more eutrophic in 1993 than they appeared in 1992, and only one lake was less eutrophic in 1993 than in 1992. All 11 lakes are located in the greater Puget Sound area. Whereas it is tempting to suggest that the 10 lakes were more eutrophic because of development and other land uses in the Puget Sound area, lakeshore development has been increasing throughout the state and not just around Puget Sound. Also, in 1992 all these lakes had values for trophic state parameters that were borderline between two trophic states, so even small changes in 1993 values could result in a change in the trophic state assessment. Most likely, changes in water budget or changes in weather conditions affected the trophic states of these lakes during 1993.

Climatic Variations

Yearly climatic variations may affect trophic states between years. Incident sunlight and ambient air temperature will affect algal photosynthesis, and precipitation will affect the availability of nutrients for algal uptake by affecting runoff and the lake's flushing rate. In recent years, low rainfall has raised many concerns about long-term effects on lake levels.

Air temperatures (annual means of daily maximum air temperatures) at Seattle and Spokane were higher in 1992 in comparison to mean values for the period of record at each station (Table 5). In Seattle, the highest mean daily maximum and mean daily minimum air temperatures for the 60-year period of record occurred during 1992. Unfortunately, climate data are only available through June 1993, so annual mean values were not available for comparisons.

Warmer air temperatures in 1991 and 1992 might suggest that water temperatures would also be warmer in the monitored lakes. Using paired t-tests of mean surface water temperatures (from volunteer-collected data), there was no significant difference in mean surface water temperature for all monitored lakes between either 1991 and 1992, or between 1992 and 1993 ($\alpha=0.05$). Using western Washington lake data only, t-tests indicated a significant difference in mean surface water temperatures for lakes monitored during 1991 and 1992 ($\alpha=0.05$; $n=20$), but there was not a significant difference in mean surface water temperatures for western Washington lakes monitored during 1992 and 1993 ($\alpha=0.05$; $n=23$). There was no significant difference in mean surface water temperatures between years in the monitored eastern Washington lakes.

Precipitation and snowfall in Seattle during 1992 were lower than the average annual values for the period of record (Table 5). In Spokane, total precipitation in 1992 was lower than the annual averages for the period of record, but snowfall in 1992 was above the average for the period of record. Early summer in Seattle was wetter during 1993 than in 1992, but climate data are not available after June 1993 and annual averages could not be used for comparisons.

Evaluating the possible effects on lakes from changes in precipitation and snowfall is difficult, not only because of the varying hydrogeologies of the monitored lakes and their watersheds, but because lake level at many of the monitored lakes is affected by control weirs, beaver dams, or blocked outlets. Another problem in evaluating lake level is that not all volunteers measured lake level each year (or if they did, not all measured lake level on a regular basis, or consistently used the same marker to measure level).

Hallock and Hopkins (1994) showed that instantaneous discharge (discharge measured during monthly sampling) at Ecology's ambient river and stream monitoring stations was unusually low in western Washington during all months in 1993. Instantaneous discharge measured monthly at eastern Washington river and stream stations in 1993 was generally near normal to below normal. Unfortunately, a similar analysis of discharge data for 1992 was not readily available.

Table 5. Air temperature, precipitation, and snowfall at Seattle and Spokane Airport weather stations.

Parameter	Period of Record*	1989	1990	1991	1992	1993
Seattle Tacoma Airport						
Temp., (Min.) (F°)	44	45	45	45	46	
Temp., (Max.) (F°)	59	60	60	61	63	
Temp., (Max.) (F°) May-June					73.4	68.6
Snow (in.)	12.25	14.2	13.6	2.9	6.7	
Precip. (in.)	38.01	34.69	44.75	35.42	32.78	
Precip. (in.) January-June					17.97	19.12
Precip. (in.) May-June					1.14	5.34
Spokane Airport						
Temp., (Min.) (F°)	38	37	38	37	39	
Temp., (Max.) (F°)	58	57	58	58	60	
Temp., (Max.) (F°) May-June					77.9	72.2
Snow (in.)	42.05	45.2	49.9	34.8	61.7	
Precip. (in.)	16.01	14.71	19.61	14.45	14.52	
Precip. (in.) January-June					7.13	6.75
Precip. (in.) May-June					1.84	1.79

Source of Data: Hydrosphere Data Products, Inc. (1993)

* Period of Record for Seattle Station: 1931 to June 1993
Period of Record for Spokane Station: 1889 to June 1993 (temperature and precipitation)
1892 June 1993 (snowfall)

Despite the discussions above, volunteer comments and recorded lake levels did suggest that, in general, lake levels were low in 1992 (see next section). The most extreme example is Lake Kahlotus in Franklin County, which completely dried up between May and August 1992 and has not yet recharged. Lake Kahlotus is fed primarily by irrigation return and runoff, and was reported to have also dried up in the 1970s (A. Moore, Ecology, pers. comm.)

Perceptions of Water Quality Problems

Each year, volunteers who participate in Ecology's LWQA program complete a questionnaire on lake and watershed uses and problems. Most of the questions in the survey remain the same each year. This annual survey was originally intended to provide a record of water quality problems for evaluating lakes individually. However, when the survey results from each year are compiled (Table 6), it is apparent that there are several similarities in the annual changes in problems perceived by the volunteers. Overall, the general perception of lake quality was better in 1992 than in 1993.

Table 6. Volunteer perceptions of water quality problems, from 1992 and 1993 surveys.

	Volunteer Responses	
Survey Year	1992	1993
No water quality problems during year	12%	6%
More algae and plants than in previous year	10%	18%
Problems Ranked Among Top Four for each lake*		
algae	53%	40%
macrophytes	50%	48%
low water level	26%	13%
swimmers itch	21%	9%
decaying plants	9%	20%
degraded aesthetics	9%	15%
suspended sediments	6%	17%
odors	6%	11%
erosion	6%	11%
undesirable fish species	3%	9%
Number of volunteers who completed survey	34	54

* Totals are greater than 100% for each year, because each volunteer ranked several problems. Only the most apparent problems, those ranked from 1-4, are included in this summary.

Changes in the volunteers' perceptions of lake level were particularly different between 1992 and 1993. Low water level was perceived to be a major problem at more lakes in 1992 than in 1993 (Table 6) . In addition, 34 volunteers indicated that low water level was not a problem at their lake in 1993 (64% of those who completed questionnaires); also, six volunteers (11%) noted that water levels were noticeably higher in 1993 than in 1992.

The volunteers' perceptions of lake water quality each year, and annual changes in their perceptions of water quality problems, may be related to annual changes in weather, as opposed to long term changes in water quality. The swimmers itch problems observed in 1992 (Table 6) occurred during a warm, dry summer that was favorable for swimming. In 1993, the erosion and suspended sediment problems observed by the volunteers were probably related to a cloudy monitoring season that had occasional storms.

PRIORITY RANKING OF LAKES BY NEED FOR EUTROPHICATION MANAGEMENT

One of the uses of data collected by the Washington State Department of Ecology's Lake Water Quality Assessment (LWQA) Program is to prioritize lakes for protection/restoration management. Prioritization of lakes is a condition of the LWQA grant and is intended to address EPA's Clean Lakes Program objective of providing "maximum recreational and environmental benefits to as many people as possible" (EPA 1988). When identifying which lakes most urgently need management, EPA urges states to consider not only lake water quality but also such criteria as public access, the number of people that will benefit, and the degree to which high-quality lakes may be threatened in the future. These factors and others are incorporated into the ranking scheme presented here.

This ranking is not used directly by Ecology to fund lake restoration or protection projects. Ecology does not use a prioritized list to fund high-priority projects directly because grant requests are initiated at the local level. However, this ranking may be used by local governments to identify potential candidates for grant applications, and as supporting documentation in applications for lake management grants.

Lakes are prioritized according to need for eutrophication management. Other reasons for managing lakes (for example, to control lake level, or to reduce bacterial contamination) are not addressed. Also, lakes are prioritized without consideration for either the source of eutrophication (natural or cultural), or the likelihood of successful management. Careful consideration of these factors is critical to a successful restoration project.

Methods Used by Other States

Adler and Smolen (1989) discuss the prioritization methods used by six representative states. Five of the states assign points and calculate a numerical score based on several criteria. For example, Ohio assigns five points to lakes between 5 and 10 m deep. One state, New Mexico, uses a decision tree where the flow is guided by answers to yes/no questions.

The basic approach differs between states. Some states prioritize all lakes for which data are available. Others prioritize only those lakes where a grant application has been made and matching funds are available. New York and Colorado prioritize waterbodies based on impairment of beneficial uses. Illinois and Ohio assess water quality using Carlson's Trophic State Index (Carlson, 1977). Rhode Island assesses threat to waterbodies based on watershed measures (such as change in the number of building permits issued).

All six states include an evaluation of public value in their ranking. Variables such as public access, recreational facilities, proximity to metropolitan areas, and uniqueness of the waterbody were considered. Some states included a subjective assessment of likelihood of success, though this was not always a part of the prioritization process. Other states used morphometric measurements to assess the potential for restoration. For example, a small watershed was considered more readily managed than a large watershed by one state.

Washington's Prioritization Method

We elected to develop a ranking method that prioritizes lakes based on the ranks of variables which, in theory, have a bearing on management decisions. Ranking lakes rather than assigning points (i.e., x points when a variable is between y and z) avoids subjective determination of boundary values (y and z). One disadvantage of ranking is that the rank for a given lake cannot be determined independently; all lakes must be evaluated together.

Variables were grouped into four categories: Susceptibility to Eutrophication, Current Water Quality, Public Value, and Trend. We used a Delphi survey (conducted in 1992) to refine the variable list and determine the relative importance of each variable and category based on their importance in making lake management decisions.

The Delphi Survey

The Delphi technique, as used here, consisted of a survey sent to local resource managers and aquatic scientists, followed by a statistical summary and analysis, followed by interviews with the Delphi panel (individuals responding to the survey). This three-step process was repeated three times, with each survey refining the questions in previous surveys. The initial survey consisted of a list of 14 variables for which data were readily available. Participants were asked to compare the relative importance of pairs of variables, as well as to suggest additional variables. Survey responses were compiled and weighting factors determined with a computer software program developed by Horner *et al.* (1986) using a method proposed by Saaty (1977).

The Delphi survey resulted in dropping two of the originally proposed variables (lake volume and percent macrophyte coverage) and adding three additional variables. The weighting factors determined for each category indicated susceptibility to eutrophication was the most important factor in prioritizing lakes according to need for water quality management (Table 7). Current water quality, public value, and trend in trophic state, in that order, were considered to be of lesser importance. Trend in trophic state was considered less important

Table 7. Variables and weighting factors used in assigning lake management priorities to monitored lakes.

SUSCEPTIBILITY TO EUTROPHICATION (Category weight: 0.34)

Weight	Variable
0.18	Flushing index (1, 2, or 3 for river, creek, or intermittent inlets, respectively)[1,2]
0.18	Population density (adjusted for sewered homes by considering two sewered homes equivalent to one un-sewered home)[1]
0.17	*Relative depth (from Wetzel, 1983)[3]
0.17	Watershed area/lake area[3]
0.17	*Mean depth[2]
0.13	Shoreline development index (high index = windy shore)[3]

CURRENT WATER QUALITY (Category weight: 0.26)

Weight	Variable
0.46	Subjective assessment[1,4]
0.34	Total phosphorus (average concentration of all spring LWQA samples)[1]
0.20	Clean Water Act Goals (1 point for each goal not met)[5]

PUBLIC VALUE OF THE LAKE (Category weight: 0.20)

Weight	Variable
0.32	Use as drinking water source (yes/no)[1]
0.20	Number of lakeshore homes[1]
0.22	Population within 30 miles[6]
0.16	Lake area[2]
0.10	*Other lakes within 30 miles, >20 acres[7]

TREND IN TROPHIC STATE (Category weight: 0.20)

Weight	Variable
1.00	Average LWQA program spring phosphorus minus 1974 phosph.[1 and 2]

* Variable was ranked in ascending order--a low result corresponds to a low rank and a high priority for management

Source of data:

1 - Lake Water Quality Assessment Program
2 - Water Supply Bulletin 43 (Bortleson, *et al.*, 1976a-e and Dion *et al.* 1976a-d)
3 - calculated from Water Supply Bulletin 43
4 - Municipality of Metropolitan Seattle (1994)
5 - 305(b) Report (Washington State Department of Ecology, 1992a)
6 - ARC/INFO tabular database of 1990 decennial census data; 30 mile radius centered on point representing the lake.
7 - ARC/INFO database from USGS 1:100,000 hydrographic data. 30 mile radius centered on point representing the lake.

by most respondents primarily because the determination of trend is based on a comparison of results from two separate surveys. This category may be weighted more heavily when trends can be assessed with more confidence.

Some states (see above) refer to the Susceptibility to Eutrophication category as "potential water quality" and assign points in reverse order to the order used here (although no two states use quite the same list of variables). Those states use this category to assess manageability, presumably on the assumption that eutrophic lakes that are not ordinarily susceptible to eutrophication will be more easily managed. For example, while a small watershed may indicate less susceptibility to eutrophication, a small watershed is also more easily managed than a large one.

The Ranking Procedure

The final ranking of lakes was produced by a dBASE IV® computer program which prioritized lakes using the following steps:

1) Lakes were ranked by each of the 15 variables in Table 7. Most variables were ranked in descending order, that is, the higher the variable, the lower (closer to one) the priority. (A lake with a low rank has a higher priority for protection/restoration.)

2) Each of the ranks of the one to six variables descriptive of each category were multiplied by a weighting factor and the results summed for all variables within the category. To account for missing data, the category sum was divided by the sum of the weighting factors for non-missing variables. (An advantage of averaging ranks within categories is that lakes can be ranked even if some data are missing.)

3) The lakes were ranked by each of the category sums, thereby reducing the 15 variable ranks to four category ranks.

4) The four category ranks were multiplied by weighting factors and summed.

5) Lakes were then ranked by the sum of category ranks.

The ordered list of lakes determined from the above procedures was divided into high, medium, and low priority groups. High priority lakes were defined as those in the upper 15th percentile, excluding lakes in the bottom half of the Public Value category. This exclusion was applied on the assumption that limited management funds should not be expended on lower-value lakes, regardless of their ranking. In general, a lake considered to be a high-priority for eutrophication management would be susceptible to eutrophication, have poor current water quality, be of high public value, and have a declining trend in water quality.

Some members of the Delphi panel felt that priority should be given to lakes susceptible to eutrophication but with *good* water quality. This led to a second ranking exercise which emphasizes *protection* rather than *restoration*. It is less expensive to protect a lake through education, watershed management, etc. than to restore a culturally eutrophic lake. Lakes were ranked a second time after reversing the order of the Current Water Quality category, so that lakes with good current water quality would be given higher priority than lower-quality lakes. High priority lakes, according to this ranking, were defined as those lakes in the upper 15th percentile, excluding lakes not in the top half of the "Public Value" category. Lakes not in the top third of the "Current Water Quality" category were also excluded since the purpose of this list is to identify lakes with good water quality needing protection.

Data Sources

Most of the current data on lake water quality, development, etc. were compiled by Ecology's LWQA program based on direct measurements and observations, surveys of volunteers in the lake monitoring program, and queries of GIS databases. Data from a few lakes were collected by METRO's lake monitoring program (Municipality of Metropolitan Seattle, 1994). Much of the geographical and morphometric data used in the analysis were compiled by Bortleson *et al.* (1976 a-e) and Dion *et al.* (1976 a-d).

Results and Discussion

Lakes monitored by Ecology's Lake Water Quality Assessment Program and some lakes monitored by METRO are prioritized according to need for management of eutrophication in Table 8. In this table, a high priority lake is more likely to have *poor* water quality. Table 8 is intended to be a ranking of lakes needing management for existing eutrophication-related problems or potential problems.

Fifteen high-priority lakes were identified. Although 31 percent of all the 154 ranked lakes have received some form of management attention besides herbicide applications, 60 percent of the high priority lakes have received attention. Only 32 percent and 14 percent of the medium and low priority lakes, respectively, have received management attention. This ranking scheme seems to be in general agreement with past management funding decisions.

This ranking is also in general agreement with Ecology's draft 1994 303(d) list. A greater percent of the high priority lakes are listed (27 percent) than medium and low priority lakes (eight and six percent, respectively). (The 303(d) list is based on current water quality and does not consider eutrophication potential, public value, or trend.)

Table 9 lists the high-priority lakes with good current water quality considered a high priority characteristic. In this table, a high priority lake is more likely to have *good* water quality. Table 9 is intended to be a ranking of lakes needing management to protect existing good water quality.

Table 8. Rankings of LWQA Program lakes according to need for management of eutrophication-related concerns--*poor* water quality was considered a high priority characteristic. The lower the rank, the higher the priority.

Lake (County	Management Status*	Public Value	Suscept. to Eutrophic	Current Water Quality	Trend	Overall Rank
<u>High Priority Lakes</u>						
WYE (KITSAP)		24	1	39	9	1
PATTERSON, SOUTH ARM (THURSTON)	AB	13	18	32	9	2
LONG (KITSAP)	AB	1	7	3	86.5	3
LONG (THURSTON)	ABH	36	6	48	20	4
LAWRENCE (THURSTON)	Ab	44	26	14	48.5	6
STEILACOOM (PIERCE)	a H	33	2	23	92	7
BIG (SKAGIT)	AB	10	11	93	16.5	9
OHOP (PIERCE)	a H	14	19	33	92	11
SILVER (SPOKANE)	H	51	43	30	22.5	12
MISSION (KITSAP)		23	58	57	13.5	14
BLACK (THURSTON)		43	53	28	41	15
SAWYER (KING)	AH	27	38	44	68	16
ELOIKA (SPOKANE)	Ab	56	32	35	62	17.5
LIMERICK (MASON)	H	62	4	90	32.5	20
DUCK (GRAYS HARBOR)	A H	52	28	12	129	23
<u>Medium Priority Lakes</u>						
KAHLOTUS (FRANKLIN)		131	8	1	7	5
LOOMIS (PACIFIC)		121	15	10	6	8
CHAMBERS (THURSTON)		113	5	15	36.5	10
BYRON (YAKIMA)		145	9	8	25.5	13
MCINTOSH (THURSTON)		99	3	17	92	17.5
KETCHUM (SNOHOMISH)	a H	138	16	7	0	19
WISER (WHATCOM)	H	105	24	13	62	21
SUNDAY (SNOHOMISH)		125	60	2	5	22
MOSES (GRANT)	AB	59.5	14	19	140	24
WHITMAN (PIERCE)		46	52	64	32.5	25
KILLARNEY (KING)	H	95	50	22	48.5	26
SPANAWAY (PIERCE)	H	39	13	56	125	27
NEWMAN (SPOKANE)	ABH	2	21	73	129	28
SACHEEN (PEND OREILLE)	AbH	18	25	85	92	29.5
ST. CLAIR (THURSTON)	H	8	70	46	76	29.5
PHILLIPS (MASON)		21	27	88	82.5	31
FENWICK (KING)	Ab	118	46	41	20	32
LIBERTY (SPOKANE)	AB	25	47	77	76	33
LELAND (JEFFERSON)		107	12	21	129	34
CLEAR (THURSTON)	H	88	92	25.5	11	35
TANWAX (PIERCE)	H	69	69	43	48.5	36
SPENCER (MASON)		20	56	116	25.5	37
ALICE (KING)		101	37	72	36.5	38.5
ROESIGER, SOUTH ARM (SNOHOMISH)	Ab	37	30	106	68	38.5
PATTERSON, NORTH ARM (THURSTON)	ABh	89	40	69	48.5	40
SOAP (GRANT)	a	90	59	6	98	41
CARLISLE (LEWIS)	ABH	152	17	9	104	42
BEAVER NO. 2 (KING)	A	92	68	61	22.5	43
LONE (ISLAND)		93	31	29	136	44
KITSAP (KITSAP)	A H	34	41	86.5	104	45
OFFUTT (THURSTON)		75	71	38	76	46
LACAMAS (CLARK)	Ab	64	66	24	116	47
TRAILS END (MASON)		70	75	75	29	48
BLACKMANS (SNOHOMISH)	A	102	72	67	13.5	49

* 'A'= Phase I, 'B' = Phase II, 'H' = Herbicide treatment; upper case = completed, lower case = in progress/pending.

Table 8. Continued

Lake (County)	Management Status	Public Value	Suscept. to Eutrophic.	Current Water Quality	Trend	Overall Rank
RAPJOHN (PIERCE)		126	64	34	48.5	50
SPRAGUE (ADAMS)		134	20	16	139	51
MUD (CLARK)		133	23	11	145	52
TIGER (KITSAP/MASON)		12	63	144	25.5	53
DEER (STEVENS)		7	34	141	86.5	54
JUMPOFF JOE (STEVENS)		58	61	81	68	55
LOMA (SNOHOMISH)	A	110	44	36	111	56
NAHWATZEL (MASON)	H	22	49	140	56.5	57
SHADOW (KING)		65	91	66	41	58
WILDERNESS (KING)		86	93	54	32.5	59
LUCERNE (KING)		79	51	126	20	60
CURLEW (FERRY)	ABH	50	105	42	68	61
CRANBERRY (ISLAND)		130	83	4	76	62
NORTH (KING)		82	45	91	76	63
CAMPBELL (SKAGIT)	AB	81	22	77	138	64.5
POTHOLES (GRANT)		127	36	25.5	135	64.5
SHADY (KING)		66	81.5	105	16.5	66
FLOWING (SNOHOMISH)		15	110	96	32.5	67
SIDLEY (OKANOGAN)		141	48	27	104	68
MAYFIELD (LEWIS)	H	74	114	70	4	69
MARTHA (MARTHA LAKE) (SNOHOMISH)	A	71	94	102	2	70
MORTON (KING)		49	42	98	120	71
BLUE (GRANT)	H	106	76	60	56.5	72
WILLIAMS (SPOKANE)		35	80	71	111	73
LEECH (YAKIMA)		153	10	100	0	74.5
SHOECRAFT (SNOHOMISH)	A	47	35	121	111	74.5
HICKS (THURSTON)	H	72	54	84	104	76
STARVATION (STEVENS)		148	33	31	133	77
DEEP (STEVENS)		55	99	82	48.5	78.5
HORSESHOE (COWLITZ)	Ab	109	65	20	133	78.5
CLEAR (SPOKANE)	H	80	74	37	125	80
ROESIGER, NORTH ARM (SNOHOMISH)	Ab	45	113	53	76	81
OSOYOOS (OKANOGAN)	H	54	89	89	68	82
PINE (KING)	AB	40	55	104	125	83
GOODWIN (SNOHOMISH)	A	30	39	136	125	84
LOST (MASON)		77	78	109	48.5	85
MEDICAL, WEST (SPOKANE)		117	98	5	111	86
ANGLE (KING)		28	90	133	48.5	87
TOAD (EMERALD) (WHATCOM)		132	123	47	1	88
Low Priority Lakes						
GENEVA (KING)		87	79	65	98	89
CRAWFISH (OKANOGAN)		112	57	92	0	90
NUMBER TWELVE (KING)	A	108	67	118	36.5	91
WENATCHEE (CHELAN)		16	130	130	9	92
SKOOKUM, SOUTH (PEND OREILLE)		154	81.5	50.5	62	93
LOUISE (PIERCE)	H	85	102	74	68	94
BOSWORTH (SNOHOMISH)		19	134	123	16.5	95
MASON (MASON)	H	4	62	148	125	96
MARTHA (LAKE MARTHA) (SNOHOMISH)	A	96	86	79	86.5	97
AMERICAN (PIERCE)	AbH	29	95	97	116	98
BOREN (KING)		116	111	59	56.5	99
BLACK (STEVENS)		76	108	108	41	100
LOON (STEVENS)		31	84	136	92	101
ISLAND (MASON)		91	87	122	48.5	102

Table 8. Continued.

Lake (County)	Management Status	Public Value	Suscept. to Eutrophic.	Current Water Quality	Trend	Overall Rank
STEVENS (SNOHOMISH)	Ab	26	150	115	16.5	103
CONCONULLY (OKANOGAN)		104	125	58	56.5	104
FLORENCE (PIERCE)	H	122	103	86.5	41	105
BUCK (KITSAP)		124	109	40	0	106
ROUND (CLARK)	Ab	140	131	18	68	107
THOMAS (STEVENS)	H	38	73	120	137	108
PEARRYGIN (OKANOGAN)		139	122	62.5	29	110
SUTHERLAND (CLALLAM)		41	101	144	56.5	110
EVERGREEN (GRANT)		136	77	50.5	125	111
SUMMIT (THURSTON)	H	6	97	146	98	112
PIPE (KING)		57	104	132	62	113
WILLIAMS (STEVENS)		150	128	49	36.5	114
MERWIN (CLARK)		67	121	142	12	115
STAR (KING)		61	85	95	143	116
MERIDIAN (KING)	ABH	32	129	129	56.5	117
DIAMOND (PEND OREILLE)	H	48	96	139	86.5	118
BIG MEADOW (PEND OREILLE)		147	100	52	0	119
SAMISH, EAST ARM (WHATCOM)		9	118	117	120	120
DEEP (KING)		129	145	62.5	25.5	121
WHATCOM (WHATCOM)	Ab	3	142	152	41	122
SAMISH, WEST ARM (WHATCOM)		17	141	111	92	123
WANNACUT (OKANOGAN)		120	119	77	76	124
KI (SNOHOMISH)	A	63	117	125	76	125
BANKS (GRANT)	H	123	120	55	104	127
GOSS (ISLAND)	H	97	106	128	62	127
CHELAN (CHELAN)		5	151	127	82.5	129
WAITTS (STEVENS)		84	138	68	104	129
WOOTEN (MASON)		42	112	151	82.5	129
KEECHELUS (KITTITAS)		135	153	99	3	131
TWIN (FERRY)	Ab	83	136	83	0	132
CORTEZ (THREE) (CHELAN)		128	137	45	111	133
STORM (SNOHOMISH)		103	127	94	92	135
WARD (THURSTON)		115	133	110	48.5	135
NUNNALLY (GRANT)		146	29	149	146	135
HOWARD (SNOHOMISH)	A	73	132	80	141	137
SULLIVAN (PEND OREILLE)		119	152	107	29	138
AENEAS (OKANOGAN)		94	115	103	131	140
PIERRE (STEVENS)		137	116	113	76	140
DAVIS (PEND OREILLE)		53	147	119	116	141
CRESCENT (CLALLAM)		11	154	147	0	143
PANTHER (SNOHOMISH)		114	135	101	104	143
PACKWOOD (LEWIS)		68	149	138	82.5	145
CAIN (WHATCOM)		98	126	124	111	145
BENSON (MASON)		78	124	150	116	146
EASTON (KITTITAS)		144	88	154	120	147
GRAVELLY (PIERCE)	H	59.5	144	131	144	148
ELLEN (FERRY)		142	107	134	0	149
MERRILL (COWLITZ)		100	148	145	98	150
CLE ELUM (KITTITAS)		111	143	153	98	151
TWIN, BIG (OKANOGAN)		143	146	112	116	152
LEO (PEND OREILLE)		149	139	114	133	153
MILL (PEND OREILLE)		151	140	136	142	154

Table 9. Rankings of LWQA Program lakes according to need for protection of good water quality--*Good* water quality was considered a high priority characteristic. The lower the rank, the higher the priority.

Lake (County)	Management Status	Public Value	Suscept. to Eutrophic.	Current Water Quality	Trend	Overall Rank
High Priority Lakes						
TIGER (KITSAP/MASON)		12	63	11.5	25.5	2
DEER (STEVENS)		7	34	14	86.5	3
NAHWATZEL (MASON)	H	22	49	15	56.5	4
SPENCER (MASON)		20	56	39	25.5	7
SOUTH ROESIGER (SNOHOMISH)	Ab	37	30	49	68	10
MASON (MASON)	H	4	62	7	125	13.5
GOODWIN (SNOHOMISH)	A	30	39	19	125	15
ANGLE (KING)		28	90	22	48.5	16
SHOECRAFT (SNOHOMISH)	A	47	35	34	111	17
WENATCHEE (CHELAN)		16	130	25	9	20
SUMMIT (THURSTON)	H	6	97	9	98	21
SUTHERLAND (CLALLAM)		41	101	11.5	56.5	23

* 'A' = Phase I, 'B' = Phase II, 'H' = Herbicide treatment; upper case = completed, lower case = in progress/pending.)

Twelve high-priority lakes were identified. When ranked this way, only 25 percent of the 12 high-priority lakes have received management attention. Four of the top six lakes are in Mason County. In addition to good water quality, the Mason County lakes tended to have higher than average public value. Most of the 12 high priority lakes with good water quality did not rank high in the Susceptibility to Eutrophication category. However, three lakes may be particularly susceptible to eutrophication and may especially warrant protective management: Deer Lake (Stevens County) and Lakes Goodwin and Shoecraft (Snohomish County). (Deer Lake has recently been sewered. Goodwin and Shoecraft are both in the Seven Lakes Sewer District which completed a Phase I study in 1986.)

As discussed previously, this ranking is intended primarily as general guidance and supporting documentation for grant applications and not as a definitive list of lakes in Washington requiring management. Some lakes may have unusual characteristics which are not reflected in these tables. For example,

- American Lake is ranked as low priority with relatively good water quality, yet it has had toxic algae blooms four of the last five years. These blooms all occurred in winter when the lake was not monitored for Ecology's LWQA Program.

- Beaver Lake ranked as medium priority, but has significant watershed development planned. Beaver Lake may be a good candidate for protective management.

- Duck Lake is ranked as high priority. This lake was created by extensively dredging wetlands; most likely, nutrient-rich wetland soils contribute to the productivity of Duck Lake. Although lake restoration measures have been proposed, Duck Lake is expected to remain eutrophic even after management (KCM Inc., 1994).

- Carlisle Lake is ranked as having low public value. However, Carlisle Lake has concerned and active community advocates who clearly value the lake. A concerned public is important to the success of any management program.

- Five of the 154 ranked lakes are on Ecology's draft 1994 303(d) list for problems not directly related to eutrophication (for example, Dieldrin, DDT metabolites, PCBs and fecal coliform bacteria). Lakes listed for these problems would not necessarily rank high for eutrophication management.

Correlations

Correlations between category ranks and the ranks of the various descriptive variables from other categories provide insight into relationships between variables, as well as circumstantial evidence that the variables used are representative of the category (Table 10). Obviously, correlations of variables within categories to the overall category rank are less meaningful, as they are a function of the weighting factors applied to the variables. The correlations discussed below are based on good water quality ranked first--which will affect the sign of the correlation coefficient, but not the magnitude.

Table 10. Normal scores correlation coefficients (and probabilities) between major category ranks and ranks of descriptive variables.

	Public Value Eutrophication	Susceptibility to Quality	Current Water	Trend
Main Categories				
Public Value	....	NS[a]	0.275 (<0.001)	NS
Susceptibility to Eutrophic.	....	....	-0.499 (<0.001)	NS
Current Water Quality	....	....	....	NS
Public Value Variables				
Drinking Water Use	0.424 (<0.001)	NS	0.191 (0.025)	NS
Lake Shore Homes	0.832 (<0.001)	0.165 (0.042)	0.260 (0.001)	NS
Nearby Population	0.363 (<0.001)	0.214 (0.008)	NS	NS
Lake Area	0.443 (<0.001)	NS	0.185 (0.022)	NS
Nearby Lakes	-0.231 (0.004)	-0.219 (0.007)	NS	NS
Susceptibility to Eutrophication Variables				
Flushing Index	NS	0.230 (0.004)	NS	NS
Population Density	0.594 (<0.001)	0.178 (0.028)	0.237 (0.003)	NS
Relative Depth	NS	0.658 (<0.001)	-0.381 (<0.001)	NS
Watershed/Lake Area	-0.237 (0.003)	NS	-0.160 (0.048)	NS
Mean Depth	-0.350 (<0.001)	0.732 (<0.001)	-0.568 (<0.001)	NS
Shoreline Development	0.198 (0.014)	0.258 (0.001)	-0.175 (0.030)	NS
Current Water Quality				
Trophic State	-0.247 (0.002)	0.440 (<0.001)	-0.799 (<0.001)	NS
Total Phosphorus	-0.285 (<0.001)	0.443 (<0.001)	-0.911 (<0.001)	0.179 (0.036)
Clean Water Act Goals	NS	NS	NS	NS

NS = not significant ($p < 0.05$). Statistics were calculated using WQHYDRO® (Aroner, 1994).

The Public Value rank was correlated with the Current Water Quality rank ($r = +0.28$, $p < 0.001$), although the Public Value category did not include any variables that might be directly descriptive of water quality. The Public Value variable with the strongest correlation to Current Water Quality was the number of lake shore homes ($r = +0.26$, $p = 0.001$). More people tend to live on lakes with good water quality than on those with poor water quality.

The Susceptibility to Eutrophication and Current Water Quality ranks were also correlated ($r = -0.50$, $p < 0.001$). The more susceptible to eutrophication a lake was, the worse its water quality tended to be. This is not surprising and provides credibility to the procedures used to determine the category ranks. Mean depth was the variable descriptive of Susceptibility to Eutrophication that was most strongly correlated with the Current Water Quality rank ($r = -0.568$, $p < 0.001$) with shallower mean depths relating to worse water quality.

Limitations

Results from this method seem reasonable and the ranks of lakes are in general accordance with best professional judgement. However, these rankings are intended as guidance only. Every high priority lake is not necessarily more deserving of limited management funds than every low priority lake. As discussed previously, in addition to funding considerations there are limitations in methods:

1) No assessment of management potential is included in the rankings. Lakes should be removed from the high priority list where management is less likely to be successful. For example, management with the intent of reducing eutrophication in naturally eutrophic lakes may not be desirable, and is less likely to be successful than management of culturally eutrophic lakes.

2) With the exception of the Public Value category, this ranking should not be used to make funding decisions about lakes needing management for problems other than eutrophication as measured by nutrient concentrations and phytoplankton abundance. Some lakes may be considered "low priority" in this ranking, yet have problems requiring management.

3) Expected water quality is not considered. For example, a lake with better than average water quality compared to other lakes statewide, may have poor water quality when compared to other lakes in the same region.

AQUATIC PLANT MANAGEMENT IN WASHINGTON

Often, conflicts between various beneficial uses of a lake will involve conflicting attitudes towards aquatic plants. Aquatic vegetation may be the greatest source of organic matter produced within a lake, hence contributing to a lake's eutrophication, and also interfering with beneficial uses such as boating, contact recreation, and water withdrawal. Non-native, invasive aquatic plants such as Eurasian water milfoil, purple loosestrife and Hydrilla can change a lake's ecological and aesthetic integrity. However, aquatic vegetation is also necessary for a good fishery, and provides habitat for aquatic macroinvertebrates, fish, waterfowl, and other wildlife. Hence, the fishable-swimmable goals of the Clean Water Act can conflict, and attitudes can differ among lake users regarding the aesthetic value of aquatic plants.

Ecology has recently made changes in its aquatic plant management to respond to evolving problems:

1) Due to advances in the technology available for controlling aquatic plants, and concern about possible environmental effects from certain aquatic herbicides, Ecology updated the environmental impact statement regarding Washington's approach to aquatic plant management, and

2) Ecology has recently created a program for controlling and containing populations of non-native plants in infested lakes, and preventing new introductions into other lakes via control projects, research and demonstration projects, and a public education project.

Ecology's roles in aquatic plant management include issuing short-term modifications to the water quality standards to allow for aquatic herbicide treatments in or near surface waters; providing guidance for the permit writers who issue the short-term modifications (through the Supplemental Environmental Impact Statement); and a grants, education, and technical assistance program known as the Freshwater Aquatic Weeds Program. Each of these is discussed below.

Short-Term Modifications to the Water Quality Standards

Application of aquatic herbicides is a common method used to control aquatic plants in Washington. Aquatic herbicides approved for use in Washington State lakes are glyphosphate (trade name Rodeo®), fluridone (Sonar®), and endothall (Aquatholl K®). Copper compounds are sometimes allowed for algae control, and 2,4-D is allowed under certain conditions to control purple loosestrife. Aquatic herbicide use requires a short-term modification to the state Water Quality Standards (Chapter 173-201 WAC), issued by regional offices of the Department of Ecology. Short-term modifications to the water quality standards are also required for mosquito control projects and fishery enhancement projects that involve the use of rotenone. A short term modification of water quality standards cannot be issued if the proposed action interferes with or becomes injurious to existing water uses or causes long-term harm to the environment.

In 1993, short-term modifications were issued, and aquatic herbicides were legally applied, at 71 lakes or ponds (Table 11). Twenty-five permits were for treating shorelines with Rodeo® to control infestations of noxious plants (mostly, Purple loosestrife). Three lakes were treated with rotenone by the Department of Wildlife to control undesirable fish species (such as goldfish). The remaining 43 lakes were treated with aquatic herbicides to control algae, submerged aquatic plants, and/or floating-leaved aquatic plants. Twenty of these 43 lakes are privately-owned, and therefore are ineligible for state or Federal funding for lake assessment and restoration activities. Limited technical assistance may be provided by Ecology's educational programs, but otherwise it is likely that aquatic herbicides will continue to be the prevalent method for managing aquatic plants at private lakes

Aquatic Plant Management Program FEIS and SEIS

Ecology published a Final Environmental Impact Statement (FEIS) in 1980 which evaluated the impacts of various aquatic herbicides. The FEIS was written as guidance for Ecology's permit writers who issue temporary modifications to the water quality standards (these modifications are often referred to as "herbicide permits").

In 1992, Ecology published a Supplemental Environmental Impact Statement (SEIS; Ecology, 1992b, 1992c) which updates, expands, and supplements the original 1980 FEIS. This update was necessary because several chemicals discussed in the FEIS were no longer approved for use in surface waters in Washington, other chemicals had since been approved, and new regulations for controlling the use of aquatic herbicides had been enacted. Updating the FEIS was also needed because concern and knowledge about the potential human and environmental health hazards from aquatic herbicides had increased in the past years, and technologies for controlling aquatic plants using mechanical, physical and biological methods had been developed and refined.

The SEIS examines various control alternatives, their impacts on the environment, and potential mitigation of significant adverse impacts. These alternatives include using chemical controls only, physical controls only, biological controls only, taking no action relative to controlling nuisance aquatic plants, or using a combination of vegetation control techniques (referred to as the "integrated management approach"). The SEIS recommends the integrated management approach for controlling nuisance aquatic plant populations. Having a variety of control methods available will provide the flexibility necessary to control nuisance aquatic plant populations in situations where it is also desirable to maintain other, often conflicting, beneficial water uses. Integrated management usually involves a minimal reliance on aquatic herbicides, which minimizes potential impacts on human and environmental health.

Table 11. Lakes treated with aquatic herbicides in 1993.

Lake (County)	Chemical	Target
Anderson (Mason)	Komeen®, Rodeo®	elodea, cattails
Aqua Vista (King)	Copper, Sonar®	algae, pondweeds
Barnes (Thurston)	Rodeo®	water lilies
Battlepoint (Kitsap)	Sonar®	pondweeds
Blue (Thurston)	Aquatholl®	milfoil
Bonney (Pierce)	Rodeo®, Sonar®	water lilies
Cherry Pond (Snohomish)	Copper	algae
Clear (Thurston)	Aquatholl®, Copper	milfoil, algae, pondweeds, elodea
Debra Jane (Pierce)	Aquatholl®	(not reported)
Elbow (Thurston)	Copper	algae
Fawn (Mason)	®Copper, Aquatholl®	algae, pondweeds
Forbes Creek Development (King)	Copper, Sonar®	algae, pondweeds
Fountain Isle Lake (King)	Aquatholl®, Copper	pondweeds
Gig Harbor, Lakes at (Pierce)	Rodeo®	lilies
Gravelly (Pierce)	Copper, Aquatholl®	algae, pondweeds, swimmers itch
Jeane (King)	Copper, Sonar®	algae, pondweeds
Ken (Thurston)	Aquatholl®, Rodeo®	pondweeds, cattails
Ketchum (Snohomish)	Aquatholl®, Copper	algae, pondweeds
Killarney (King)	Copper, Sonar®	algae, pondweeds
Kent, Lakes at (King)	Copper	algae
Lakeland Village (Pierce)	Aquatholl®	(not reported)
Leisure Time Pond (Lewis)	Aquatholl®	pondweeds
Limerick (Mason)	Copper, Sonar®	algae, pondweeds, elodea
Louise (Pierce)	Copper	algae, swimmers itch
Lorene (King)	Copper, Sonar®	(not reported)
Mayfield (Lewis)	Sonar®	elodea
Mercer Island, Lakes at (King)	Copper, Sonar®	algae, pondweeds
Minterwood (Pierce)	Sonar®	elodea
Ohop (Pierce)	Aquatholl®	pondweeds
Palmer (Pierce)	Aquatholl®, Copper	pondweeds, algae
Pioneer Trails	Sonar®, Rodeo®, Copper	pondweeds, cattails, algae
Ponce de Leon (King)	Copper, Sonar®	(not reported)
Reflection	Sonar®	Elodea
Sixty-01 Lakes	Rodeo®	(not reported)
Star (Mason)	Sonar®, Rodeo®	pondweeds, lily pads
Swofford Pond (Lewis)	Sonar®	Eurasian milfoil
Sylvia (Pierce)	Copper	algae
Small Timber (Mason)	Aquatholl®	pondweeds
Big Timber (Mason)	Sonar®, Aquatholl®, Rodeo®	lily pads
Wallace Pond	Sonar®	milfoil
Washington -- at Newport Shores	Aquatholl®, Sonar®	milfoil
Westridege Ponds	Sonar®	milfoil
Weyerhaeuser Ponds	Copper	algae, elodea

Source of information: 1993 Spray reports to Ecology from licensed herbicide applicators

Table 11. Lakes Treated with Aquatic Herbicides in 1993, cont.

Shorelines treated with fluridone (Sonar®) to control Purple loosestrife (unless otherwise indicated)

Burke (Grant)
Caliche (Grant)
Canal Lake, Long Lake (Grant)
Capitol (Thurston)
Upper Clark Pond (Franklin)
Corral (Grant)
Crater (Grant) (thistle and knapweed)
Evergreen (Grant)
Fan (Pend Oreille)
George and Martha (Grant)
Lower Goose Lake (Grant)
Upper Goose Lake (Grant)
Hilltop (Grant)
Ione Mill (Pend Oreille)
Long (Spokane)
Loon (Spokane)
Quincy (Grant)
Red Rock (Yakima)
Royal City Lakes (aka Clementine)
Skagit Wetlands
Stan Coffin (Grant)
Terrell (Whatcom)
Warden
Winchester
Winderemere (reed canary grass)

Lakes Treated with Rotenone to Control Undesirable Fish Species

Burke (Grant)
West Medical (Spokane)
Quincy (Grant)

Source of information: 1993 Spray reports to Ecology from licensed herbicide applicators

The SEIS also recommends that the group or agency who proposes aquatic plant control develop a lake or watershed management plan. This recommendation is based on the recognition that some beneficial uses conflict, some beneficial uses can be affected by aquatic plant control activities or methods, and all waterbody users should be involved in identifying and prioritizing the beneficial uses to be protected in the waterbody. Ideally, management plans will also address the sources of aquatic plant problems (such as loading of sediments and organic matter) to reduce the need for additional plant control planning in the future.

Freshwater Aquatic Weeds Program

In 1991 the Washington legislature created a program that provides public education, technical assistance, and financial assistance for managing aggressive non-native aquatic plants such as Eurasian water milfoil. Funding for the program is from a fee added to the cost of a boat trailer license. The program is coordinated by Ecology's Water Quality Financial Assistance Program, and is known as the Freshwater Aquatic Weeds Program. Financial assistance from the Freshwater Aquatic Weed Management Fund is available on a yearly competitive basis for projects that prevent, remove, reduce or manage invasive, non-native freshwater aquatic plants. "Emergency" early infestation funds are also available on a continual basis to fund eradication projects for waterbodies that have been recently infested with a noxious invasive aquatic plant. Only lakes and rivers with public boat launches are eligible for funds through the Aquatic Weeds Fund.

In 1993 and 1994, nine local governments were awarded grants through the Aquatic Weeds Fund for the following projects:

- four projects will prepare aquatic plant management plans;
- two projects will control new infestations of noxious aquatic plants (Purple loosestrife and Eurasian water milfoil);
- diver dredging will be used to control Eurasian water milfoil in Silver Lake, Snohomish County;
- aquatic plants in 28 lakes in Stevens County will be characterized and mapped; and
- the utility of using aerial imaging to detect aquatic plants will be investigated.

The Aquatic Weeds Program is also funding the preparation of a plant identification manual for freshwater aquatic plants found in Washington.

The Aquatic Weeds Program emphasizes the need for an integrated aquatic plant management plan before aquatic plant control activities begin. Guidance for developing these plans is provided in A Citizen's Manual for Developing Integrated Aquatic Plant Management Plans, First Edition (Gibbons *et al.*, 1994).

The Freshwater Aquatic Weeds Program is coordinated with Ecology's ongoing milfoil control program, which is funded by the Army Corps of Engineers. This program also provides education, and funding for research, site-specific control projects, and demonstration projects. This program is limited to projects that address Eurasian water milfoil.

Current Eurasian watermilfoil control projects include:

- an evaluation using diver surveillance of three lakes which were treated with Sonar®;
- harvest or rotovation of three waterbodies which have large areas with well-established milfoil population;
- treatment of Carlisle Lake with Sonar®;

Both the Freshwater Aquatic Weeds Program and the milfoil control program include public education on aquatic plant ecology and control. Aquatic Plant Control (Ecology, 1994) was produced to educate the public on methods used to control aquatic plants, advantages and disadvantages for each method, permits required for each method, cost estimates, and contacts.

ECOLOGY'S LAKE RESTORATION PROGRAM

Washington has coordinated a lake restoration program since 1976. The passage of Referendum 26 in 1972 and Referendum 39 in 1980 provided over $25 million of state funding for lake water quality improvement projects. With the passage of the Centennial Clean Water Fund (CCWF) legislation in 1986, additional lake funding was assured through 1993. In 1994, special categories (including the lakes category) were eliminated, leaving only the activities and facilities categories. Currently, Phase I projects compete for funding under the activities category, and Phase II projects compete either in the activities or the facilities category.

Washington's lake restoration program parallels the federal Clean Water Act Section 314 Clean Lakes Program. All projects are initiated at the grass roots level, and a public entity must serve as the local sponsor and provide at least 25% of the total project cost. Projects have been funded with state agencies, indian tribes, municipalities, and county governments. Lake restoration projects at 45 lakes have been funded by Ecology since the funding program began (Table 12). Lake restoration projects at 18 lakes have been funded through the federal Clean Lakes Program (Table 13).

All lake restoration projects begin with a Phase I diagnostic/restoration feasibility assessment. Phase I projects are designed to assess the physical, chemical, and biological characteristics

Table 12. State funded lake restoration projects.

Lake (County)	Reference	Project Status (Completion Date)
Beaver (King)	Beaver Lake Management Plan (Entranco, 1993)	Phase I (1994)
Big (Skagit)	Big Lake Restoration Study Final Report (URS Company, 1977)	Completed (1978)
Black (Thurston)		Phase I grant declined 1994
Blackmans (Snohomish)	City of Snohomish Blackman Lake Phase I Restoration Study Final Report (KCM, Inc., 1994)	Phase I (1994)
Capitol (Thurston)		Phase I (1984), Phase II (1988)
Carlisle (Lewis)	Lake Carlisle Restoration Phase II: Water Quality Monitoring (Moore, 1990)	Phase I (1985); Phase II (1991)
Clear (Pierce)	Clear Lake Water Quality Assessment Project Final Report (Tacoma-Pierce County Health Department, 1994)	Phase I (1994)
Cottage (King)		Phase I - Active
Crabapple (Snohomish)	Seven Lakes Water Quality Analysis and Management Plan (Entranco Engineers, Inc., 1986a)	Phase I (1986)
Curlew (Ferry)	A Study of the Water Quality of Curlew Lake, Washington (Juul, 1988)	Phase I (1989); Phase II (1994)
Desire (King)		Phase I - Active

Table 12, cont'd. State funded lake restoration projects.

Lake (County)	Reference	Project Status (Completion Date)
Duck (Grays Harbor)	Duck Lake Phase I Restoration Study Final Report (KCM, Inc, 1994)	Phase I (1994)
Eloika (Spokane)	Water Quality Assessment and Restoration Feasibility for Eloika Lake, WA (Soltero *et al.*, 1987)	Phase I (1989); Phase II Active
Goodwin (Snohomish)	Seven Lakes Water Quality Analysis and Management Plan (Entranco Engineers, Inc., 1986a)	Phase I (1986)
Horseshoe (Clark)	Horseshoe Lake: Water Quality, Nutrient Loading, and Management (Welch *et al.*, 1992)	Phase I (1993); Phase II - Active
Howard (Snohomish)	Seven Lakes Water Quality Analysis and Management Plan (Entranco Engineers, Inc., 1986a)	Phase I (1986)
Ketchum (Snohomish)		Phase I - Active
Ki (Snohomish)	Seven Lakes Water Quality Analysis and Management Plan (Entranco Engineers, Inc., 1986a)	Phase I (1986)
Kitsap (Kitsap)	Kitsap Lake: A Restoration Analysis and Watershed Management Plan (Parametrix, Inc., 1983)	Phase I (1983)
Lacamas (Clark)	Lacamas Lake Restoration Project, Restoration Plan (Intergovernmental Resource Center, 1988); Lacamas-Round Lake Diagnostic and Restoration Analysis (Beak Consultants an Scientific Resources, Inc., 1985)	Phase I (1986); Phase II -Active

Table 12, cont'd. State funded lake restoration projects.

Lake (County)	Reference	Project Status (Completion Date)
Larsen (King)	City of Bellevue Storm and Surface Water Utility Phantom/Larsen Lake Phase II Restoration Project Final Report (KCM, Inc., 1993)	Phase I (1987); Phase II (1993)
Lawrence (Thurston)	Lake Lawrence Phase I Restoration Analysis Final Report (KCM, Inc., 1991)	Phase I (1992); Phase II - Active
Loma (Snohomish)	Seven Lakes Water Quality Analysis and Management Plan (Entranco Engineers, Inc., 1986a)	Phase I (1986)
Lake Martha (Snohomish)	Seven Lakes Water Quality Analysis and Management Plan (Entranco Engineers, Inc., 1986a)	Phase I (1986)
Martha Lake (Snohomish)	Martha Lake Phase I Restoration Report (Entranco, 1991)	Phase I (1994)
Medical (Spokane)	Restoration of Medical Lake Final Report (Gasperino *et al.*, 1980)	Phase I (1977); Phase II (1980)
Meridian (King)	A Study of the Trophic Status and Recommendations For the Management of Lake Meridian (METRO, 1978)	Completed (1978)
Newman (Spokane)	Newman Lake Restoration Feasibility Study (Funk and Moore, 1988)	Phase I (1988); Phase II - Active
Number Twelve (King)	Lake Twelve Management Plan Final Report (Envirovision and KCM, Inc., 1994)	Phase I (1994)

Table 12, cont'd. State funded lake restoration projects.

Lake (County)	Reference	Project Status (Completion Date)
Ohop (Pierce)		Phase I grant pending
Phantom (King)	City of Bellevue Storm and Surface Water Utility Phantom/Larsen Lake Phase II Restoration Project Final Report (KCM, Inc., 1993)	Phase I (1987); Phase II (1993)
Roesiger (Snohomish)	Lake Roesiger Phase I Restoration Analysis (KCM, Inc, 1989)	Phase I (1990); Phase II - Active
Sacheen (Pend Oreille)	Water Quality Assessment and Restoration Alternatives for Sacheen Lake, Washington (Kennedy Engineers, 1991)	Phase I (1991); Phase II - Active
Sammamish (King)	Lake Sammamish Water Quality Management Project Technical Report (Entranco, 1989)	Phase I (1991); Phase II - Active
Scriber (Snohomish)	Scriber Lake Restoration Diagnostic Feasibility Study (URS Consultants, 1986)	Phase I (1987); Phase II - Active
Shoecraft (Snohomish)	Seven Lakes Water Quality Analysis and Management Plan (Entranco Engineers, Inc., 1986a)	Phase I (1986)
Silver (Cowlitz)	Silver Lake Restoration Phase I: Diagnostic/ Feasibility Study (Moore , 1990)	Phase I (1990); Phase II Active
Silver (Snohomish)		Phase I (1988); Phase II (1993)

Table 12, cont'd. State funded lake restoration projects.

Lake (County)	Reference	Project Status (Completion Date)
Snake (Pierce)	Final Environmental Impact Statement for Snake Lake Nature Center New Interpretive Building and Restoration Feasibility Study (Metropolitan Park District of Tacoma, 1989)	Phase I (1989)
Spada (Snohomish)		Phase I (1977)
Spokane (Spokane)	Lake Spokane Phase I Restoration Project Completion Report (Soltero *et al.*, 1992)	Phase I (1993)
Steilacoom (Pierce)		Phase I - Active
Stevens (Snohomish)	Lake Stevens Restoration Final Environmental Impact Statement (Snohomish County Public Works, 1991)	Phase I (1983); Phase II - Active
Twin (Ferry)	Twin Lake Restoration Analysis (Phase I) (Juul, 1987)	Phase I (1988); Phase II - Active
Whatcom (Whatcom)	Lake Whatcom Watershed Management Plan	Phase I (1988); Phase II - Active

Table 13. Federal Clean Lakes Program restoration projects in Washington.

Lake (County)	Reference	Project Status
American (Pierce)	American Lake Phase I Restoration Project Final Report (KCM, Inc., 1993)	Phase I (1993); Phase II - Active
Ballinger (Snohomish)	Restoration of Lake Ballinger, Phase III Final Report (KCM, Inc., 1986)	Phase I (1977); Phase II (1987)
Beaver (King)	Beaver Lake Management Plan (Entranco Engineers, 1993)	Phase II Grant Pending*
Campbell (Skagit)	Erie and Campbell Lakes Final Report: Restoration Implementation and Evaluation (Entranco Engineers, Inc., 1987)	Phase I (1984); Phase II (1988)
Erie (Skagit)	Erie and Campbell Lakes Final Report: Restoration Implementation and Evaluation (Entranco Engineers, Inc., 1987)	Phase I (1984); Phase II (1988)
Fenwick (King)	Lake Fenwick Phase IB Restoration Project (Entranco, 1991)	Phase I (1991); Phase II -Active
Green (King)	An Addendum to the Green Lake Water Quality Improvement Project Final Environmental Impact Statement (URS Consultants, 1990)	Phase I (1983); Phase II - Active
Giffin (Yakima)	Giffin Lake Restoration Phase I: Diagnostic/Feasibility Study Final Report (Moore *et al.*, 1992)	Phase I (1993); Phase II - Active
Hicks (King)	Hicks Lake Post-Restoration Monitoring Study (Gendron and Pedersen, 1987)	Phase I (1982); Phase II (1987)
Liberty (Spokane)	Extended Post-Restoration Evaluation of Liberty Lake, Washington Final Report (Breithaupt *et al.*, 1986)	Phase I (1979); Phase II 1988)

* Funded from a Clean Water Act Section 319 grant. All other federal projects listed are funded from Section 314 grants.

Table 13, cont'd. Federal Clean Lakes Program restoration projects in Washington.

Lake (County)	Reference	Project Status
Long (Kitsap)	Water Quality and Phosphorus Dynamics as Affected by Alum Treatment in Long Lake, Kitsap County (Welch *et al.*, 1988)	Phase I (1977); Phase II (1982)
Long (Thurston)	Pattison and Long Lakes Restoration Project Final Report (Entranco Engineers, 1987)	Phase I (1982); Phase II (1987)
Moses (Grant)	Moses Lake Clean Lake Project Final State 3 Report (Bain and Moses Lake Conservation District, 1987)	Phase I (1978); Phase II (1989)
Pattison (Thurston)	Pattison and Long Lakes Restoration Project Final Report (Entranco Engineers, 1987)	Phase I (1982); Phase II (1987)
Pine (King)	Pine Lake Response to Diversion of Wetland Phosphorus Phase II Restoration of Pine Lake (Anderson and Welch, 1991)	Phase I (1982); Phase II (1991)
Sacajawea (Cowlitz)	Lake Sacajawea Restoration Project (Gibbs *et al.*, 1987)	Phase I (1976); Phase II (1987)
Sawyer (King)	Diagnostic Study of Lake Sawyer King County, Washington (Carroll and Pelletier, 1991); Lake Sawyer Hydrogeologic Study Black Diamond, Washington (Hart-Crowser, 1990)	
Vancouver (Clark)	Operations Plan - Rehabilitation of Vancouver Lake for the Port of Vancouver (Dames and Moore, 1980)	Phase I (1978); Phase II (1993)
Wapato (Pierce)	Wapato Lake Restoration Final Report: A Discussion of Design Considerations, Construction Techniques and Performance Monitoring (Entranco Engineers, 1986b)	Phase I (1981); Phase II (1987)

of each lake. At a minimum, 12 months of continuous water quality data are collected. Data are interpreted and various lake restoration approaches are evaluated to determine which approach(es) are most feasible for implementation. Guidance for conducting assessments to meet Ecology grant requirements is provided in Technical Guidance for Assessing The Quality of Aquatic Environments (Cusimano, 1994).

Phase II projects begin with the implementation of the restoration plan. Appropriate environmental review precedes actual construction and implementation activities to ensure adequate environmental safeguards are in place. After construction or implementation activities are complete, at least one year of post-restoration data are collected to evaluate the effectiveness of the chosen approach.

Lake Restoration Techniques

Lakes in Washington have been manipulated for several decades, especially for enhancing fisheries or increasing shoreline for development. Notable examples of early lake management include:

- Heavy use of rotenone from the 1950s to the 1970s to enhance trout fisheries (Department of Wildlife, no date)
- Lime additions in bog and wetland lakes to enhance fisheries during the 1950s (Menasveta, 1961)
- Extensive lake and wetland dredging projects for increasing shoreline for development (e.g., Duck Lake, Grays Harbor County, and several Snohomish County lakes including Lake Martha and Flowing Lake)
- Dam construction to create lakes for recreation enhancement (e.g., Big Meadow Lake, Pend Oreille County), for property development (e.g., Lake Limerick, Mason County), or for hydroelectric power generation (e.g., Lake Roosevelt)

Regulations in Washington now limit these management activities on public property. Currently, lake management in Washington focuses on fisheries management, aquatic plant management, and lake protection and restoration. Restoration techniques are usually targeted to enhance lakes for all uses, and often involves complementing the restoration with strategies to manage fish habitat, aquatic plants, and sources of water quality problems.

Many lake restoration techniques have been used in Washington. Documentation of methods used in this state is available primarily for projects which were funded through Ecology's lake restoration program (Tables 10 and 11). Most of the following lake restoration techniques have been used in Washington.

Phosphorus Precipitation and Inactivation

For phosphorus precipitation and inactivation, salts of iron, calcium, or aluminum are added to lake water to bind with particulate and soluble phosphorus. Aluminum sulfate (alum) is the most commonly used salt to precipitate and inactivate phosphorus in Washington lakes.

Phosphorus precipitation refers to physically and chemically removing phosphorus from the water column, so that phosphorus is not available for algae uptake in the photic zone. To precipitate phosphorus, a slurry of metal salts is applied to surface water. The resulting floc settles to the lake bottom, removing bound phosphorus from the water column. The floc also forms a barrier which retards the migration of phosphorus from the sediments to the overlying water.

Phosphorus inactivation refers to inhibiting the release of phosphorus from lake sediments by forming a physical and chemical barrier to nutrient recycling. To inactivate phosphorus in lake sediments, the salt slurry may be applied in the hypolimnion. Stability of the floc (and the length of the effectiveness of the treatment) varies considerably between lakes. Alum has been used in Long Lake (Thurston County), Long Lake (Kitsap County), and many others.

Dredging

Dredging is the physical removal of lake sediments, and is considered to be a long-term lake restoration technique. Sediments are dredged to deepen lakes and improve navigation, or to remove toxic substances or nutrient-rich sediment. Various types of dredges used to remove sediment include grab-bucket dredges, hydraulic dredges, pneumatic dredges or other special purpose dredges. Costs of dredging and disposal of dredge spoils, and disruption of sediment ecology, often limits dredging as a restoration option. Examples of Washington lakes which have been dredged include Lake Carlisle (Lewis County), Lake St. Clair (Thurston County; to improve navigation between lake basins), Liberty Lake (Spokane County), and Vancouver Lake (Clark County).

Dilution and Flushing

Nutrient-poor water is introduced to dilute the nutrient concentrations within a lake's water column. In Washington, dilution has been used in Green Lake (King County) and in Moses Lake (Grant County; Cooke *et al.*, 1986), and in Wapato Lake (Pierce County).

Diversion

The intent of diversion is to reduce nutrient loading to a lake. Usually, diversion refers to relocating a point source discharge to another waterbody. In Washington, the classic example is the diversion of Seattle sewage effluent from Lake Washington to Puget Sound. Diversion may also refer to the diversion and treatment of nutrient-rich inflow, such as wetland diversion away from Pine Lake (King County).

Drawdown

As a lake restoration technique, drawdown is most often used to control aquatic plants or to consolidate the sediments. Usually, lake level is lowered during winter, so that aquatic plant roots are frozen or desiccated. Because Western Washington has a temperate climate, this technique is used more effectively in Eastern Washington. Lake Eloika in Spokane County was drawn down to reduce the amount of emergent vegetation. Drawing lakes down in non-freezing conditions is sometimes used as a wetland enhancement technique, to aerate sediment for rooted plants.

Hypolimnetic Injection and Withdrawal

Hypolimnetic injection refers to directly introducing nutrient-poor water into the bottom waters of a lake during thermal stratification. Hypolimnetic withdrawal, on the other hand, is the removal of nutrient-rich bottom waters without disturbing thermal stratification. Disturbing thermal stratification during injection or withdrawal activities would prematurely initiate overturn, and could potentially stimulate algal growth. Hypolimnetic withdrawal has been used at Lake Ballinger in Snohomish County.

Artificial Circulation

As a lake restoration technique, lakes are artificially circulated by pumping compressed air into the deepest area of the lake to prevent stratification or to destratify the water column. Although this method is intended to oxygenate water to minimize internal loading, mixing some lakes has increased nutrient concentrations in the water column and reduced water clarity (Cooke *et al.*, 1986). This is not a common lake restoration technique, because results are not always predictable. However, artificial circulation is used by the Department of Fish and Wildlfe to enhance fish habitat and reduce fish kills in winter. Big Meadow Lake in Pend Oreille County and Lake Sidley in Okanogan County are examples of lakes which are aerated by the Department of Fish and Wildlife.

Hypolimnetic Aeration

Aeration is used to enhance fish and invertebrate habitat in the hypolimnion, and/or to keep phosphorus oxidized and bound in lake sediments. Water in the hypolimnion is aerated using an air-lift or partial air-lift, without disrupting stratification. Aeration techniques are designed to supplement oxygen concentrations without increasing the concentrations of other gases such as nitrogen, carbon dioxide, or methane. Hypolimnetic aeration is sometimes used in conjunction with alum treatments, to prolong the effectiveness of the treatment. Hypolimnetic aeration has been used at Medical Lake, Spokane County, and is presently used at Lake Stevens, Snohomish County.

Aquatic Macrophyte Harvesting

Harvesting refers to the cutting and removal of rooted aquatic plants. Various tools for harvesting are available. Plants may by cut and removed by hand, by a mechanical harvester, or by rotovation. As a lake restoration technique, harvesting is used to open up lake area for fish spawning and foraging, to improve boating, swimming, and other recreational uses, and to reduce oxygen demand in the water by reducing organic biomass. Harvesting has also been used in some lakes to remove nutrients bound in the biomass. Mechanical harvesters have been used in Lake Washington (King County), Lake Osoyoos (on the Canadian side of the border), and Long Lake (Thurston County) to open up areas choked with Eurasian watermilfoil; Long Lake in Kitsap County has been harvested to remove mats of Brazilian elodea.

Biological Controls

Ecology, the U. S. Army Corps of Engineers, and the Washington State Department of Wildlife are funding a demonstration project using the white amur, also known as the grass carp, to control excessive aquatic vegetation. The goals for this project include verifying sterility of the triploid grass carp, and determining growth rates and fish stocking rates. At present, grass carp may be introduced into waterbodies when permitted by the Washington State Department of Fish and Wildlife. Silver Lake (Cowlitz County), and Chambers Lake (Thurston County) have been stocked with grass carp to control aquatic plants. Preliminary research is also underway to investigate the safety and feasibility of introducing a native weevil to control Eurasian water milfoil.

"Biomanipulation" techniques can be used to manipulate algal populations by introducing zooplankton which graze on algae, increasing the populations of planktivorous fish, or reducing populations of zooplanktivorous fish.

Nutrient Source Controls

Nutrient loading may come from point ("end of pipe") or nonpoint sources. Although few lakes in Washington receive point source discharges directly, some lakes are fed by tributaries that are the receiving waters for point source discharges. Managing indirect nutrient loading to lakes from wastewater may be addressed by Ecology's recent efforts toward basin-wide evaluations prior to reissuing State Waste Discharge and NPDES permits.

Local governments manage nonpoint sources of nutrients--the most important of which are on-site septic systems and stormwater. Best Management Practices (BMPs) are also used to control nonpoint nutrient sources. Agricultural BMPs and stormwater BMPs have been used as lake restoration techniques. At Lacamas Lake (Clark County), BMPs were implemented to reduce nutrient loading from several dairy farms within the lake's watershed. Nutrient source control is a lake protection effort that involves planning and cooperation among local, state, and federal jurisdictions, as well as lakeshore residents, lake user groups, conservation groups, resources users, and major landowners within the watershed. Nutrient source control is a common goal of lake watershed management plans.

LAWS AND REGULATIONS THAT PROTECT WASHINGTON'S LAKES

Most laws and regulations that protect lakes are created and enforced at the local level; as a result, lake protection efforts tend to vary between Washington's counties. The following list is not all-inclusive, but lists laws that are commonly used by local governments and state agencies to protect lakes.

Water Quality Standards

The state of Washington Water Pollution Control Act (RCW 90.48) and the State Surface Water Quality Standards (Chapter 173-201 WAC) require the Department of Ecology to establish criteria and programs necessary to protect waters of the state. These standards are intended to protect public health and maintain beneficial uses of surface waters. Beneficial uses include recreational activities such as swimming, boating, and aesthetic enjoyment; public water supply; stock watering; fish and shellfish migration, rearing, spawning, and harvesting; wildlife habitat; and commerce and navigation.

All significant publicly-owned lakes must meet or exceed water quality criteria for Lake Class waters, and their inlet tributaries must meet or exceed water quality criteria for Class AA (extraordinary) waters, unless otherwise designated.

The Water Quality Standards also specifically allow Ecology to modify the water quality criteria on a short-term basis to accommodate essential activities, respond to emergencies, or otherwise protect the public interest. The most common activity in lakes that requires a short-term modification of water quality standards is aquatic herbicide treatment. This is discussed further in the Aquatic Plant Management Program section.

Shoreline Management Act

The Shoreline Management Act (Chapter 90.58 RCW) was enacted in 1971 to preserve, protect and manage development and uses of the state's shorelines. This Act requires local governments to develop master programs for regulating shoreline development, and to issue permits for "substantial development" within a shoreline. Guidance for development of these master programs is provided in Chapter 173-16 WAC, and guidance for development and administration of a permit program for shoreline development is provided in Chapter 173-14 WAC. Lakes which are under the purview of the Shoreline Management Act are listed in Chapter 173-20 WAC. Although local governments are ultimately responsible for shoreline management, Ecology reviews permits and insures compliance with the policies and provisions of the Shoreline Management Act.

State Environmental Policy Act (SEPA)

The State Environmental Policy Act (Chapter 43.21C RCW) is intended to minimize adverse environmental impacts from construction or management activities. SEPA provides guidance to evaluate environmental impacts of activities, identify methods to reduce the impacts, and involve the public. SEPA contains specific policies and goals which apply to actions at all levels of government within the state, except the judiciary and state legislature. The SEPA rules (Chapter 197-11 WAC) include guidance and requirements for compliance with SEPA. Actions requiring SEPA documentation include projects which require an agency decision (e.g., construction that requires one or more permits), as well as non-project actions that involve agency decisions on policies, plans, or programs (e.g., zoning modifications).

Activities which normally have low or no impact on the environment are listed as "categorical exemptions" under WAC 197-11-800-880. These activities are exempt from SEPA requirements. Some areas, though, have characteristics (such as unstable soils, steep slopes, wetlands, unusual or unique plants or animals) that make them more susceptible to environmental damage from activities. These areas can be designated as Environmentally Sensitive Areas (ESAs), in which case categorical exemptions do not apply. Cities or counties can designate and map areas as ESAs and identify the exemptions which do not apply in those areas. Ecology keeps a record of ESAs. Designation of ESAs has been used in watershed management planning in Washington, and can be an effective tool for lake management or protection.

Projects which are not exempt from SEPA requirements will require a review of the project proposal by a designated lead agency. This agency will decide whether the activity will have a probable, significant, and adverse environmental impact. If the review leads to a "determination of significance", the lead agency will scope the requirements of an environmental impact statement (EIS). The EIS is used to consult with agencies, tribal nations, and the public, to identify all concerns and potential impacts from the project.

Limits on Phosphorus Content of Household Detergents

In 1992, Spokane County banned the sale of household detergents that contain high concentrations of phosphorus, and efforts to impose statewide phosphorus limits began. Substitute Senate Bill 5320, which passed in April 1993, limits the content of phosphorus in household detergents sold or distributed within the state. Effective July 1, 1994, laundry detergents may contain up to 0.5 percent phosphorus by weight, and dishwashing detergents may contain up to 8.7 percent phosphorus by weight.

Passage of this bill acknowledges that household detergents contribute to phosphorus loading to surface and ground waters. Many areas of the U.S. have already passed limits or bans on phosphorus-containing detergents.

Lake Management Districts

Chapter 36.61 RCW created a mechanism by which property owners can create a taxing district to fund lake protection and management activities. Lake management districts can be initiated by a county legislative authority, or by filing a petition signed by 10 landowners or twenty-five percent of the landowners within the proposed lake management district, whichever is greater. Districts may only be created by a county after the landowners within the proposed lake management district approve the proposal by a simple majority vote. If approved, the county legislative authority will adopt by ordinance the creation of the management district. Votes and assessments are weighed by the amount of property held by a landowner. At Long Lake, Thurston County, a lake management district was formed to fund activities related to eradicating Eurasian watermilfoil in the lake.

Sewer Districts

Sewer districts have the authority to reduce, minimize, or eliminate pollutants in lakes, streams, ground water and waterways. Sewer districts may fund all or part of these actions by authorizing the issuance of bonds, and may also impose rates and charges on property owners for stormwater control facilities. The Liberty Lake Sewer District in Spokane County spearheaded lake restoration efforts at Liberty Lake, and has been in the forefront of comprehensive watershed planning that included control of nonpoint nutrient sources such as stormwater and yard debris.

The Hydraulic Code

To preserve, protect, and perpetuate fish and shellfish resources of the state, the state legislature passed the Hydraulic Code (RCW 75.20.100-140) in 1949. This law requires a hydraulic project approval from the Department of Fish and Wildlife for any construction activity on or near state waters that will use, divert, obstruct, or change the bed or natural flow of state waters, or will utilize any of the salt or fresh waters or materials from the beds. Activities that require hydraulic project approval include streambank protection; construction of bridges, piers and docks; pile driving; channel change or realignment; culvert installation; dredging; gravel removal; pond construction; and log, log jam or debris removal. Many lake restoration projects require a hydraulic project approval.

ACID DEPOSITION IN WASHINGTON LAKES

Neither the current assessment of lakes nor Ecology's former Acid Deposition Program have revealed any lakes in Washington that are affected by acid deposition. Research and monitoring to assess effects of acid deposition in Washington has focused on sensitive resources in alpine and subalpine areas of the Cascade Mountains. Initial reconnaissance level surveys conducted between 1980 and 1983 evaluated the extent and distribution of sensitive lakes in Washington. In 1985, the U.S. EPA conducted a survey of 117

Washington lakes to further identify lakes sensitive to acid deposition. From 1983 to 1991, Ecology's Acid Deposition Program focused on key indicator lake basins to provide an "early warning system" for detection of acid deposition effects. Due to funding constraints, Ecology's program was discontinued in 1991.

Dilute lakes in certain areas of Washington were found to be extremely sensitive to acid deposition, with acid neutralizing capacity (ANC) less than or equal to 50 μeq/L and pH values less than or equal to 6.0. The U.S. EPA has estimated that 219 lakes in Washington, primarily in the Cascade mountains, have ANC values in this range. In addition, the U.S. EPA estimated that 31 lakes have pH values less than or equal to 6.0. This estimate was statistically derived, so the actual total acres of lakes threatened is unknown. The sensitivity of Cascade mountain lakes is due largely to geologic factors which result in very low natural buffering capacity. By contrast, lakes in the Olympic mountains have relatively high buffering capacity.

Three separate study areas representing the North Cascades, Central Cascades, and South Cascades, were the focus of Ecology's annual monitoring and research efforts. Objectives of the alpine lakes studies were to conduct long-term monitoring of lake chemistry and other indicators of acid deposition, study lake response to changes in acid oxide air emission, and evaluate precipitation-watershed-lake relationships. The basic lakes monitoring program collected surface water samples during the ice-free period for analysis of acid-base chemistry. Mountain precipitation was sampled at three locations in the Cascades to evaluate snow chemistry and deposition rates for significant ions, such as nitrate and sulfate.

Significant snowmelt-related effects on lake chemistry have been documented, particularly in fast-flushing lakes (flushing rates exceeding 20 times per year). Snowmelt episodes generally result in depressed pH and ANC and reduced concentrations of base cations while sulfate levels remain relatively constant. The seasonal effects demonstrate the degree to which water quality conditions in the Cascade lakes are influenced by precipitation chemistry. The potential for episodic acidification appears to be the greatest pollution threat currently facing these sensitive resources. It has not been determined whether seasonal reductions in pH and ANC are currently having any effect on aquatic biota in the lake basins.

Acid oxide emissions potentially affecting sensitive alpine lakes in Washington have changed substantially from the early 1980's. Data from a six-year study in the Central Cascade lakes indicate statistically significant decreases in sulfate levels in the lakes but no overall trend in alkalinity associated with reductions of sulfur dioxide emissions from two major sources (Mt. St. Helens and a large copper smelter). Sulfate levels decreased by an average of 3.6 μeq/L (or 33%) in the slow-flush lakes and 6.5 μeq/L (or 34%) in the fast flush lakes from 1983 to 1988. Loads from other minor sources of sulfur dioxide have not been assessed or tabulated. No restoration methods have been implemented since no adverse impacts to these lakes have been observed.