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EPA

TMDL Case Study

Lake Chelan, Washington

Key Feature: A phosphorus TMDL to protect a threatened lake

Project Name: Lake Chelan
Location: EPA Region X/Chelan County, Washington
Scope/Size: Lake, watershed 2,393 km^2
Land Type: Ecoregion 10, high mountains
Type of Activity: Forest, agriculture, urban
Pollutants: Phosphorus, bacteria
TMDL Development: PS, NPS
Data Sources: State and local
Data Mechanisms: Steady-state model
Monitoring Plan: Yes
Control Measures: Increased public sewerage, development limits, boat sewage pump-outs, agricultural and stormwater management

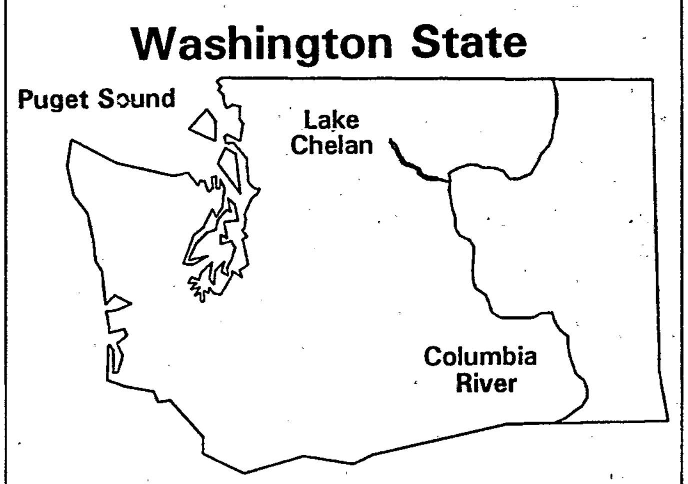

FIGURE 1. Location of Lake Chelan in central Washington

Summary: Lake Chelan, located in the Northern Cascades of central Washington State (Figure 1), is classified as ultra-oligotrophic. It has extremely low nutrient levels and a high degree of clarity. Although it is not on Washington's 303(d) list, increasing development pressures have raised concerns about maintaining the lake's high water quality. During 1989, in an effort to protect this unique and highly valuable natural resource, the Washington State Department of Ecology (DOE) conducted the Lake Chelan Water Quality Assessment which determined the nutrient loading limits that will maintain the lake's ultra-oligotrophic condition.

In 1990, the Lake Chelan Water Quality Committee, which is composed of representatives from local public agencies, prepared a water quality plan based on the assessment. The plan included a list of action items for controlling nutrients and bacteria from on-site septic systems, underground sewer lines, agricultural runoff, and urban stormwater runoff. The water quality plan also included a TMDL for total phosphorus in Lake Chelan. To support the Committee's effort, DOE conducted the technical TMDL analyses for several options, based on potential development patterns in different portions of the basin. The most-likely option was chosen and a phosphorus TMDL of 51 kg/day was submitted to and approved by EPA Region X. The TMDL includes load allocations of 0.5 kg/day for future growth, 6.3 kg/day for existing sources, and 44.2 kg/day for background loads (Pelletier, 1991). The Lake Chelan Water Quality Committee is responsible for implementing the water quality plan in order to meet the TMDL. The committee is currently investigating various control approaches such as sewer line replacement, sewer system extension, boat sewage pump-out facilities, agricultural runoff management, and stormwater management.

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BACKGROUND

Lake Chelan is located in the northern Cascades, approximately 100 miles east of Seattle and 50 miles south of the Canadian border. Lake Chelan serves as a water supply for more than 6,000 residents, provides irrigation water for approximately 18,000 acres, and produces hydroelectric power (Beck and Assoc., 1991). It is also an important location for water-related recreation and fisheries production. It is considered one of the most pristine bodies of water in North America, with a high degree of clarity and extremely low nutrient levels.

Lake Chelan is over 50 miles long with an average width of 1 mile. It has a surface area of 52 mi^2 (134 km^2) and a watershed of approximately 924 mi^2 (2393 km^2). Lake Chelan discharges to the Chelan River at a small hydroelectric dam in the city of Chelan (Figure 2). The dam, which was constructed in 1927, raised the level of the lake by 24 feet. Beyond the dam, the Chelan River flows only a few miles before emptying into the Columbia River. The average annual discharge from Lake Chelan is 2,050 cubic feet per second (cfs); its bulk detention time (i.e., the average amount of time it takes for the all of the water in the lake to be exchanged) is approximately 10.6 years (Patmont et al., 1989).

Lake Chelan has two distinct basins, which are distinguished mainly by their bathymetry. The upper basin is extremely deep and approximately 38 miles in length. The maximum recorded depth is 1,486 feet although some local residents maintain that the lake "has no bottom." The lower basin, which is bordered by the city of Chelan, is approximately 12 miles long and has an average depth of approximately 141 feet (Patmont et al., 1989).

The upper basin is very remote and accessible only by boat or plane. Consequently, the vast majority of its watershed remains heavily wooded and undisturbed. Most of the watershed is public land, including the Lake Chelan National Recreation Area, the Sawtooth Wilderness, the Wenatchee Forest, and portions of the North Cascades National Park and Glacier Peak Wilderness. Land use in the lower watershed is a mixture of forest, apple orchards, and urban land. Table 1 summarizes the distribution of land uses in the watershed as a whole.

The total resident population of the Chelan basin was approximately 6,600 in 1987. However, the population changes seasonally due to fluctuations in the farm labor force, tourism, and recreation. Nearly all of the residents live in the lower basin, primarily in the city of Chelan and the town of Manson. In the upper basin,

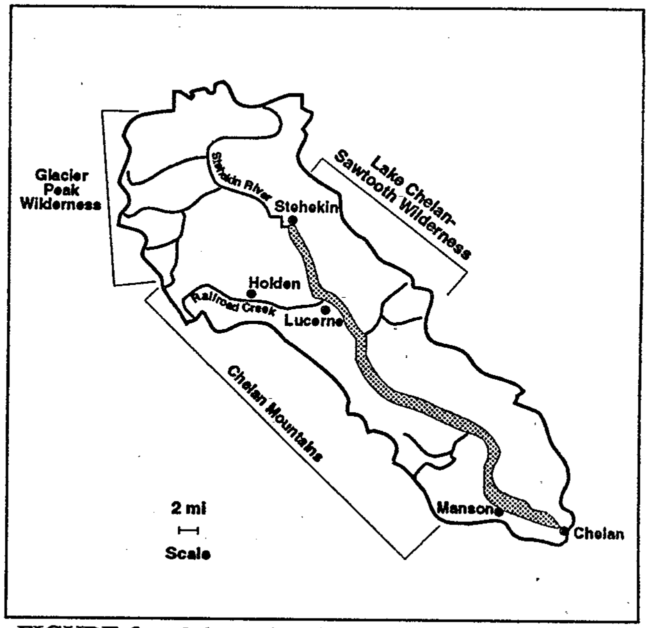

FIGURE 2. Schematic of the Lake Chelan watershed

approximately 130 people live in the villages of Stehekin, Lucerne, and Holden. Between 1910 and 1950, a mine operated in the Holden area and the upper basin was more populated. The lower basin reported a 12.5 percent population increase between 1970 and 1980, a growth rate that is likely to continue or increase in the future because of the basin's recreational appeal (Patmont et al., 1989).

ASSESSING AND CHARACTERIZING THE PROBLEM

Targeting and Prioritizing

Identifying and protecting threatened good-quality waters are important to the TMDL program. Although Lake Chelan is not currently classified as water quality-limited and does not appear on Washington's 1992 section 303(d) list, there is concern that, without comprehensive planning, increasing development in the watershed could degrade water quality. It is for this reason that, in April, the Lake Chelan Water Quality Committee developed a phosphorus TMDL for Lake Chelan.

Monitoring and Data

In 1989, Washington's Department of Ecology (DOE) conducted the Lake Chelan Water Quality Assessment. This intensive study was designed to (1) provide baseline water quality data; (2) evaluate the suitability of on-site wastewater disposal systems within the developing lower basin; and (3) estimate the potential sources and impacts of nutrients, bacteria, and other chemicals of concern.

TABLE 1. Land use within the Lake Chelan watershed (Patmont et al., 1989)

Land Use	Area (mi^2)	Percent of Total
Lake Chelan	52	5.6
Other Water Bodies	1.5	0.2
Forested Public Lands	772	83.9
Forested Private Lands	63	6.8
Agriculture - Orchard	18	2.0
Agriculture - Nonorchard	12	1.3
Residential	2.3	0.3
Roadways	2.3	0.2
Commercial and Public Buildings	0.38	0.0
TOTAL	923.9	100

The State's report detailed the lake's present condition and supplied most of the technical information for developing this TMDL (Patmont et al., 1989). Table 2 summarizes the lake's water quality characteristics for several parameters of concern.

Phosphorus

Phosphorus is the principal nutrient controlling algal growth in Lake Chelan. This was determined through analysis of water column and particulate matter nitrogen-to-phosphorus ratios (Table 2). Both ratios indicated that phosphorus is the nutrient limiting algal growth.

The Lake Chelan Water Quality Assessment estimated that from 75 to 90 percent of the phosphorus input to the lake comes from natural sources, largely forest runoff and direct precipitation. Of the remaining 10 to 25 percent attributable to anthropogenic sources, roughly half comes from agricultural activities, primarily orchards. A large portion of the total agricultural runoff loads are attenuated in three small lakes located in orchard areas approximately 1 mile north of the lake's north shore. However, loading values associated with the runoff from orchard operations have not been quantified (Beck and Assoc., 1991).

The remaining phosphorus loads in the basin are attributable to stormwater runoff and septic system inputs (Patmont et al., 1989). Homes using on-site waste disposal contribute approximately 0.08 kg P/day/1,000 homes. This includes phosphorus from the septic system and from lot runoff. Homes on public sewer systems are estimated to contribute only to the runoff component, or 0.001 kg P/day.

Chinook salmon net pens are the only point source of phosphorus in the watershed. Net pens are large, floating, barge-like structures that contain dense populations of fish being raised for market. The fish, which are fed with special preprocessed food packs, are estimated to contribute 0.01 kg P per day per 2,000 lb of fish (Beck and Assoc., 1991).

Bacteria

In addition to phosphorus enrichment, pathogens from septic systems pose a health concern for those who use the lower basin as a source of drinking water. At the lake outlet, fecal streptococcus, fecal coliform, and total coliform are within state and federal criteria for water contact recreational use; however, values do regularly exceed the State's potable water standard of 1 count/100 ml (Patmont et al., 1989). The Chelan-Douglas Health District chlorinates water prior to distribution.

The Management Plan

In 1990, the City of Chelan, Chelan County, the Chelan County Public Utility District, the Lake Chelan Sewer District, and the Lake Chelan Reclamation District formed the Lake Chelan Water Quality Committee. With funding from the Washington Centennial Clean Water Fund, the Committee prepared the Lake Chelan Water Quality Plan, which specifies steps to ensure that Lake Chelan maintains its present ultra-oligotrophic status. Since urbanization is a major concern in the watershed, the plan's primary recommendations are to

TABLE 2. Average spring/summer values for selected water quality parameters for Lake Chelan, Washington

Parameter	Average Epilimnetic Value (95% CI)
Secchi Disk Depth (m)	12.1 +/- 0.5
Temperature (°C)	13.2 +/- 0.4
pH	7.67 +/- 0.02
Dissolved Oxygen (mg/L)	10.6 +/- 0.1
Total Suspended Solids (mg/L)	0.1 +/- 0.0
Sp. Conductance (umho/cm)	56.7 +/- 0.1
Total Phosphorus (ug/L)	3.01 +/- 0.18
Total Nitrogen (ug/L)	103 +/- 6
Total Coliform (#/100 ml)	2.2 +/- 0.5
Particulate N:P	> 15:1
Water Column N:P	30:1 +/- 3:1

expand existing sewerage facilities and to extend services to presently unsewered areas. Specific concerns are as follows (Beck and Assoc., 1991):

On-site wastewater management - Older on-site systems may not perform satisfactorily. For certain situations, hookup to public sewers may become mandatory.

Stormwater management - Runoff from newly developed areas may increase pollutant loadings to the lake. New ordinances for stormwater and drainage standards are being developed.

Agricultural activities - Runoff from agriculture impacts the lake; monitoring to determine potential impacts may be considered, as may improved farmer education and the increased development of farm plans.

Boat sewage disposal - As boat recreation increases, so will potential for pollution. A task force to develop an improved program for regulation and education, additional facilities, and new licensing provisions have been proposed.

TMDL DEVELOPMENT

The goal is to preserve the ultra-oligotrophic condition of Lake Chelan. Additional total phosphorus (TP) loadings to the lake (over the 1986-87 load) are considered acceptable only if there is less than a 5 percent chance that such additions will cause in-lake (lower basin) TP concentrations to exceed 4.5 μg/L, which is a generally accepted value for the ultra-oligotrophic classification. Management goals are expressed in terms of their effect on the lower basin because the lower basin is relatively shallow and consequently more prone to the effects of increased phosphorus loads. DOE conducted these analyses as technical support for the Lake Chelan Water Quality Committee's water quality plan.

Using a steady-state mass balance model and Monte Carlo analysis techniques, DOE calculated that the 4.5 μg P/L goal could be achieved by allowing a maximum load increase to the lower basin of 0.5 kg P/day above the 1986-87 load (Patmont et al., 1989). DOE included a margin of safety by calculating the permissible loading conservatively so that the probability of remaining ultra-oligotrophic is 95 percent.

The allowable increased load of 0.5 kg P/day was based on the assumption that all growth will occur in the lower basin. However, when conducting the TMDL analysis, DOE modelers considered three different population growth options (Table 3): (1) growth in the lower basin, no growth in the upper basin; (2) a mixture of growth in the upper and lower basins; and (3) growth in the upper basin, no growth in the lower basin.

Because of its great depth, the upper basin allows greater TP settling relative to the lower basin. Therefore, a greater loading can be permitted in the upper basin while still meeting the management objective. DOE modelers calculated that phosphorus loads to the upper basin have about half the impact on lower basin TP of loads that enter the lower basin directly. Specifically, a 1 kg P/day load in the upper basin was equivalent to a 0.52 kg P/day load in the lower basin (in terms of the effect on lower basin TP). These values were calculated by using annual steady-state mass balance equations for the upper and lower basins (Pelletier, 1991). Based on this information, load allocations were developed for each growth option (Table 3).

The TMDL that DOE submitted to EPA Region X on behalf of the Committee specifies Chinook net pens, tributaries, and groundwater as phosphorus sources. The tributaries and groundwater are assumed to cover loads from urban runoff and septic systems. The TMDL sets total phosphorus loading to 51.0 kg P/day. In terms of population scenarios, this corresponds to either Option 1 or the first two scenarios in Option 2 (Table 3). Based on the projected level of growth for the basin, it will be about 35 years before growth will become limited by the allocations set by this TMDL. EPA Region X approved the TMDL for Lake Chelan on January 26, 1993.

Allocating loads to specific sources depends upon future development patterns in the watershed. The Lake Chelan Water Quality Plan therefore considered load allocations for the four different development scenarios shown in Table 4. Scenario 1 is the most likely development path given current trends.

IMPLEMENTATION

A schedule for the implementation of nutrient control measures has been developed as part of the Lake Chelan Water Quality Plan. The schedule is referenced in the TMDL as the means of implementation. Table 5 summarizes the primary activities in the schedule.

The Lake Chelan Water Quality Committee is responsible for implementing the plan's activities. Since the development of the plan in 1991, the committee has been meeting on a monthly basis. Subcommittees are actively pursuing water quality issues on several fronts. Some recent activities are summarized below (B.

TABLE 3. Summary of load allocation strategies for future development in the upper and lower basins of Lake Chelan (Pelletier, 1991)

	LOAD ALLOCATIONS (kg P/day)				
	Existing (1986-87) land uses in lower basin	Future growth in lower basin	Future growth in the upper basin	Background load from upper basin watershed and precipitation	TMDL
OPTION 1: No growth in upper basin	6.3	0.50	0.00	44.2	51.0
OPTION 2: Mixture of growth in upper and lower basins	6.3	0.47	0.05	44.2	51.0
	6.3	0.45	0.10	44.2	51.0
	6.3	0.40	0.20	44.2	51.1
	6.3	0.34	0.30	44.2	51.1
	6.3	0.29	0.40	44.2	51.2
	6.3	0.24	0.50	44.2	51.2
	6.3	0.19	0.60	44.2	51.3
	6.3	0.14	0.70	44.2	51.3
	6.3	0.08	0.80	44.2	51.4
OPTION 3: No growth in lower basin	6.3	0.00	0.96	44.2	51.5

Wengreen, Public Utility District #1 of Chelan County, personal communication, September 22, 1993):

Wastewater treatment - Although the Chelan Treatment Plant discharges into the Columbia River, the collector pipe for the Lake Chelan Sewer District runs under the lake shore. This has sparked significant water quality and health concerns. Negotiations are underway regarding the replacement of the sewer collector line for the district.

Stormwater - Proposed regulations for stormwater management are currently being developed by the City of Chelan and Chelan County.

Boat Sewage - One new boat sewage pump-out station has been installed, bringing the total in the lake to three. Additional pump-outs are being investigated.

LONG-TERM MONITORING

The Lake Chelan Water Quality Plan includes a long-term water quality monitoring strategy. The plan states that permanent stations will be chosen and selected parameters will be monitored on a repeating year cycle. This has not yet occurred; however, the Lake Chelan Reclamation District has received a $176,000 grant (75 percent cost share) to initiate a short-term "Irrigation Water Management and Drain Monitoring" project in the watershed.

The drain monitoring portion of the plan will assess water quality trends and runoff from agricultural drains to evaluate pollutant loading during worst case conditions. At a minimum, the following parameters will be evaluated: flow, fecal coliform, total suspended solids, turbidity, dissolved oxygen, temperature, pH, TP, ammonia nitrogen, nitrites, nitrates, and conductivity. DOE also conducts monthly TP sampling at the lake outlet.

The irrigation water management portion of the project will involve extensive soils analysis to determine the optimum procedure for managing irrigation rate, timing, and duration. The goal is to help growers minimize the amount of water leaving the site either through runoff or deep percolation (DOE, 1993).

TABLE 4. Load allocations for four Lake Chelan development scenarios (Beck and Assoc., 1991)

Scenario 1: Sewer system extended, but proportion of homes on septic remains the same

This scenario assumes that net pens remain at their current size, agricultural lands do not increase in size, and the percentage of homes on septic systems remains the same.

Source Type	Allowable Load	Development Potential
Homes using on-site disposal	0.16 kg P per day	800 new residential units
Homes on sewer systems	0.33 kg P per day	3,300 new residential units
Chinook net pens	0.01 kg P per day	2000 lb of fish (existing)
Agricultural activities	0.00 kg P per day	No additional acres

Scenario 2: Comprehensive sewerage

This scenario assumes that a comprehensive sewer plan is developed and implemented. This would result in the construction of very few, if any, on-site sewer systems in the future.

Source Type	Allowable Load	Development Potential
Homes on sewer systems	0.49 kg P per day	4,900 new residential units
Chinook net pens	0.01 kg P per day	2,000 lb of fish (existing)
Agricultural activities	0.00 kg per day	No additional acres

Scenario 3: Sewer systems not extended

This scenario assumes that sewer systems are not expanded beyond their current service areas and that sewered homes are built until the capacity of the treatment plant is reached.

Source Type	Allowable Load	Development Potential
Homes on sewer systems	0.23 kg P per day	2,300 new residential units
Homes with on-site disposal	0.26 kg P per day	1,440 new residential units
Chinook net pens	0.01 kg P per day	2000 lb of fish (existing)
Agricultural Activities	0.00 kg per day	No additional acres

Scenario 4: Agricultural land converted to home sites

This scenario assumes that some agricultural lands are converted to home sites. This is considered highly probable and will likely occur in conjunction with any of the first three scenarios.

Conversion to homes with sewer systems	1 additional home for every 0.24 acre converted
Conversion to homes with on-site septic systems	1 additional home for every 2.0 acres converted

TABLE 5. Summary of required actions (Beck and Assoc., 1991)

Agency/Action Item	Cost ($ 1990)
WQ Advisory Committee	
• Plan approval	—[a]
• Expand and formalize committee	—[a]
• Establish boat sewage task force	—[a]
• Submit sewer hookup ordinances	—[a]
• Establish on-site wastewater task force	—[a]
• Submit stormwater ordinances	—[a]
• Submit amended boat registration rates	—[a]
City of Chelan	
• Prepare stormwater management plan	150,000
• Construct interim facilities	350,000
• Relocate primary facilities and expand wastewater plant	6,700,000
Chelan Public Utility District	
• Relocate interceptor	3,500,000
• Construct lakeside/primary plant interceptor	850,000
• Construct Minneapolis Beach/Yacht Club interceptor	4,630,000
• Construct Yacht Club/Fields Landing interceptor	3,620,000
Chelan County	
• Prepare stormwater management plan	150,000
Lake Chelan Reclamation District	
• Extend sewer past Willow Point	1,390,000
Chelan County Conservation District	
• Conduct agricultural drain monitoring	75,000
• Prepare farm plans	—[a]
Washington State Parks	
• Construct 25 Mile Creek wastewater facilities	2,160,000
WSU Cooperative Extension	
• Establish education programs for growers	—[a]
Chelan County Fire Marshall	
• Survey storage tank practices	—[a]

[a] Funds from each agency's ongoing programs.

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This case study was prepared by Research Triangle Institute, Research Triangle Park, NC, in conjunction with EPA, Office of Office of Wetlands, Oceans, and Watersheds, Watershed Management Section. To obtain copies, contact your EPA Regional 303(d)/TMDL Coordinator.