Table 5-1. Hydrologic budget associated with each budget component, Payette 1995-1996.

	1995		1996	
	Volume hm^3	Percent of Total	Volume hm^3	Percent of Total
Gaged Inflows	**Inflow**		**Inflow**	
North Fork Payette River	304	70.7	399	74.7
Fall Creek	17.3	4.0	15.3	3.6
Deadhorse Creek	11.7	2.7	11.4	2.6
[1] **Ungaged Tributaries**	90	20.8	101	23.6
[2] **Direct Surface Runoff** Developed and Undeveloped Lake Perimeter	2.9	0.7	2.7	0.6
Precipitation	4.7	1.1	4.1	0.9
	Outflow		**Outflow**	
North Fork Payette River	408	96.2	528	97.1
Evaporation	4.3	1.0	4.2	1.0
Municipal withdrawal	11.4	2.7	11.4	2.7
Summary				
Total Inflow	430		534	
Total Outflow	424		544	
Change in Lake Storage	30		-87	
[3] Residual	-24		77	

[1] Includes runoff contributions from watersheds below USGS gage 13238322 and other tributaries draining directly to the lake.

[2] Runoff = Area *rainfall*runoff coefficient. Runoff coefficients based on land types and values as presented in Tables 5-4 through 5-13 and 5-4 through 5-14.

[3] (Total inflow-total outflow)-change in lake storage.

Table 5-2. Annual coefficients for unit runoff and nutrient export for three gaged inflow stations and one gaged outflow station, Payette Lake, 1995-1996. [km^2, square kilometer; kh^3/km^2, cubic hectometer per square kilometer; kg/km^2, kilogram per square kilometer; TP, total phosphorus; TN, total nitrogen].

Station Name (Figure 3-2)	Drainage area (km^2)	Unit-runoff coefficient (hm^3/km^2)		Nutrient export coefficient (kg/km^2)			
				TP		TN	
		1995	1996	1995	1996	1995	1996
North Fork Payette River below Fisher Creek	221	1.38	1.81	12.0	16.5	725	951
Dead Horse Creek	12.8	0.93	0.91	15.5	13.9	370	307
Fall Creek	17.3	1.00	0.88	842	46.4	1,500	797
North Fork Payette River at McCall	373	1.09	1.42	6.2	8.0	278	400

5.2 Nutrient Budgets

Substantially more total phosphorus entered Payette Lake in 1995-96 than was discharged from the lake (Table 5-3). In 1995, the largest single source load of phosphorus to the lake was Fall Creek (55.4%). This creek was heavily impacted by the 1994 fire and contained high concentrations of phosphorus in the runoff. Accordingly, computed loadings and the standard error of the estimate for this creek was extremely high (6,682-22,480 kg). Assuming the lower loading estimate better approximates the phosphorus yield, the Fall Creek contribution of phosphorus would have exceeded 36% of all inputs. More stable post fire conditions in 1996 provide a better basis for comparing relative importance of the inflows to Payette Lake. These results indicate the N.F. Payette River accounted for 46 percent of the total loading of phosphorus to the lake. Other ungaged surface-water tributaries accounted for 23.6 percent of the incoming load. These two sources together accounted for nearly 70 percent of the incoming load. Direct surface runoff around the perimeter contributed 9.5 percent of the total phosphorus load. Atmospheric deposition accounted for roughly 8 percent of the load. The City of McCall's municipal water withdrawal accounted for about 3-percent of the outflow of total phosphorus; the remainder was via the lake's outlet.

As with total phosphorus, Payette Lake received substantially more total nitrogen in 1995-96 than it discharged (Table 5-4). The North Fork Payette River inflow dominated the inflow budget in both years; the next largest contribution was from ungaged tributary inflow. Atmospheric deposition accounted for less than 3-percent of the load. About 2-percent of the outflow of total nitrogen was via municipal water withdrawal.

Table 5-3. Total phosphorus budget Payette Lake, 1995-1996.

	1995		1996	
	Load kg/yr	Percent of Total	Load kg/yr	Percent of Total
Gaged Inflows	**Inflow**		**Inflow**	
North Fork Payette River	2,660	10.1	3,640	46.3
[1] Fall Creek	14,571	55.5	803	10.2
Deadhorse Creek	198	0.8	178	2.3
[2] **Ungaged Tributaries**	7,360	28.0	1,860	23.6
[3] **Direct Surface Runoff** Developed and Undeveloped Lake Perimeter	818	3.1	725	9.2
Atmospheric Deposition	660	2.5	660	8.4
	Outflow		**Outflow**	
North Fork Payette River	2,300		2,960	97.7
Municipal withdrawal	49		69	2.9
Summary				
Total Inflow	26,267		7,866	
Total Outflow	2,349		3,029	
Change in Lake Storage	129		-531	
[4] Residual	23,789		5,368	
Percent Retention	90.6		68.2	

[1] Estimate based on two consecutive sampling periods in which extremely high concentrations of TP were measured during high flow events. Estimated TP load with standard errors ranges from 6,682 to 22,460 kg/yr.

[2] Includes runoff contributions from watersheds below USGS gage 13238322 and other tributaries draining directly to the lake.

[3] Load=Area *Rainfall*runoff coefficient*TP concentration. Runoff coefficients based on land types and values as indicated in Tables 5-4 through 5-13 and 5-4 through 5-14. A runoff concentration of 14 mg/m3 TP was used for undeveloped lands. Mean pollutant concentrations used for developed lands as described in stormwater section (4.3.1).

[4] (Total inflow-total outflow)-change in lake storage.

Payette Lake acted as a trap (Outflow-Inflow = positive residual) for total phosphorus and total nitrogen (Tables 5-3 and 5-4). For example, the residual for total phosphorus in 1995 was 23,789 kg and 5,368 kg in 1996; thus the lake trapped roughly 90% of the inflow TP in 1995 and approximately 68% in 1996. The high trapping efficiency of the lake is due, in part, to its long residence time and the presence of a shallow morphometric constriction between the northern and southwestern basins. Model calibration indicated phosphorus sedimentation rates were particularly high resulting in rapid removal of particulate phosphorus from the water column as this material quickly settles to the lake bottom (see Model Calibration). Total nitrogen retention was also high at roughly 55 to 53% for the two water years.

Due to the long residence time, nutrient character of the source waters entering the lake are quite different compared to the outflow. The total and dissolved forms of phosphorus and nitrogen for the two North Fork Payette River stations (inflow and outflow) were concurrently measured and associated loads computed for each water year (Table 5-5). The percentage contribution of dissolved orthophosphorus to total phosphorus of the inflow averaged 22.4 percent and declined to 15.6 percent for the outflow station. Similarly, the percentage contribution of dissolved inorganic nitrogen to total nitrogen averaged 67.1 percent for the inflow station and 34 percent for the outflow station. These declines in the percentage contribution of the dissolved fractions between the inflow and outflow stations is attributable, in part, to phytoplankton and periphyton assimilation and conversion to the particulate nutrient pool of the lake (detrital algae).

Nitrogen and phosphorus was also added to Payette Lake from decomposition of kokanee salmon carcasses remaining from the autumn spawning run into the lower reach of the North Fork Payette River. About 7 kg of phosphorus and 55 kg of nitrogen were added to the lake in 1995 and 1996. These loads were not reported in the nutrient budgets (tables 5-3 and 5-4), but would have been a very small percentage addition. The loads were calculated using two data sources. Data from IDFG on numbers of spawning fish, mean biomass per fish and predation losses (P. Janssen, IDFG, written communication, 1996) were multiplied by the percentage composition of phosphorus and nitrogen in the carcasses. Phosphorus and nitrogen comprised 0.364 and 3.0 percent, respectively, of the biomass of rainbow trout *(Oncorhynchus mykiss)* as reported by Schuldt and Hershey (1995); these values were assumed to apply to kokanee salmon in the North Fork Payette River. Although this load was a small addition to Payette Lake's nutrient budget, it occurs annually and, thus, represents a long term, cumulative nutrient load.

An unquantified nutrient load to Payette Lake was from periphyton in the North Fork Payette River downstream from the USGS gaging station downstream from Fisher Creek (Figure 5-3). This lower most reach of the river supports a substantial amount of periphyton during the summer, partly because this is a quiescent reach affected by backwater from Payette Lake. Backwater conditions were produced by the damming of the lake in the early 1940's. In the autumn and winter, the periphyton become senescent and some portion, in a particulate and dissolved form, is scoured and transported into the lake with streamflow. This nutrient load was not quantifiable, but is probably not large in relation to the lake's nutrient budget. However, it represents another long term nutrient load.

Table 5-4. Total nitrogen budget Payette Lake, 1995-1996.

	1995		1996	
	Load kg/yr	Percent of Total	Load kg/yr	Percent of Total
Gaged Inflows	**Inflow**		**Inflow**	
North Fork Payette River	16,000	64.3	210,000	74.5
Fall Creek	25,960	10.4	13,782	4.9
Deadhorse Creek	4,730	1.9	3,934	1.4
[1] **Ungaged Tributaries**	48,069	19.3	44,631	15.8
[2] **Direct Surface Runoff** Developed and Undeveloped Lake Perimeter	3,532	1.4	2,965	1.1
Atmospheric Deposition	6,560	2.6	6,560	2.3
	Outflow		**Outflow**	
North Fork Payette River	104,000	98.2	149,000	98.3
Municipal withdrawal	1,890	1.8	2,530	2.4
Summary				
Total Inflow	248,851		281,872	
Total Outflow	105,890		151,530	
Change in Lake Storage	4,980		-19,300	
[3] Residual	137,981		149,642	
Percent Retention	55.4		53.1	

[1] Includes runoff contributions from watersheds below USGS gage 13238322 and other tributaries draining directly to the lake.

[2] Load=Area*Rainfall*runoff coefficient*TP concentration. Runoff coefficients based on land types and values as indicated in Tables 4-13 and 4-14. A runoff concentration of 305.7 mg/m3 TN was used for undeveloped lands. Mean pollutant concentrations used for developed lands as described in stormwater section (4.3.1).

[3] (Total inflow-total outflow)-change in lake storage.

Table 5-5. Loads of nitrogen and phosphorus for water years 1995 and 1996 at North Fork Payette River below Fisher Creek (13238322) and North Fork Payette River at McCall (13239000).

		Load (kg/yr)	
Station	Constituent	1995	1996
13238322	TP	2,660	3,640
	DOP	591	820
	TN	160,200	210,200
	TON	52,800	69,300
	DIN	107,400	141,000
	DN+N	106,200	139,400
	DAMM	1,200	1,570
13239000	TP	2,300	2,960
	DOP	356	462
	TN	103,500	148,700
	TON	66,200	101,200
	DIN	37,400	47,500
	DN+N	36,600	46,400
	DAMM	733	973

5.3 Limnology

5.3.1 Water temperature

Solar heating was sufficient to develop thermal stratification and thermoclines (decrease in water temperature with depth exceeds 1 C per meter) at the four stations in both years (Figure 5-1). Thermoclines developed during June and persisted into October. Thermocline depths ranged from about 4 m in June to about 10 m in October. Maximum water temperatures in both years were measured near the surface in late July. In 1995, the maximum was 21.1 C at station 1; in 1996, the maximum was 20.6 C at station 3. Minimum water temperatures reached 0 C immediately beneath the ice that covered the lake surface during the winter months. Hypolimnetic water temperatures ranged from about 4 C during ice cover to between 5 and 6 C near the end of thermal stratification.

5.3.2 Water-column transparency

The two measures of water-column transparency, secchi-disc transparency and euphotic-zone depth, had a strong positive correlation ($r=0.77$, $p<0.00001$, $n=71$). The smallest values for the two variables were measured during June of both years when snowmelt runoff had increased turbidity in the lake (Figure 5-2). After June, the two variables steadily increased in depth as suspended sediment settled. One exception to this trend was at station 1 during 1996 when both variables either decreased in depth or failed to deepen substantially. Among the four stations, station 1 had the highest density of phytoplankton; thus, its water-column transparency was accordingly reduced.

Median secchi-disc transparencies at the four stations during 1995 were equal to or less than those measured in 1996 (Table 5-6). Median euphotic-zone depths were equivalent between the two years, except at station 3. The euphotic zone was typically deeper than the thermocline at each of the four stations. Under that condition, the phytoplankton circulating within the epilimnion (mixed zone above the thermocline) remain exposed to amounts of PAR sufficient for photosynthetic production of carbon in excess of respiratory demands.

Table 5-6. Medians and ranges of secchi-disc transparency and euphotic-zone depth at four limnetic stations, Payette Lake, 1995-1996.

	Secchi-disc transparency (meters)		Euphotic-zone depth (meters)		
Limnetic station	Median	Range	Median	Range	No. of Samples
1995					
1	4.5	2.5-7	11	9-13	9
2	5.3	2.3-7.2	11	9-13	9
3	4.6	2.5-8	10.5	8-13	8
4	4.2	2.5-6.6	11	8-13	9
1996					
1					
2	4.5	3.5-7	11	10-13	9
3	5.5	3.1-7.6	11	9-13	9
4	5.2	3.6-7.6	11	9-13	9
	5.3	3.5-7.8	11	9-13	9

Figure 5-1. Lines of equal temperature, in degrees celsius, at stations 1-4 during selected months of 1995-1996.

Figure 5-2. Depths of euphotic zone and secchi-disc transparency at stations 1-4 during 1995-1996.

5.3.3 Specific conductance

Specific conductance is a measure of the ability of water to conduct electricity and is typically proportional to the water's dissolved-solids concentration. For most natural waters, the ratio of dissolved-solids concentration to specific conductance ranges from 0.55 to 0.75 (Hem, 1985).

Specific conductance in Payette Lake ranged from 17 to 35 uS/cm; most values were about 20 uS/cm (Brennan and others, 1996, 1997). These values are considered low for natural waters (Hem, 1985). The values above 30 uS/cm were measured in the lower hypolimnion at station 1 in conjunction with anoxic dissolved-oxygen concentrations. The lowest values were measured during June and represented the dilution effects of snowmelt runoff.

5.3.4 pH

The variable pH represents the negative base-10 logarithm of the hydrogen ion activity in moles per liter. In dilute solutions, the overall range in pH can be 0 to 14; values above 7 are considered basic and those below 7 are considered acidic.

The overall range of pH in the lake was 6.2 to 8.8 (Brennan and others, 1996, 1997). The general trend in pH was larger values in the euphotic zone during July (1995) or August and September (1996) and smaller values in the hypolimnion during late summer and autumn. This overall pattern in pH fits that described for many lakes. In the summer, pH in the euphotic zone increases in response to photosynthetic utilization of carbon dioxide, whereas pH in the hypolimnion decreases as carbon dioxide is added by decomposition of organic matter.

5.3.5 Dissolved oxygen

The concentration of dissolved oxygen in natural freshwater is affected by temperature, barometric pressure, production of oxygen by photosynthesis, consumption of oxygen by respiration and decomposition, and mixing of water masses. The ratio (expressed as a percent) of measured dissolved-oxygen concentrations to those that would exist under saturated conditions at the same temperature and pressure is useful for comparing dissolved oxygen when significant variations in temperature and pressure exist, such as comparisons spanning time or depth.

The overall range in dissolved-oxygen concentration over depth and time at the four stations was 0 to 11.7 mg/L in 1995 and 0 to 11.0 mg/L in 1996 (Figure 5-3). The maximum concentration for each year was measured at station 4; in mid-June of 1995 and in late July of 1996. The anoxic concentrations were measured during both years, but only in the lower hypolimnion at station 1 (See station locations in Figure 3-3 on page 39). The pattern within a year was that maximum dissolved-oxygen concentrations were measured within the epilimnion during the summer when photosynthetic production of oxygen exceeded oxygen consumption by respiration and decomposition; minimum concentrations were measured in the hypolimnion during late summer and autumn when thermal stratification had reduced mixing of the oxygenated epilimnion with the

Figure 5-3. Lines of equal dissolved oxygen concentration, in milligrams per liter, at stations 1-4 during selected months of 1995-1996.

hypolimnion. An important feature at station 1 was the lack of full re-aeration of the water column during spring circulation. In both years, dissolved-oxygen concentrations in the hypolimnion were increased to about 7.0 mg/L whereas the other three stations were re-aerated to about 10.0 mg/L.

Stations 1 and 4 had an additional period of low dissolved-oxygen concentrations in the spring, shortly after loss of the lake's ice cover (Figure 5-3). In early May, 1995, both stations had hypolimnetic dissolved-oxygen concentrations as low as 4 mg/L. In mid-April, 1996, station 1 almost developed anoxia in its lower depths. These incidences of dissolved-oxygen minima in the spring indicate that stations 1 and 4 can have a substantial hypolimnetic dissolved-oxygen deficit under winter ice cover. One set of winter samples were collected through the ice cover at stations 1 and 4 on February 21, 1996, about midway through the 4-month period of ice cover. Dissolved-oxygen concentrations in the lower hypolimnion were 6.2 and 5.8 mg/L at stations 1 and 4, respectively. As shown in Figure 6, dissolved-oxygen concentrations in the lower hypolimnion of station 1 continued to decline to 0.5 mg/L in mid-April; dissolved-oxygen concentrations at station 4 did not change much until the lose of ice cover.

The overall range in percent saturation of dissolved oxygen over depth and time at the four stations was 0 to 129 percent in 1995 and 0 to 122 percent in 1996 (Figure 5-4). The maximum percentage for each year was measured at station 4 in mid-June of 1995 and at station 1 in late July of 1996. The zero percents were measured in the lower hypolimnion of station 1 during the late summer and autumn of both years. Saturation greater than 100 percent (supersaturation) was measured in the euphotic zone of each station. During 1995, supersaturation began in May at stations 1 and 4 and in June at stations 2 and 3 and extended into October at the four stations. During 1996, the period of supersaturation at station 1 was comparable to 1995; however, the other three stations became supersaturated in June and ended supersaturation either in September (stations 2 and 3) or in August (station 4).

Depletion of dissolved oxygen within the hypolimnion of a stratified lake is an important symptom of eutrophication because it reflects the decay of organic matter produced within the euphotic zone or input to the lake by terrestrial sources. Dissolved oxygen was depleted in the hypolimnia of Payette Lake's four stations during both years; however, only station 1 developed anoxic dissolved-oxygen concentrations. Accordingly, an areal hypolimnetic oxygen depletion rate (AHOD) was calculated for station 1 for each year. AHOD, in milligrams per square meter per day, is defined as the rate of decrease of dissolved oxygen mass in the hypolimnion divided by the surface area of the hypolimnion. If AHOD is divided by the mean depth of the hypolimnion, one obtains the volumetric hypolimnetic oxygen depletion rate (VHOD), which is the rate of decrease of the volume-weighted-average dissolved-oxygen concentration in the hypolimnion. AHOD and VHOD were calculated for Payette Lake's station 1 for both years using procedures in Walker (1996). The calculated values represent the period from initial thermal stratification to the onset of anoxia in the hypolimnion. For 1995, this period was from June 12 to September 5; for 1996, it was from June 18 to September 24. The AHOD and VHOD for 1995 were 756 mg/m^2/day and 24.9 mg/m3/day, respectively. These values were somewhat smaller in 1996; AHOD was 451 mg/m2/day and VHOD was 14.8 mg/m3/day.
Hutchinson (1957) used AHOD to define limits for oligotrophic and eutrophic lakes: if AHOD is

less than 250 mg/m2/day, the lake is considered oligotrophic; if AHOD is more than 550 mg/m2/day, the lake is considered eutrophic. On the basis of these limits, Payette Lake would be considered eutrophic in 1995 and bordering on eutrophic in 1996. The 1981 study of Payette Lake (Falter and Mitchell, 1981) reported an AHOD for the west basin (station 1, this study) of 300 mg/m2/day; this result places the lake slightly above the threshold for oligotrophic but well below that for eutrophic.

5.3.6 Phosphorus

Phosphorus is one of several essential nutrients in the metabolism of aquatic plants. Eutrophication research has focused heavily on phosphorus because it is the nutrient typically found to have the smallest supply-to-demand ratio for aquatic plant growth. Phosphorus concentrations for this study are reported as total phosphorus and dissolved orthophosphorus, as phosphorus. Total phosphorus represents the phosphorus in solution and contained in or attached to biotic and abiotic particulate material. Dissolved orthophosphorus is determined from the filtrate that passes through a filter with a nominal pore size of 0.45 um. The orthophosphate ion is the most important form of phosphorus because it is directly available for metabolic use by aquatic plants.

Median concentrations of total phosphorus at the four stations ranged from 4 to 6.5 ug/L in the euphotic zone and from 4 to 8.5 ug/L in the lower hypolimnion; the largest median concentrations were at station 1 in 1996 (Table 5-7). Median concentrations of total phosphorus in the euphotic zone and lower hypolimnion were slightly larger in 1996, except at station 4. The median concentrations of dissolved orthophosphorus were 0.5 ug/L in the euphotic zone at the four stations; the medians for the lower hypolimnion samples ranged from 0.5 to 1 ug/L (Table 5-7).

Total phosphorus concentrations at the four stations ranged from 0.5 to 65 ug/L during 1995 and from 0.5 to 52 ug/L during 1996, whereas dissolved orthophosphorus concentrations ranged from 0.5 to 14 ug/L during 1995 and from 0.5 to 23 ug/L during 1996 (Figure 5-5). The largest concentrations of both constituents were measured in the hypolimnion of station 1 from September through November, 1995 when near-bottom water had become anoxic. Under anoxic conditions, constituents such as phosphorus, ammonia, iron, and manganese in the lakebed sediments are solubilized and released into the hypolimnion (Stumm and Morgan, 1970).

Phytoplanktonic uptake of dissolved orthophosphorus in the euphotic zone during the summer growing season can sometimes be discerned by distinct declines in that constituent and concomitant increases in total phosphorus as the phytoplankton population converts dissolved orthophosphorus into particulate phosphorus. Such a relationship was not evident in Payette Lake, on the basis of the temporal patterns illustrated in Figure 5-5. The relationship may have been masked by the very low concentrations of dissolved orthophosphorus typically measured in Payette Lake's euphotic zones.

Figure 5-4. Lines of equal dissolved oxygen, as percent saturation, at stations 1-4 during selected months of 1995-1996.

Table 5-7. Medians of total phosphorus and dissolved orthophosphorus from the euphotic zone and lower hypolimnion at four limnetic stations, Payette Lake, 1995 - 1996.

	Total phosphorus (µg/L)				Dissolved orthophosphorus (µg/L)			
Limnetic station	Euphotic Zone		Lower Hypolimnion		Euphotic Zone		Lower Hypolimnion	
	Median	n	Median	n	Median	n	Median	n
1995								
1	4	9	5	9	0.5	9	1	9
2	4	9	4	8	.5	9	.5	8
3	4	8	4	8	.5	8	1	8
4	6	9	5	9	.5	9	.5	9
1996								
1	6.5	10	8.5	10	.5	10	.8	10
2	6	9	5	9	.5	9	.5	9
3	6	9	5	9	.5	9	.5	9
4	6	10	6	10	.5	10	.5	10

5.3.7 Nitrogen

Nitrogen, like phosphorus, is essential to the metabolism of aquatic plants. The supply-to-demand ratio for nitrogen is small and, thus, nitrogen may limit the growth of aquatic plants as phosphorus does. The nitrogen cycle in aquatic ecosystems is complex because most processes involving nitrogen are biologically mediated. In aquatic ecosystems, nitrogen commonly exist in the following forms: dissolved molecular nitrogen, nitrogen-containing organic compounds, ammonia, ammonium, nitrite, and nitrate. Nitrogen concentrations for this study were analyzed as total ammonia plus organic nitrogen (commonly called Kjeldahl nitrogen), dissolved ammonia, and dissolved nitrite plus nitrate, as nitrogen. Total ammonia plus organic nitrogen represents the ammonia (includes ammonium) and organic nitrogen compounds in solution and associated with biotic and abiotic particulate material. The dissolved concentrations represent the ammonia (includes ammonium) or nitrite plus nitrate in filtrate that passes through a 0.45-um filter. The following discussion is for total nitrogen (the sum of total ammonia plus organic nitrogen and dissolved nitrite plus nitrate) and dissolved inorganic nitrogen (the sum of dissolved ammonia and dissolved nitrite plus nitrate).

Figure 5-5. Concentrations of total phosphorus and dissolved orthophosphorus in the euphotic zone and lower hypolimnion at stations 1-4 during 1995 - 1996.

Median concentrations of total nitrogen at the four stations ranged from 158 to 272 ug/L in the euphotic zone and from 197 to 431 ug/L in the lower hypolimnion; 1996 medians were distinctly larger than those in 1995 (Table 5-8). Median concentrations of dissolved inorganic nitrogen at the four stations ranged from 28 to 170 ug/L in the euphotic zone and from 84 to 360 ug/L in the lower hypolimnion; as with total nitrogen, 1996 medians were larger than 1995 medians (table 8). The larger median concentrations of nitrogen measured in 1996 were attributable to the larger nitrogen loads delivered to the lake in 1996.

Table 5-8. Medians of total nitrogen and dissolved inorganic nitrogen from the euphotic zone and lower hypolimnion at four limnetic stations, Payette Lake, 1995-1996.

	Total nitrogen (µg/L)				Dissolved inorganic nitrogen (µg/L)			
Limnetic station	Euphotic Zone		Lower Hypolimnion		Euphotic Zone		Lower Hypolimnion	
	Median	n	Median	n	Median	n	Median	n
1995								
1	158	9	197	9	28	9	84	9
2	226	9	290	8	60	9	188	8
3	230	8	319	7	51	8	202	8
4	188	9	315	8	51	9	174	9
1996								
1	244	10	304	10	102	10	180	10
2	253	9	406	9	111	9	301	9
3	270	8	431	9	111	9	360	9
4	272	10	361	10	170	10	318	10

Total nitrogen concentrations at the four stations ranged from 86 to 493 ug/L during 1995 and from 83 to 529 ug/L during 1996 (Figure 5-6). Dissolved inorganic nitrogen concentrations at the four stations ranged from 7 to 335 ug/L during 1995 and from 13 to 397 ug/L during 1996 (Figure 5-6). Lower-hypolimnion concentrations of total nitrogen and dissolved inorganic nitrogen were larger than those in the euphotic zone. The increased hypolimnetic concentrations of the two constituents reflect the settling and decomposition of organic matter from the euphotic zone into the hypolimnion. The increase in dissolved inorganic nitrogen concentrations is also indicative of nitrification in the hypolimnion, whereby, under aerobic conditions, organic and ammonia nitrogen is converted to nitrite and then nitrate. The large increase in ammonia in the lower hypolimnion of station 1 during September and October of 1995 (Figure 5-6) reflects the release of ammonia from lakebed sediments when the hypolimnion became anoxic.

Figure 5-6. Concentrations of total nitrogen, dissolved inorganic nitrogen, and dissolved ammonia in the euphotic zone and lower hypolimnion at stations 1-4 during 1995-1996.

5.3.8 Limiting nutrient

The limiting nutrient concept of Liebig, in concert with the stoichiometry of the photosynthesis equation, led to formulation of nitrogen-to-phosphorus ratios (N:P). These ratios have been used extensively in eutrophication studies to determine whether nitrogen or phosphorus was most likely to limit phytoplankton growth. The atomic ratio of nitrogen to phosphorus, 16N:1P, in the photosynthesis equation corresponds to a mass ratio of 7.2N:1P. Typically, N:P values are calculated using the biologically available forms of these two nutrients, dissolved inorganic nitrogen and dissolved orthophosphorus. If N:P (by weight) is less than 7.2, then nitrogen may be limiting, whereas if N:P exceeds 7.2, then phosphorus may be limiting (Ryding and Rast, 1989).

The N:P values in Table 5-9 and Figure 5-7 indicate a very strong tendency towards phosphorus limitation of phytoplankton growth in Payette Lake. The lowest ratio, 8.8, still exceeded the threshold of 7.2. The median ratios for 1996 were higher than those for 1995. This difference resulted from the higher concentrations of dissolved inorganic nitrogen measured in 1996 because dissolved orthophosphorus concentrations were nearly equal between the two years.

Table 5-9. Medians and ranges of ratios of dissolved inorganic nitrogen to dissolved orthophosphorus in samples from the euphotic zone at four limnetic stations, Payette Lake, 1995-1996.

	Ratio		
Limnetic station	Median	Range	No. of samples
1995			
1	38	8.8-112	9
2	76	14-394	9
3	102	38-326	8
4	88	40-222	9
1996			
1	180	26-440	10
2	180	38-480	9
3	222	66-732	9
4	254	92-666	10

Figure 5-7. Dissolved inorganic nitrogen to dissolved orthophosphorus ratio at stations 1-4 during 1995-1996.

5.3.9 Chlorophyll-a

Chlorophyll-a is the primary photosynthetic pigment of phytoplankton and, as such, is used as an estimator of phytoplanktonic biomass. Median concentrations of chlorophyll-a at Payette Lake's four stations ranged from 1.6 to 2.4 ug/L during 1995 and from 0.8 to 1.3 ug/L during 1996 (Table 5-10). The 1995 median was highest at station 4, whereas the 1996 median was highest at station 1. The overall range in concentrations was from 0.2 to 5.2 ug/L with the largest concentration at station 1 in 1995 (table 10). Chlorophyll-a concentrations at the four stations had a distinct peak during June of 1995; temporal variation was more muted during 1996 (Figure 5-8).

5.3.10 Phytoplankton

Phytoplankton collected at the four stations during 1995-96 comprised five phyla (Chlorophyta, or green algae; Chrysophyta, or yellow-brown algae; Cryptophyta, or crytomonads; Cyanophyta, or blue-green algae; and Pyrrhophyta, or dinoflagellates), 44 genera, and 67 species (Table 5-11). The taxonomic composition was strongly dominated by the subphylum Bacillariophyceae, or diatoms. The Cyanophyta, represented by Anacystis marina and Chroococcus minimus, were a very minor component.

Lakewide, median density and biovolume for the 64 samples was 663 cells/ml and 384,000 um^3/ml, respectively. Among the four stations, median biovolume was highest at station 1 in both years (Table 5-10). Biovolume peaked in July of both years; only station 1 had a substantial secondary peak in the autumn of both years (Figure 5-9). Biovolume was dominated by one diatom, Tabellaria fenestrata, which, on average, contributed 52 percent of the lakewide biovolume.

Table 5-10. Medians and ranges of chlorophyll-a concentrations and phytoplankton biovolumes in samples from the euphotic zone at four limnetic stations, Payette Lake, 1995-1996.

Limnetic station	Chlorophyll-a concentration (µg/L)			Phytoplankton biovolume (μm^3/ml)		
	Median	Range	n	Median	Range	n
1995						
1	2.2	0.7-5.2	8	962,000	70,000-2,770,000	7
2	1.6	1.0-3.4	8	426,000	189,000-2,520,000	7
3	1.6	.7-5	8	420,000	97,100-2,820,000	7
4	2.4	.7-5	8	774,000	109,000-2,840,000	7
1996						
1	1.3	.5-2.1	10	556,000	313,000-1,890,000	9
2	1.0	.2-1.8	9	184,000	88,200-923,000	9
3	1.1	.3-1.5	8	189,000	81,900-1,700,000	9
4	.8	.3-1.3	10	230,000	76,600-2,340,000	9

Figure 5-8. Chlorophyll-a concentrations at stations 1-4 during 1995-1996.

Table 5-11. Phytoplankton taxa at four limnetic stations, Payette Lake, 1995-1996.

Figure 5-9. Phytoplankton biovolume at stations 1-4 during 1995-1996.

5.3.11 Trophic state

The biological productivity, or trophic state, of a lake is commonly categorized into one of three trophic states: oligotrophic, or low productivity; eutrophic, or high productivity; and mesotrophic, or moderate productivity. Numerous variables have been used as the basis for trophic-state classification; some of the most frequently encountered are total phosphorus, total nitrogen, chlorophyll-a, and secchi-disc transparency. These four variables were used by Ryding and Rast (1989) to develop an open-boundary trophic-state classification system which compensates for the overlap in classification that commonly occurs with a fixed-boundary system. Under the open-boundary system, a lake is considered correctly classified if three of the four classification variables are within two standard deviations of their geometric mean for the same trophic state.

Annual geometric means for euphotic-zone values of total phosphorus, total nitrogen, chlorophyll-a, and secchi-disc transparency were computed for Payette Lake for comparison to the open-boundary trophic-state classification system (Table 5-12). The lake was classified as oligotrophic in both years on the basis of total phosphorus, total nitrogen, and chlorophyll-a. On the basis of secchi-disc transparency, the lake was mesotrophic in both years.

Three earlier studies also classified the trophic state of Payette Lake. During the late 1970's, the lake was classified as oligotrophic on the basis of chemical and biological variables (Idaho Department of Health, 1970). The National Eutrophication Survey of 1975 classified the lake as early mesotrophic (U.S. Environmental Protection Agency, 1977). Falter (1984) used areal phosphorus loading as his basis for classifying the lake as mesotrophic in the early 1980's. These three studies indicate an increasing trend in trophic state; however, the trend may be misleading because the basis for trophic-state classification was not consistent among the three studies.

Table 5-12. Trophic state of Payette Lake during 1995-1996 based on annual geometric mean values for four limnological variables.

Limnological Variable	Statistic[1]	Open-boundary trophic state classification[2] 0	M	E	Payette Lake[3] 1995	1996	1995-96
Total	χ	8.0	26.7	84.4	4.5	4.9	4.7
phosphorus	χ ±1 SD	4.8-13.3	14.5-49.0	48.0-189.0	2.0-6.8	0.9-8.9	1.4-8.0
(µg/L)							
	χ	661	753	1,875			
Total nitrogen	χ ±1 SD	371-1,180	485-1,170	861-4,081	199	252	225
(µg/L)					137-261	141-363	135-315
	χ	1.7	4.7	14.3			
Chlorophyll-a	χ ±1 SD	0.8-3.4	3.0-7.4	6.7-31.0			
(µg/L)					1.9	0.9	1.3
	χ				0.8-3.0	0.4-1.4	0.4-2.2
	χ ±1 SD	9.9	4.2	2.4			
Secchi-disc		5.9-16.5	2.4-7.4	1.5-4.0			
transparency					4.3	5.2	4.7
(m)					2.6-6.0	3.8-6.6	3.1-6.3

[1] Annual geometric mean and plus or minus one standard deviation.
[2] Modified from Ryding and Rast (1989).
[3] Annual geometric mean of euphotic-zone values.

5.3.12 Sediment nutrients

The lakebed sediments at the four stations had the following ranges for concentrations of total phosphorus and total nitrogen: 1,400 to 4,800 mg/kg and 720 to 920 mg/kg, respectively (Table 5-13). Station 1 had the highest concentration of total phosphorus, whereas station 4 had the highest for total nitrogen.

Table 5-13. Concentrations of total phosphorus and total nitrogen in lakebed sediments at four limnetic stations, Payette Lake, July 1996.

		Concentrations (Mg/kg)	
Limnetic station	Water depth (m)	Total phosphorus	Total nitrogen
1	68	4,800	720
2	55	1,400	910
3	90	1,900	740
4	34	1,400	920

Guidelines have been published for assessing the potential effects on benthic organisms of trace elements and nutrients in aquatic sediments (Persaud and others, 1993). The guidelines include three levels of effect: no effect, lowest effect, and severe effect. The lowest effect level signifies sediment contamination that can be tolerated by most benthic organisms whereas the severe effect level signifies polluted sediment that will significantly affect benthic organisms. For total phosphorus, the lowest and severe effect levels are 600 and 2,000 mg/kg, respectively. For total nitrogen, the lowest and severe effect levels are 550 and 4,800 mg/kg, respectively. The severe effect level for total phosphorus was clearly exceeded by station 1 and nearly met by station 3; total nitrogen concentrations at the four stations were well below the severe effect level (Table 5-13).

5.4 Littoral Zone

5.4.1 Periphyton production

Periphyton production in the littoral zone of Payette Lake was assessed to determine whether a statistical relation existed between periphyton production and various indices of nearshore development. The indices for each littoral station included housing density, percentage of lawn area, relative age of development, relative level of disturbance of natural soils and vegetation, and lake subbasin. The hypothesis was that stations with little or no disturbance of natural conditions would have low levels of periphyton production, whereas increased levels of disturbance would produce increased nutrient loads which would stimulate periphyton production.

Median periphyton production, as chlorophyll-a, at the 19 (one station was lost) littoral stations ranged from 0.38 (station 12) to 12.9 (station 22) mg/m^2, a difference of 33.9 times (Table 5-14). When normalized to PAR input, the median production ranged from 0.0007 (station 12) to 0.02 (station 22) (mg/m^2)/E, a difference of 28.6 times. For both comparisons, production was lowest at station 12 and highest at station 22. The nearshore development at station 12 included a very large home surrounded by an extensive lawn area. At station 22, new construction of several large homes had disturbed the majority of the soil and vegetative cover. This station is also at the former site of a lumber mill. On the basis of ranks, PAR-normalized periphyton production at stations 10, 11, and 15 was some of the lowest in the lake even though these three stations had substantial nearshore development. Conversely, stations 1, 2, and 4, all undisturbed, had some of the highest periphyton production.

Multiple linear regression (Helsel and Hirsch, 1992) was used to investigate the relation between PAR-normalized periphyton production and the five indices of nearshore development. Periphyton production was normalized with PAR to remove its influence from the predictive equation. Scatterplots and a correlation matrix indicated little, if any, relationship between PAR-normalized periphyton production and any of the indices of nearshore development. This observation was confirmed with the regression analyses. When the five indices were included in the model they explained 41-percent of the variation in the dependent variable; however the p-value for the F statistic was 0.175, indicative of no relationship. Of the five partial-regression coefficients, only relative level of disturbance was significant, with a p-value of 0.033.

Table 5-14. Periphyton production, as chlorophyll-a, at 19 littoral stations, Payette Lake, July-August 1996.

			Periphyton production normalized to PAR	
Littoral station	PAR input (E)[1]	Periphyton production (mg/m^{2})[2]	[(mg/m^{2})/E][2]	Rank[3]
1	637	1.01	0.0016	10
2	516	1.12	.0022	15
4	560	.97	.0017	12
6	546	.94	.0017	12
8	597	1.07	.0018	14
9	695	.84	.0012	7
10	559	.42	.0008	3.5
11	617	.52	.0008	3.5
12	552	.38	.0007	1
13	602	1.37	.0023	16
14	548	.66	.0012	6
15	560	.51	.0009	2
16	662	.63	.0010	5
17	653	.94	.0014	8
18	653	1.10	.0017	12
19	640	2.15	.0034	17
21	609	.88	.0014	9
22	647	12.9	.020	19
23	559	2.71	.0048	18

[1] Quantity of photon flux, as Einsteins (1 E = 1 mole of photons), input to periphyton during incubation period.

[2] Median of three values.

[3] Low production to high production.

The absence of a strong relationship between periphyton production and selected indices of nearshore development at Payette Lake was similar to results of a recent study at Priest Lake reported by Rothrock and Mosier (1996). Periphyton production, as chlorophyll-a, was measured on natural substrates at 21 nearshore locations during the summers of 1994-95 in Priest Lake, a 95-km2, oligotrophic lake in northern Idaho. Periphyton production in Priest Lake had no strong relationship with any of the following variables: site aspect, bank slope, fetch distance, developed versus undeveloped nearshore, and interstitial nutrient concentrations.

Boat Docks

The water quality impacts from the nearshore areas of Big Payette Lake also include boat docks. In discussions of the water quality impacts of boat docks, both existing and proposed, the emphasis usually centers on issues such as additional boat traffic, disturbances of soil (terrestrial and lakebed) during construction, encroachment into the nearshore zone of the lake, and dumping of trash. Another issue that has been neglected, but may be very relevant to Big Payette Lake, is the additional surface area of the piling and dock surfaces (those in contact with the lake water) that now grow periphyton. In the shallow, well lighted nearshore zone where docks are built, light conditions are optimal for periphyton growth. Docks tend to be built in developed areas where additional supplies of nutrients are available via urban runoff, lawn fertilizers, and septic system leachates. During the summer, additional growth of periphyton on docks may be regarded as a nuisance, but unless it is excessive, does not cause much concern. However, the water quality problem is more related to the demise of the periphyton during the fall and early winter when cold temperatures and reduced light levels cause it to die and slough off the docks. As the dead periphyton decomposes, either while settling through the water column or on the lakebed, it consumes oxygen and eventually releases the algal nutrients carbon, nitrogen and phosphorus. These nutrients may be incorporated into the lakebed sediments of the nearshore zone or currents may carry them to deeper areas of the lake. The hypolimnetic dissolved oxygen depletion within the southwest basin of Big Payette Lake is caused by an excessive oxygen demand which is fueled by the influx of organic matter undergoing decomposition. The influx is from various sources, both terrestrial and aquatic. The relative contribution of these sources is not quantifiable with the present data base. However, some portion of that influx is from the decay of periphyton from docks around the lake.

5.4.2 Aquatic macrophytes

Payette Lake contained nine genera of aquatic macrophytes on the basis of sampling at 19 littoral stations (Table 5-15). Isoetes lacustris and Myriophyllum spicatum var. exalbescens occurred most frequently, being found at 16 and 13 of the stations, respectively. Nitella sp. and Ranunculus aquatilis were each found at 8 of the stations. Chara sp. was found only at station 14. Diversity was highest at stations 11, 16, and 17, which had five genera, and lowest at station 15, which was devoid of aquatic macrophytes. Of particular interest was the discovery of M.

spicatum var. spicatum at stations 21 and 22 which are adjacent to the city boat ramp. This plant, whose common name is Eurasian Milfoil, is considered a nuisance because it grows aggressively, can propagate via fragmentation, and is extremely difficult to eradicate. The occurrence of Eurasian Milfoil near the boat ramp suggests it was introduced to Payette Lake from a boat or boat trailer that had been used in a lake infested with the plant.

Table 5-15. Aquatic macrophyte taxa at 19 littoral stations, Payette Lake, July 1996.

Aquatic macrophyte taxa[1]	Littoral station No.
Phylum Chlorophyta	
Family Characeae	
Chara sp.	14
Nitella sp.	1,2,4,5,11,12,16,23
Phylum Pteridophyta	
Family Isoetaceae	
Isoetes lacustris	1,2,4,5,6,8,10,11,12,13,14,16,17,19,21,23
Phylum Spermatophyta	
Class Angiospermae	
Family Haloragaceae	4,6,8,9,10,11,12,13,14,16,17,18,23
Myriophllum spicatum var. exalbescens	21,22
M.spicatum var. spicatum	
Family Hydrocharitaceae	6,11,13,16,17,18,22
Elodea canadensis	
Family Naiadaceae	4,5,11,17,23
Potamogeton robbinsii	6,11,19
P. zosteriformis	
Family Ranunculaceae	8,9,13,16,17,18,19,22
Ranunculus aquatilis	

[1] Taxonomy based on Prescott (1969) and Steward and others (1963).

An earlier survey of aquatic macrophytes at six locations in Payette Lake was conducted in July and September, 1981 by Falter and Mitchell (1981). The 1981 taxonomic composition was similar to that of the current study, but only six genera were found and P. robbinsii was the dominant genera. Eurasian Milfoil was not reported in the 1981 study.

5.5 Fire Effects on Lake Water Quality

The effects of the 1994 forest fires on Payette Lake's water quality were evaluated on the basis of a limited data base collected by DEQ at four limnetic stations during July, September, and October of 1992 and August and September of 1993 (D. Worth, Idaho Division of Environmental Quality, written commun., September, 1995). DEQ data for chlorophyll-a and dissolved oxygen were compared with data collected during similar time periods in 1995 and 1996.

Hydrologically, lake outflow during the 1992 water year was 49 percent of the long-term mean; in the 1993 water year, lake outflow was 106 percent of the long-term mean. Thus, the lake's residence time in 1992 was 4.8 years, or about twice its normal value; in 1993, it was 2.2 years, or about normal. Residence times for the 1995 and 1996 water years were 1.84 and 1.42 years, respectively; thus, both years had shorter than normal residence times.

The limnological basis for the comparison of residence times is that longer residence times are expected to enhance a lake's biological production because nutrients and phytoplankton are retained longer in the lake. If one disregards the effects of the 1994 forest fires in this comparison, one would expect Payette Lake to have been most productive in 1992, the year with the longest residence time. However, post-fire chlorophyll-a concentrations were about double those measured in the two years prior to the fires, even though post-fire residence times were much less than normal. Chlorophyll-a concentrations for the 1992 samples ranged from 0.2 to 1.15 ug/L and had a median concentration of 0.71 ug/L. The 1993 chlorophyll-a concentrations ranged from 0.5 to 1.0 ug/L and had a median concentration of 0.65 ug/L. A similar period in 1995 had chlorophyll-a concentrations that ranged from 0.7 to 2.7 ug/L, with a median of 1.4 ug/L; for 1996, the range was from 0.8 to 2.1 ug/L, with a median of 1.3 ug/L.

Payette Lake received substantially larger loads of nitrogen during 1995-1996 as a result of the 1994 forest fires. Phosphorus loads also increased substantially in 1995, largely because of loads from Fall Creek. A comparison of in-lake nutrient concentrations indicated post-fire concentrations of nitrogen were much larger than pre-fire concentrations, whereas post-fire concentrations of phosphorus were smaller. During August and September of 1993, median concentrations, in micrograms per liter, of dissolved inorganic nitrogen, total phosphorus and dissolved ortho-phosphorus were 12, 10.5 and 10 in the upper water column and 122, 23 and 11 in the lower hypolimnion, respectively. For similar dates during 1995-96, median concentrations, in micrograms per liter, of dissolved inorganic nitrogen, total phosphorus and dissolved ortho-phosphorus were 50, 5 and 0.5 in the upper water column and 251, 5 and 0.5 in the lower hypolimnion, respectively. The 2 to 4 fold increase in dissolved inorganic nitrogen is reasonable in that this constituent is soluble and is not readily adsorbed to particulate material which may settle rapidly after introduction to the lake. In contrast, the absence of a large post-fire increase in phosphorus may be due to its ready adsorption to particulate material.

Dissolved-oxygen concentrations were also measured by DEQ in 1992 and 1993; however, the profiled depths were inconsistent and often did not occur in the deepest parts of the four basins. Thus, the assessment of pre- and post-fire development of the hypolimnetic dissolved-oxygen deficit in the southwest basin (limnetic station 1, this study) is incomplete. The most valid comparison is for late July, 1992 when a dissolved-oxygen concentration of 2.8 mg/L was measured at the 71-m depth in the southwest basin. Similar dates and depths in 1995 and 1996 for this location had dissolved-oxygen concentrations of 2.6 and 1.0 mg/L, respectively. On the basis of this comparison, the fire effects on the hypolimnetic dissolved-oxygen deficit were undetectable.

5.6 Nutrient Load/Lake Response Model

5.6.1 Model Description

The empirical nutrient load/lake response model (Walker, 1996) applied to Payette Lake provided a mathematical method for simulating the lake's limnological responses to alterations in hydrologic and nutrient loads delivered to the lake from various sources. The model combined data on the lake's morphometrics, hydrologic and nutrient budgets, and limnological characteristics in order to simulate the following eutrophication-related variables: concentrations of total phosphorus, total nitrogen, and chlorophyll-*a*; secchi-disc transparency; and hypolimnetic dissolved-oxygen deficit.

Three programs, FLUX, PROFILE, and BATHTUB, compose the model. The FLUX program quantifies tributary loads of water and nutrients using a variety of calculation methods. The PROFILE program generates statistical summaries of water-quality conditions in the water body within a temporal and spatial context. The BATHTUB program applies nutrient-balance and eutrophication-response models within a spatially segmented hydraulic framework that accounts for advection, diffusion, and sedimentation. BATHTUB is a highly evolved version of empirical lake-eutrophication models, and incorporates additional variables to account for important processes such as nonlinear nutrient-sedimentation kinetics, inflow nutrient partitioning, seasonal and spatial variations, and algal growth limitation by factors such as phosphorus, nitrogen, light, and flushing rate. If error estimates are provided for input variables, BATHTUB can express out-put variables in probabilistic terms. An important feature of BATHTUB is the ability for modeling linked segments of the lake to account for spatial variations in water quality. Segment boundaries can be selected on the basis of factors such as lake morphometry, important sources of water and nutrients, and lake hydrodynamics.

Payette Lake was divided into four segments (Figure 3-3 on page 39); each segment's characteristics are listed in table 5-16 on page 224. Segment 1 is the deep, northeastern basin; it covers 6.5 km^2 and contains 0.28 km^3. This segment receives the lake's primary inflow from the North Fork Payette River. Segment 2 is the southeastern basin which covers 1.7 km^2 and contains 0.04 km^3. This segment is the most hydrologically isolated from the primary inflow and is furthest from the lake's outflow. Segment 3 is the smallest basin and connects the northeastern and southwestern basins. This segment covers 1.4 km^2 and contains 0.04 km^3. Segment 4 is the southwestern basin and contains the lake's outlet into the North Fork Payette River. This segment has the largest area and volume, 10.9 km^2 and 0.4 km^3.

Water-quality characteristics for each segment were input to BATHTUB. The characteristics were computed with PROFILE using data from the four limnetic stations. Excepting the hypolimnetic dissolved-oxygen deficit, the characteristics represented mean annual values for the euphotic zone for water years 1995 and 1996. The euphotic zone was the primary focus for modeling because most of the empirical relations used by BATHTUB were derived from studies of euphotic zones.

The hydrologic and nutrient budgets (Tables 5-3 through 5-5) were the source of water and nutrient loads input to BATHTUB. Each segment received water and nutrient loads from the subwatersheds draining into it. If a subwatershed contributed to more than one segment its water and nutrient load was apportioned between the segments on the basis of drainage area.

5.6.2 Model Calibrations

Model Calibration and Verification

The model was calibrated with 1996 data using a selection of submodels discussed in the user manual (Walker, 1996, Table 4.2). The submodels for phosphorus and nitrogen sedimentation were based on second-order decay rates. The chlorophyll-*a* submodel was based on phosphorus, light, and flushing rate, whereas the secchi-disc transparency submodel was based on chlorophyll-*a* and turbidity. The dispersion submodel was numerically based per Fischer and others (1979). The submodels for calibration of nitrogen and phosphorus applied calibration factors to sedimentation rates, not concentrations. The initial calibration with submodels was adequate for most variables; however, several variables required calibration coefficients to achieve a satisfactory fit between estimated and observed conditions. The calibration coefficient for chlorophyll-*a* was 0.625, whereas it was 3.0 for the hypolimnetic dissolved-oxygen deficit.

Model calibration results for each segment and the area-weighted, lakewide mean values are summarized in table 17. Lakewide, the ratios between observed and estimated values for total phosphorus, total nitrogen, chlorophyll-*a*, and secchi-disc transparency were 1.11, 1.08, 1.01, and 1.0, respectively. In model segment 4, the ratio between the observed and estimated hypolimnetic dissolved-oxygen deficit was 1.12.

The model was verified with 1995 data and the submodels used in the calibration; the results are summarized in table 17. Lakewide, the ratios between observed and estimated values for total phosphorus, total nitrogen, chlorophyll-*a*, and secchi-disc transparency were 0.33, 0.7, 0.77, and 1.07, respectively. In model segment 4, the ratio between the observed and estimated hypolimnetic dissolved-oxygen deficit was 1.19.

The comparison of observed and estimated mean values is not the only criterion on which to judge the model's performance. The model output displays the mean value, plus or minus one standard error for each observed and estimated value. These statistical estimates are computed on the basis of errors associated with the model, as well as errors associated with each input variable. The presence or absence of overlap in the standard errors for each variable and segment is listed in table 18. For the calibration, the standard errors for all variables overlap in each segment and lakewide. For the verification, the standard errors do not overlap as follows: total phosphorus; all segments and lakewide; total nitrogen, segments 1,4, and lakewide; chlorophyll-*a*, segment 1. The lack of overlap for total phosphorus is largely attributable to the unusually large, but transient, load delivered by Fall Creek during May, 1995. When the model verification was performed with the 1995 total phosphorus load from Fall Creek adjusted to levels equivalent with those delivered by Fall Creek in 1996, then the standard errors for total phosphorus overlap in all segments.

Table 5-16. Results of model calibration with 1996 data and model verification with 1995 data, Payette Lake

[TP, total phosphorus, in micrograms per liter; TN, total nitrogen, in micrograms per liter; CHL, chlorophyll-*a*, in micrograms per liter; SD, secchi disc transparency, in meters; HODV, hypolimnetic dissolved oxygen deficit, volumetric, in micrograms per cubic meter per day]

		Calibration Mean Value			**Verification Mean Value**		
Segment (Fig.3-3)	**Variable**	**Observed**	**Estimated**	**Ratio of observed to estimated value**	**Observed**	**Estimated**	**Ratio of observed to estimated value**
1	TP	6.4	7.3	0.88	4.4	18.8	0.23
	TN	328	319	1.03	229	326	0.70
	CHL	1.0	1.3	0.79	1.9	4.0	0.47
	SD	5.4	5.2	1.04	5.2	4.1	1.28
2	TP	8.1	6.9	1.17	6.2	13.4	0.46
	TN	314	270	1.16	210	278	0.76
	CHL	0.9	1.2	0.75	2.2	2.7	0.82
	SD	4.8	4.6	1.04	4.9	4.6	1.06
3	TP	6.6	6.4	1.02	5.3	14.1	0.37
	TN	323	276	1.17	231	278	0.83
	CHL	1.1	1.1	1.00	1.8	2.9	0.63
	SD	4.8	4.8	1.00	5.2	4.6	1.14
4	TP	7.4	5.8	1.28	4.2	10.5	0.40
	TN	262	239	1.10	160	237	0.68
	CHL	1.2	1.0	1.24	2.3	2.0	1.15
	SD	4.3	4.4	0.97	4.9	5.1	0.96
	HODV	14.8	13.2	1.12	24.9	21.0	1.19
Lakewide	TP	7.1	6.4	1.11	4.5	13.7	0.33
	TN	291	270	1.08	191	272	0.70
	CHL	1.1	1.1	1.01	2.1	2.8	0.77
	SD	4.7	4.7	1.00	5.0	4.7	1.07

Table 5-17. Presence or absence of overlap in standard errors for observed and estimated values for five limnological variables for calibration and verification model runs, Payette Lake

[Lakewide, LW; Y, overlap present; N, overlap not present; —, not measured]

Variable	Calibration					Verification				
	Segment No. (Fig. 3-3)					Segment No. (Fig. 3-3)				
	1	2	3	4	LW	1	2	3	4	LW
Total Phosphorus	Y	Y	Y	Y	Y	N	N	N	N	N
Total Nitrogen	Y	Y	Y	Y	Y	N	Y	Y	N	N
Chlorophyll-*a*	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Secchi disc transparency	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Hypolimnetic dissolved oxygen deficit	—	—	—	Y	—	—	—	—	Y	—

5.6.3 Simulation Results

A wide variety of simulations was possible owing to the complexity of Payette Lake and its drainage basin, as well as to a diverse assortment of nutrient-load alterations that could be proposed and evaluated. Simulations of nutrient-load alterations were achieved by decreasing or increasing nutrient concentrations of the inflows to the lake. The water volume delivered by the inflow source was not altered because nutrient-management scenarios were assumed to affect concentrations, not flows. Limnological responses to the nutrient-load alterations were simulated with the 1996 data. The magnitudes of the responses were evaluated by comparison with the 1996 conditions estimated by the model. The output format of the simulations allowed evaluation of changes in the mean value of each response variable, either within a segment or on an area-weighted, lakewide basis.

Simulation 1 estimated limnological conditions prior to the 1994 forest fires. Concentrations of total phosphorus, dissolved orthophosphorus, total nitrogen, and dissolved inorganic nitrogen in tributaries affected by the 1994 fires were scaled back to pre-fire concentrations. For the North Fork Payette River inflow, pre-fire concentrations were those measured in the 1975 National Eutrophication Survey of Payette Lake (U.S. Environmental Protection Agency, 1977). For Fall Creek, and the Box/Lemah Creek watershed, nitrogen and phosphorus concentrations were set equal to those for Dead Horse Creek in 1996. On a lakewide basis, concentrations, in micrograms per liter, of total phosphorus increased from 6.4 to 6.5 and total nitrogen decreased from 270 to 127 (Table 5-18). Chlorophyll-a and secchi-disc transparency were unchanged. The hypolimnetic dissolved-oxygen deficit in model segment 4 increased about 1 percent. The largest change was in total nitrogen concentrations because the 1994 fires primary impact on Payette Lake was the large increases in nitrogen loads. Because the lake's phytoplankton production is strongly limited by phosphorus, not nitrogen, there was little reduction in chlorophyll-a concentrations and, consequently, little change in secchi-disc transparency and hypolimnetic dissolved-oxygen deficit. The large reduction in nitrogen concentrations did not shift the lake's phytoplankton production from phosphorus to nitrogen limitation.

Table 5-18. Simulation 1: Limnological response to estimated phosphorus and nitrogen loads delivered to Payette Lake prior to 1994 forest fires.

	Total phosphorus (µg/L)		Total nitrogen (µg/L)		Chlorophyll-a (µg/L)		Secchi-disc transparency (m)		Hypolimnetic dissolved-oxygen deficit [(mg/m^3)/d]	
Segment (Fig.3-3)	1996	Response	1996	Response	1996	Response	1996	Response	1996	Response
1	7.3	7.1	319	138	1.3	1.2	5.2	5.2	---	---
2	6.9	7.1	270	129	1.2	1.3	4.6	4.6	---	---
3	6.4	6.5	276	128	1.1	1.1	4.8	4.8	---	---
4	5.8	6.1	239	120	1.0	1.0	4.4	4.4	13.2	13.3
Lakewide	6.4	6.5	270	127	1.1	1.1	4.7	4.7	---	---

Simulation 2 took the opposite approach to simulation 1: the one-half of the watershed not burned in the 1994 fires was assumed to be burned with a severity similar to the 1994 fires. Total nitrogen and dissolved inorganic nitrogen concentrations were increased by a factor to 2.5 for the North Fork Payette River inflow, Fall Creek and the Box/Lemah Creek watershed. The smaller multiplier for these three tributaries was because about one-half of their watersheds were burned in the 1994 fires. Total phosphorus and dissolved orthophosphorus concentrations were increased 1.5 times on the six tributaries to simulate increased soil erosion. On a lakewide basis, concentrations, in micrograms per liter, of total phosphorus, total nitrogen, and chlorophyll-a increased from 6.4 to 8.4, 270 to 476, 1.1 to 1.5, respectively; secchi-disc transparency declined from 4.7 to 4.5 m (Table 5-19). The hypolimnetic dissolved-oxygen deficit in model segment 4 increased 19 percent. The in-lake increases in total nitrogen concentrations were the most noticeable impact; smaller increases in total phosphorus concentrations helped create increase chlorophyll-a concentrations and the hypolimnetic dissolved oxygen deficit; increased chlorophyll- a caused a decline in secchi-disc transparency.

Table 5-19. Simulation 2: Limnological response to increased phosphorus and nitrogen loads caused by forest fires in watershed areas not burned during the 1994 forest fires.

	Total phosphorus (µg/L)		Total nitrogen (µg/L)		Chlorophyll-a (µg/L)		Secchi-disc transparency (m)		Hypolimnetic dissolved-oxygen deficit [(mg/m^3)/d]	
Segment (Fig.3-3)	1996	Response	1996	Response	1996	Response	1996	Response	1996	Response
1	7.3	10.1	319	607	1.3	1.9	5.2	4.8	---	---
2	6.9	8.7	270	454	1.2	1.6	4.6	4.4	---	---
3	6.4	8.6	276	493	1.1	1.6	4.8	4.5	---	---
4	5.8	7.3	239	399	1.0	1.3	4.4	4.3	13.2	15.7
Lakewide	6.2	8.4	270	476	1.1	1.1	4.7	4.7	---	---

Simulation 3 used the responses to simulated pre-fire nutrient concentrations (simulation 1, Table 5-18) as the basis for assessing the lake's response to 20-percent reductions in nutrient loads from developed shoreline areas. An assumption was made that substantive nutrient-management actions would not occur until after the limnological effects of the 1994 fires had been muted by natural recovery processes in the watershed and lake. Accordingly, concentrations of total phosphorus, dissolved orthophosphorus, total nitrogen, and dissolved inorganic nitrogen were reduced 20-percent for the developed shoreline areas of the southwest and southeast basins, the McCall urban area and the west shore of the peninsula. Sylvan, Dead Horse and Fall Creeks were assigned nutrient reductions of 10 percent to simulate management of their developed shoreline areas. On a lakewide basis, concentrations, in micrograms per liter, of total phosphorus, total nitrogen, and chlorophyll-a declined from 6.5 to 6.4 and 127 to 125, respectively (Table 5-20). Chlorophyll-a and secchi depth transparency were unchanged. The hypolimnetic dissolved-oxygen deficit in model segment 4 decreased about 1 percent. Small responses occurred in model segment 1, the northern basin, because it has very little developed shoreline to affect its large volume. Model segment 4, the southwest basin, also has a large volume, but has a substantial level of shoreline development. The responses of these two model segments were similar because both have large volumes in relation to the amount of nutrient loads delivered to them from developed shoreline areas.

Table 5-20. Simulation 3: Limnological response to 20-percent reduction in phosphorus and nitrogen loads from developed shoreline areas; comparison is to simulated response to pre-1994 forest fires (Simulation 1, Table 5-18).

	Total phosphorus (µg/L)		Total nitrogen (µg/L)		Chlorophyll-a (µg/L)		Secchi-disc transparency (m)		Hypolimnetic dissolved-oxygen deficit [(mg/m^3)/d]	
Segment (Fig.3-3)	Pre-fire	Response	Pre-fire	Response	Pre-fire	Response	Pre-fire	Response	Pre-fire	Response
1	7.1	7.0	138	136	1.2	1.2	5.2	5.2	---	---
2	7.1	6.9	129	127	1.3	1.2	4.6	4.6	---	---
3	6.5	6.4	128	126	1.1	1.1	4.8	4.8	---	---
4	6.1	5.9	120	118	1.0	1.0	4.4	4.4	13.3	13.2
Lakewide	6.5	6.4	127	125	1.1	1.1	4.7	4.7	---	---

Simulation 4 also used the responses from simulation 1 as the basis for assessing the lake's response to 20-percent reductions in nutrient loads from watershed areas subjected to timber harvest activities. Concentrations of total phosphorus, dissolved orthophosphorus, total nitrogen, and dissolved inorganic nitrogen were reduced 20-percent for the North Fork Payette River inflow, Box/Lemah Creek watershed, and Fall, Deadhorse, Copet, and Sylvan Creeks. On a lakewide basis, concentrations, in micrograms per liter, of total phosphorus, total nitrogen, and chlorophyll-a declined from 6.5 to 5.8, 127 to 108, and 1.1 to 1.0, respectively; secchi-disc transparency increased from 4.7 to 4.8 m (Table 5-21). The hypolimnetic dissolved-oxygen deficit in model segment 4 decreased about 8 percent. Model segment 1 had the largest percentage responses because most of the nutrient load reductions occurred in its tributary watersheds. The smallest percentage responses were in model segment 4 because its tributary watersheds were unaffected in this simulation.

Table 5-21. Simulation 4: Limnological response to 20-percent reduction in phosphorus and nitrogen loads from watershed areas subjected to timber-harvest activities; comparison is to simulated response to pre-1994 forest fires (Simulation 1, Table 5-18).

	Total phosphorus (µg/L)		Total nitrogen (µg/L)		Chlorophyll-a (µg/L)		Secchi-disc transparency (m)		Hypolimnetic dissolved-oxygen deficit [(mg/m^3)/d]	
Segment (Fig.3-3)	1995	Response	1995	Response	1995	Response	1995	Response	1995	Response
1	7.1	6.1	138	115	1.2	1.0	5.2	5.4	---	---
2	7.1	6.4	129	111	1.3	1.1	4.6	4.7	---	---
3	6.5	5.7	128	109	1.1	0.9	4.8	4.9	---	---
4	6.1	5.5	120	104	1.0	0.9	4.4	4.4	13.3	12.3
Lakewide	6.5	5.8	127	108	1.1	1.0	4.7	4.8	---	---

Simulation 5 combined the nutrient load reductions applied in simulations 3 and 4. On a lakewide basis, concentrations, in micrograms per liter, of total phosphorus, total nitrogen, and chlorophyll-a declined from 6.5 to 5.7, 127 to 108, and 1.1 to 0.9, respectively; secchi-disc transparency increased from 4.7 to 4.8 m (Table 5-22). The hypolimnetic dissolved-oxygen deficit in model segment 4 decreased about 8.5 percent. Of the three nutrient-reduction simulations, this one achieved the largest responses lakewide and in each of the four model segments.

Table 5-22. Simulation 5: Limnological response to 20-percent reduction in phosphorus and nitrogen loads from developed shoreline areas and watershed areas subjected to timber-harvest activities; comparison is to simulated response to pre-1994 forest fires (Simulation 1, Table 5-18).

	Total phosphorus (µg/L)		Total nitrogen (µg/L)		Chlorophyll-a (µg/L)		Secchi-disc transparency (m)		Hypolimnetic dissolved-oxygen deficit [(mg/m^3)/d]	
Segment (Fig.3-3)	Pre-fire	Response	Pre-fire	Response	Pre-fire	Response	Pre-fire	Response	Pre-fire	Response
1	7.1	6.1	138	114	1.2	1.0	5.2	5.4	---	---
2	7.1	6.2	129	110	1.3	1.1	4.6	4.7	---	---
3	6.5	5.7	128	108	1.1	0.9	4.8	4.9	---	---
4	6.1	5.4	120	104	1.0	0.9	4.4	4.5	13.3	12.2
Lakewide	6.5	5.7	127	108	1.1	0.9	4.7	4.8	---	---