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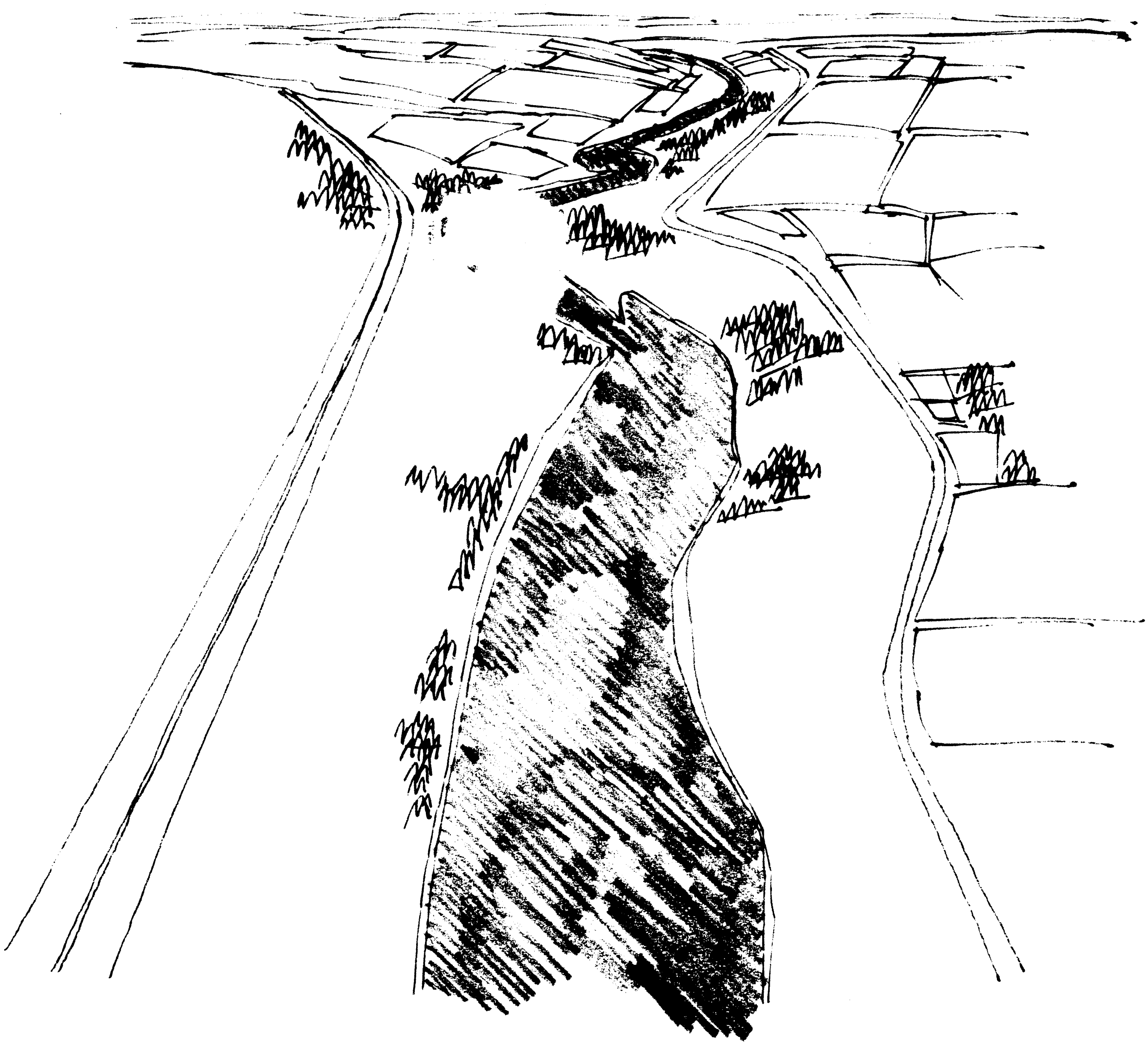
Department of Ecology

Spokane River Wasteload Allocation Study

Phase I



Prepared by URS Company

WASHINGTON STATE

DEPARTMENT OF ECOLOGY

SPOKANE RIVER

WASTELOAD ALLOCATION STUDY

PHASE I

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SUMMARY

The work described in this report constitutes Phase 1 of the Spokane Wasteload Allocation Study. The major objective of this phase of the study was development of a wasteload allocation procedure to be used by the Washington Department of Ecology (DOE).

The first six chapters present background information on the Spokane River/Aquifer system. The river is characterized by a series of impoundments and free-flowing reaches. The major reservoir in the system is Long Lake, which is 22 miles long. Considerable interchange occurs between the river and the aquifer; therefore, possible effects on the aquifer were considered in development of the wasteload allocation procedure.

The major beneficial uses of this system that depend on water quality include water supply (sole source aquifer), fish and wildlife habitat, and recreation.

Data on existing water quality conditions are reviewed. The major pollutant sources include several municipal sewage treatment plants, several industries, agricultural and urban runoff, and the Idaho drainage basin (loads carried by the river when it enters the study area). The quality of groundwater is excellent. The Spokane River carries moderately high loads of heavy metals (zinc, copper, lead, cadmium, mercury) and occasionally has dissolved oxygen (DO) levels below 8 mg/l in the reach above the city.

Long Lake has been characterized by low hypolimnetic DO levels and excessive algal growth in late summer and early fall. Phosphorus removal at the Spokane STP has reduced algal growth; however, low DO levels continue to occur.

Criteria to protect beneficial uses are discussed. In addition, it has been assumed that the allocation procedure should be compatible with the non-degradation policy for the aquifer. Toxicant levels below those demonstrated to be harmful to aquatic life in the Spokane River should be maintained. State water quality standards define required DO levels (8 mg/l). Various criteria for mean seasonal chlorophyll a are identified and evaluated with respect to associated phosphorus load reductions required. The value of 10 ug/l is used in an allocation example. It would result in a water clarity of about three meters and is considered a reasonable value from the standpoint of protecting water quality in Long Lake. Public input is essential in selection of water quality criteria for protection of beneficial uses and as the basis for a wasteload allocation.

Comparison of existing conditions to criteria indicates that several current and projected problems are present: 1) algal growth in Long Lake, 2) low DO levels in and below the lake, 3) high heavy metal (zinc, copper, lead, cadmium, and mercury) levels, and 4) combined sewer overflows.

A well-established cause/effect relationship that provides a technically adequate basis for wasteload allocation is available only for phosphorus. Phosphorus has been identified as a controllable factor related to excessive algal growth in Long Lake.

A system model was developed for use in making wasteload allocations. It initially consists of a simple steady-state river mass-balance model plus a linear regression between phosphorus and seasonal chlorophyll a in Long Lake. Application of this model to the Spokane system is described. Models available for other parameters and input data needs are summarized.

The data needs identified in the review of the system and development of the system model are presented. Additional data are needed for problem identification and input to the system model. A study program has been designed to fill these data needs through a combination of modifications to existing monitoring and new studies. These studies are described and prioritized with respect to usefulness for wasteload allocation.

The wasteload allocation procedure is explained and illustrated by development of a phosphorus allocation example. Estimated future phosphorus loadings will result in mean seasonal chlorophyll a levels higher than 10 ug/l unless very high levels of phosphorus removal are required for all major sources to the system or wasteloads due to anticipated growth can be controlled so that increased phosphorus loadings to the river do not occur.

Seasonal phosphorus removal at municipal STPs along the river was found to be feasible for the Spokane River system. Phosphorus loads must be reduced long enough before the critical algal growth season to ensure low levels through the season. Phosphorus retained in the lake sediments is apparently unavailable to algae during this season.

CHAPTER 1

INTRODUCTION

For a number of years, Long Lake has experienced nuisance algal blooms and low hypolimnetic dissolved oxygen levels during late summer and early fall. Cunningham and Pine (1969) documented the hypolimnic anoxia in September 1969. Subsequent investigations by Soltero and others (1973, 1974a, 1975a, 1976, 1978) showed that the lake was eutrophic, that high concentrations of phosphorus occurred after fall overturn, and that the hypolimnion of the lake became anoxic during the late summer and early fall. These studies also revealed that the Spokane Sewage Treatment Plant (STP), which discharges to the Spokane River several miles upstream from the lake, was the major source of phosphorus during the summer. This work provided a major impetus for the decision to upgrade the Spokane Treatment Plant to the advanced waste treatment (AWT) level, including phosphorus removal.

Recent investigations (Soltero, et al., 1979, 1980) indicate that AWT has substantially decreased phosphorus loading to the lake, and produced a resulting improvement in lake water quality. Phosphorus concentration in the lake at overturn is lower, and algal assay tests indicate that phosphorus is now the limiting nutrient both upstream and downstream from the STP outfall. Continuing studies will clarify the effect on Long Lake of AWT.

Nonetheless, considerable concern remains in both the private and government sectors that lake quality may deteriorate again if a stringent management policy is not adopted to control future wastewater loadings to surface waters of the Spokane-Coeur d'Alene River basins. Rapid population growth and continuing commercial development are projected for this area.

The Spokane-Rathdrum aquifer flows beneath the Spokane River basin. Considerable exchange occurs between the surface and ground waters. Because the Spokane aquifer is the sole source of domestic water in the Spokane Metropolitan Area, which has a population of about 340,000 people, protection of the water quality in the aquifer is a key concern.

This wasteload allocation study is part of an agreement between the Washington Department of Ecology and the U.S. Environmental Agency, reached on 24 July 1979, to develop a wasteload allocation plan for the Spokane Basin over the next three years. The agreement was made as part of a stipulation included in the court settlement, James A. Schasre and Lake Spokane (Long Lake) Environmental Association versus Liberty Lake Sewer District No. 1 and the Department of Ecology, Spokane County Superior Court Case No. 79202662-4. The Spokane River wasteload allocation study is also in response to Section 303(d)(1)(c) of the Clean Water Act, which requires that total maximum daily loads be established for those pollutants which affect water quality criteria.

CHAPTER 2

THE PHYSICAL SETTING

THE STUDY AREA

The study area includes the eastern Washington portion of the Coeur d'Alene-Spokane drainage system (Figure 2-1). The Spokane River originates at the outlet of Lake Coeur d'Alene, and flows westward through eastern Washington, through the city of Spokane, to its confluence with the Columbia River (Lake Roosevelt) 106 river miles from its source. Two major tributaries feed the Spokane River: Hangman Creek, which drains a dryland agricultural area to the south of Spokane and joins the river below the Spokane city center at river mile (RM) 72, and the Little Spokane River, which drains an area north of Spokane and enters the Spokane River at the head of Long Lake, river mile 58.

Spokane River

A series of dams operated by Washington Water Power regulates streamflow; therefore, much of the river is more lakelike than streamlike. The reach from Post Falls to Plantes Ferry (RM 99-85) is free-flowing, as is the reach from Hangman Creek to the backwater behind Nine Mile Dam (RM 72-64). The remainder of the river is a series of impoundments interspersed with free-flowing segments. The major reservoir in the system is Long Lake, which is backed up about 22 miles behind Long Lake Dam.

Mean monthly flows for the period from 1970 to 1977 for the Spokane River, Hangman Creek, and the Little Spokane River are given in Table 2-1. This table shows that most of the inflow to Long Lake is provided by the Spokane River. The discharge of Hangman Creek is relatively small, typically providing less than 10 percent of the inflow to the Spokane River. Flow in the Little Spokane River is relatively constant through the year, reflecting the influence of inflow from the Spokane aquifer. The year-to-year variability in discharge of the Spokane River at Spokane is reflected in the total monthly discharges shown in Figure 2-2. High flows typically occur from March to June but vary considerably from year to year. Low flows, which usually occur from July through November, are quite consistent from year to year. Thus, years such as 1973 and 1977, which were unusually dry, have much lower than normal inflows during the typical high flow season (March to June), but only slightly lower than normal flows during the low flow season (August to November).

Aquifer/River Interchange

As the Spokane aquifer flows along the axis of the valley, it exchanges water with the Spokane and Little Spokane Rivers. Bolke and Vaccaro (1979) reported annual stream gains and losses for the water year 1950 between gaging stations for seven reaches of the Spokane and Little Spokane Rivers. The location of the gaging stations and the annual exchanges are shown in Figure 2-3.

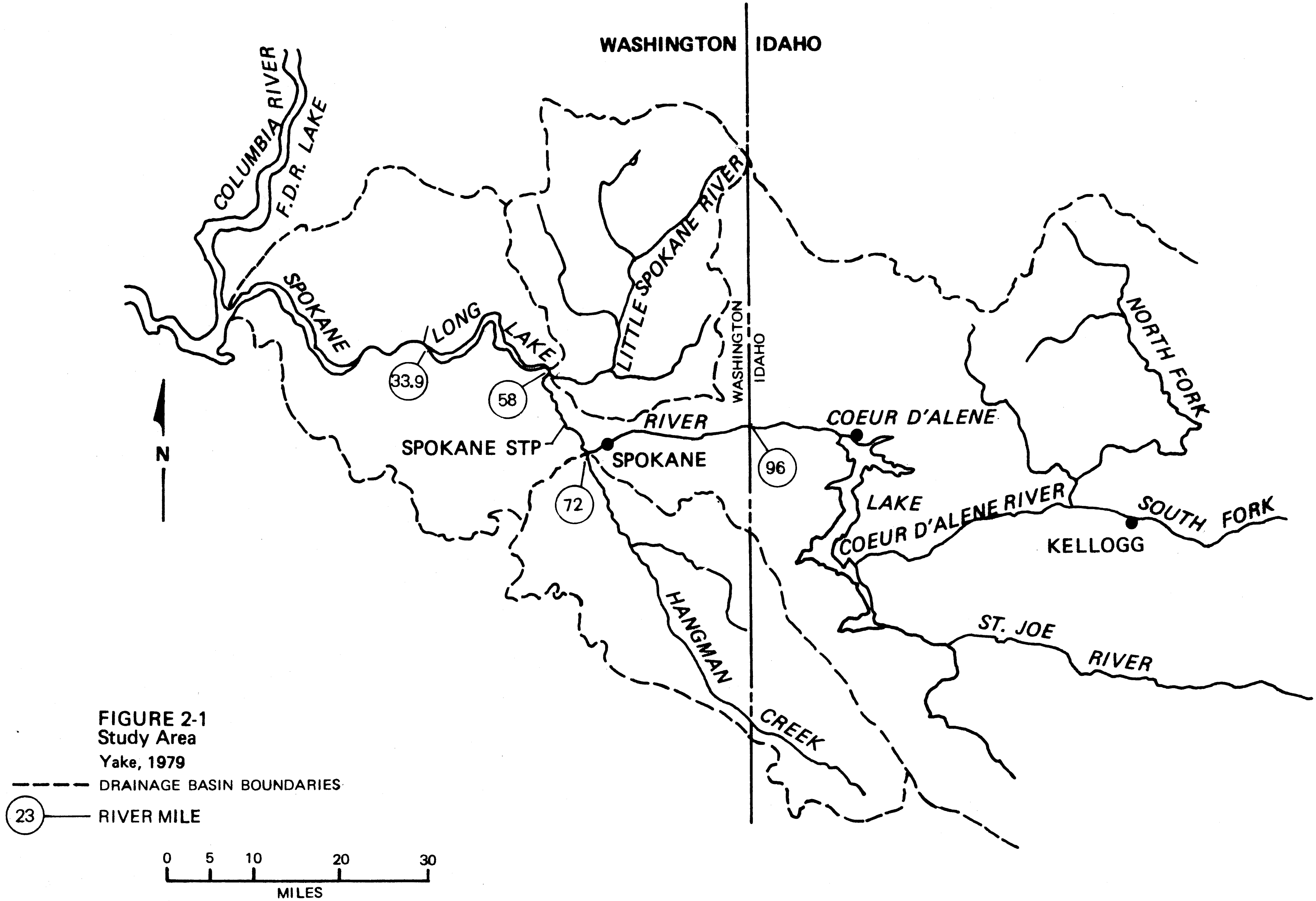


FIGURE 2-1
Study Area

Yake, 1979

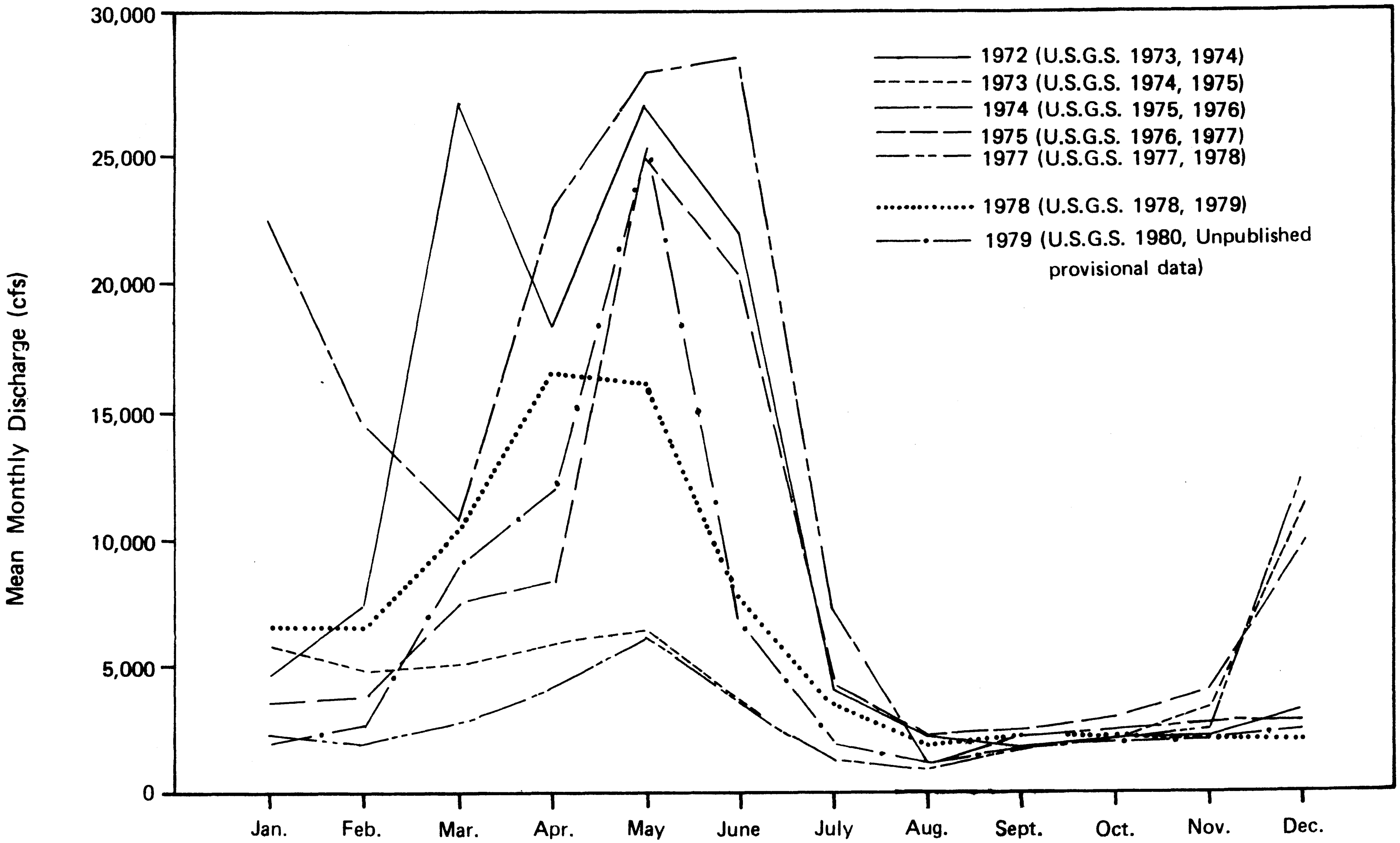


FIGURE 2-2
Mean monthly discharge (cfs) for the Spokane River at Spokane, Washington (1972-1975; 1977; 1978)

Source: Soltero, et al, 1979

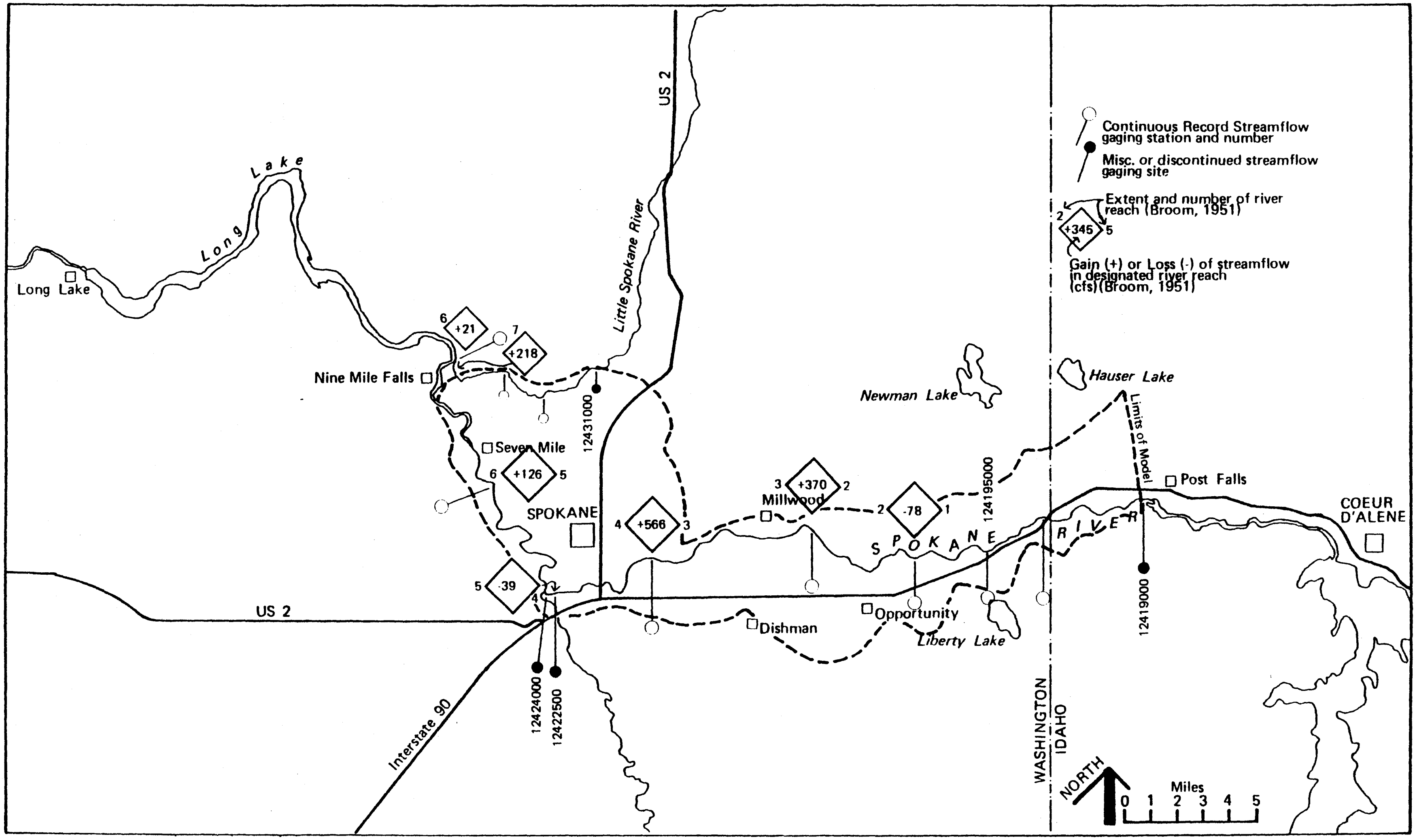


FIGURE 2-3
LOCATION OF STREAMFLOW GAGING STATIONS

BOLKE & VACCARO 1979

TABLE 2-1

MEAN MONTHLY FLOWS - 1/70 to 9/77

Month	Post Falls & Otis Orchards[1] Flow (cfs) RM 100.7	Riverside State Park[1,2] Flow (cfs) RM 66.1	Long Lake[1] Flow (cfs) RM 33.9	Hangman Creek[1] Flow (cfs) RM 72.3	Little Spokane River[3] Flow (cfs) RM 56.3
Jan.	6,732	7,797	8,915	616	580
Feb.	7,054	8.287	9,204	597	529
Mar.	8,699	9,880	11,120	737	629
Apr.	11,778	12,804	13,192	333	639
May	18,840	19,849	19,902	159	630
June	13,628	14,823	15,323	83	440
July	2,663	3,481	4,208	22	392
Aug.	1,156	1,700	2,332	23	358
Sept.	1,514	1,939	2,551	15	384
Oct.	2,231	2,262	2,922	21	434
Nov.	2,390	2,836	3,587	42	442
Dec.	4,592	5,178	6,032	283	440

[1] From "Water Quality Records, Washington State." United States Geological Survey, 1970-1977.

[2] Spokane River at Spokane flows, plus Hangman Creek flows, 1970-1977.

Source: Yake, 1979

[3] Department of Ecology data, 11/70-6/78, Intermittant Data Base.

The movement of water between the river and aquifer can be approximated from the head difference between stream surface elevations and aquifer. Drost and Seitz (1978) reported that the levels of both the Spokane River and the water table generally fluctuate about 10 feet per year; however, because these fluctuations do not coincide, the amounts, direction, and locations of interchanges of water vary during the year. On a short-term basis, flow of water between the aquifer and the river may change drastically, although the long-term average exchange for any reach of the river is fairly constant (Vaccaro, personal communication, 1980).

Bolke and Vaccaro's (1979) model of the Spokane Valley Aquifer indicated that the Spokane River alternately loses water to and gains water from the aquifer from Post Falls to Long Lake. The average gains and losses during the May 1977 - April 1978 period, as calculated by the aquifer model, are shown in Figure 2-4. Each reach either consistently gains or consistently loses streamflow. The largest gain is 270 cfs in the reach near the east part of Spokane and the largest loss is 200 cfs in the reach above Spokane Falls.

Long Lake Reservoir

Morphometric data for Long Lake at maximum capacity are given in Table 2-2. Water is normally discharged through the power penstocks (centerline elevation 457 m). The normal operating pattern for the reservoir is to maintain a constant level for power generation. In wet years, the level is often lowered in late winter to provide storage capacity for peak flows in the spring.

Detention times for the reservoir vary with inflow and reservoir operation. During 1978, Soltero, et al. (1979) observed a minimum detention time of about 7 days during the high flow months of April and May, and a maximum detention time of 51 days, which occurred in August. The mean detention time was calculated to be 27.3 days.

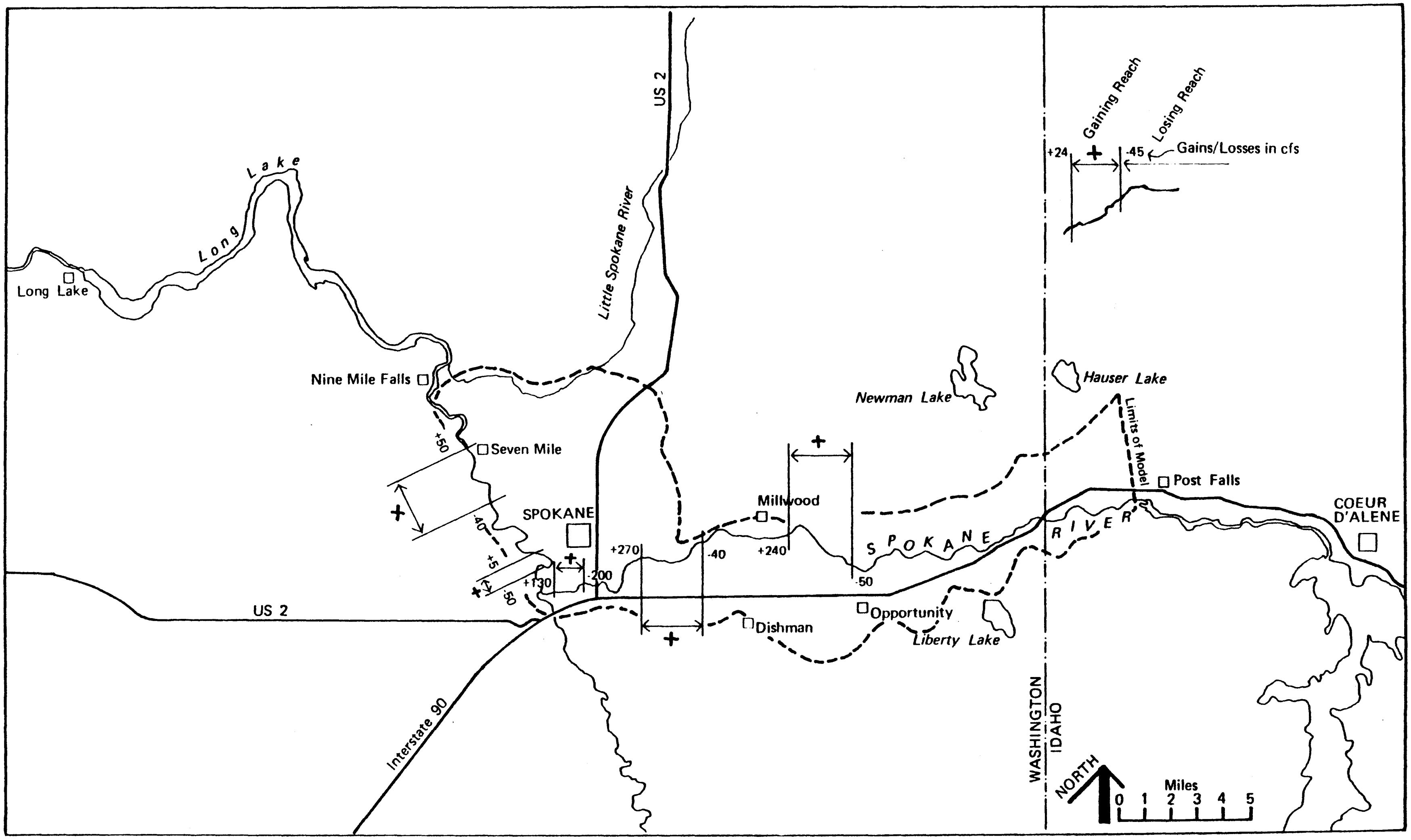


FIGURE 2-4
RIVER/AQUIFER INTERCHANGE
(USGS Simulation Model)
BOLKE & VACCARO 1979

TABLE 2-2

MORPHOMETRIC DATA FOR LONG LAKE AT MAXIMUM CAPACITY
(ELEVATION 468.2 M)

Maximum Length	35.4 km (22.0 mi)
Maximum Effective Length	5.8 km (3.6 mi)
Maximum Width	1.1 km (0.7 mi)
Maximum Effective Width	1.1 km (0.7 mi)
Mean Width	571.8 m (1,875.9 ft)
Maximum Depth	54.9 m (180.0 ft)
Mean Depth	14.6 m (48.0 ft)
Area	208.4×10^5 m^2 (5,149.7 acres)
Volume	304.9×10^6 m^3 (247,186 acre-ft)
Shoreline Length	74.3 km (46.2 mi)
Shoreline Development	4.6
Bottom Grade	0.15%

Source: Soltero, et al. (1979)

CHAPTER 3

BENEFICIAL USES

INTRODUCTION

The Spokane-Rathdrum Aquifer was designated as a "sole source" of water supply for the Spokane-Coeur d'Alene area by the EPA in 1978. Thus the most important beneficial use of the aquifer/river system is water supply. A non-degradation policy was recommended for the aquifer as part of the '208' Water Quality Management Program.

The Spokane River has been classified as Class A (excellent) from the Idaho border to its mouth. Beneficial uses established by DOE for Class A waters include: 1) water supply, 2) wildlife habitat and stock water, 3) general recreation and aesthetic enjoyment, 4) commerce and navigation, and 5) fish and shellfish reproduction, rearing, and harvesting.

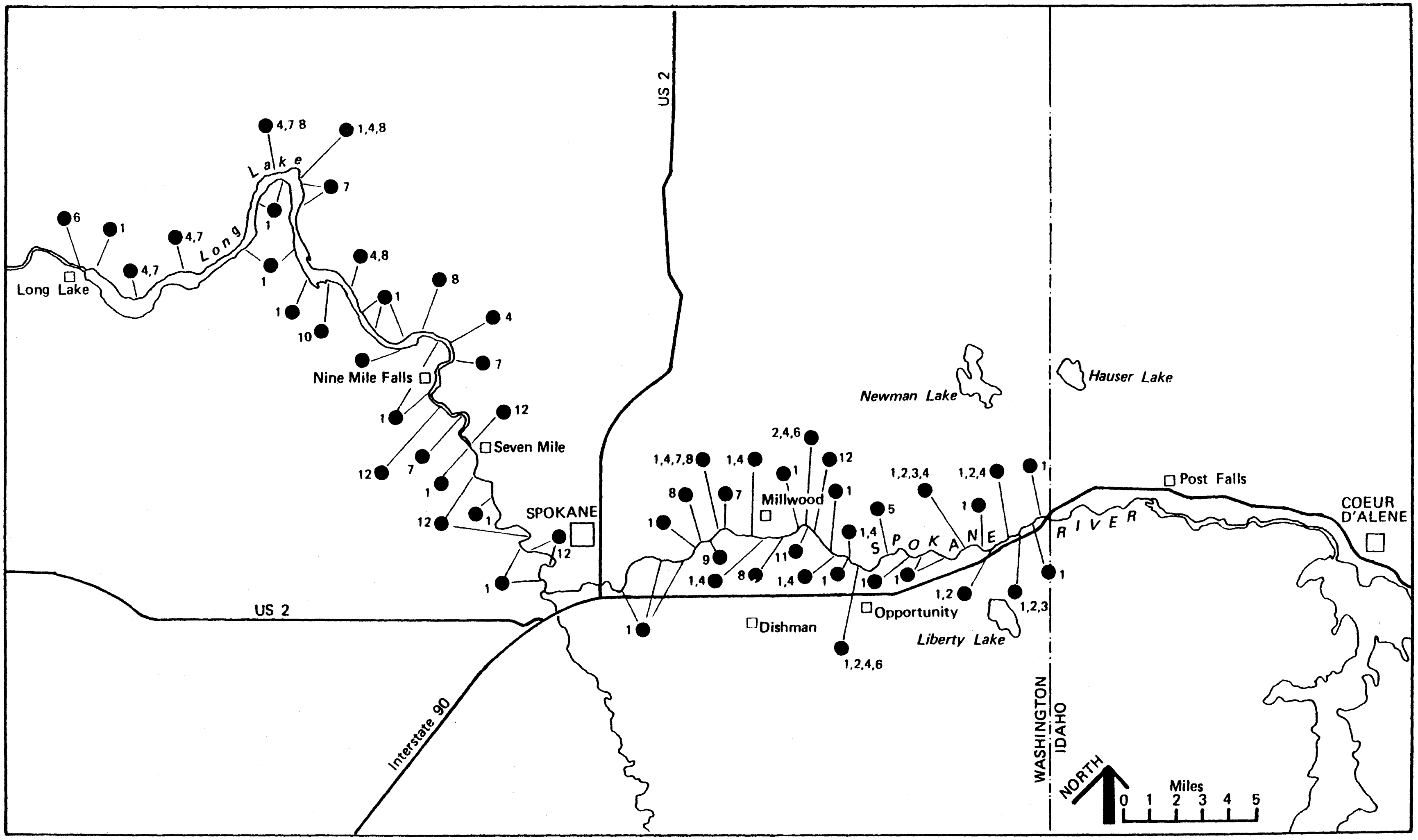
The most important water quality dependent, existing beneficial uses in Spokane River-Long Lake system are recreation, fish habitat, water fowl habitat, and aesthetic enjoyment. Recreational use, particularly water contact activities, swimming and rafting, is most intensive during the summer. Other uses, such as fishing, continue during other seasons. Fish habitat and aesthetics are, of course, year round beneficial uses. Use by waterfowl is heaviest during fall migration.

SPOKANE AQUIFER

Groundwater is used for domestic, irrigation, and industrial water supply in the area overlying the aquifer. Public water supply systems in Washington pumped 115 cfs from the aquifer for domestic use in 1976. Additional water was pumped for irrigation and industrial supply.

SPOKANE RIVER

As shown in Figure 3-1, water contact recreation along the river occurs mainly at a number of points above Upriver Dam (RM 80). During the summer, swimming is popular and occurs wherever there is access to slow moving water (Bailey, 1980). The most heavily used swimming areas are those closest to the city (Angov, 1980). In addition, some wading occurs downstream from Spokane near the mouth of Hangman Creek and in Riverside State Park (Angov, 1980). Rafts and kayaks also use the upper portion of the river from Post Falls Dam (RM 99) downstream to about Plantes Ferry (RM 85) as shown on Figure 3-1 (Bailey, 1980).



KEY to ACTIVITIES:

1 FISHING
2 RAFTING
3 CAMPING
4 SWIMMING
5 LIMITED ACCESS
6 PICNICKING
7 BOAT LAUNCH
8 WATERSKIING
9 FLOAT PLANES
10 DUCK BLINDS
11 KAYAKING
12 STATE PARKS, PARKS

FIGURE 3-1
Recreational Use of the Spokane River and Long Lake

The period of greatest fishing use in the river is longer than the swimming season (June to September). The river above Greene Street is open to trout fishing from April 20 to September 30, with a one fish limit. Heaviest fishing occurs between Harvard Road (RM 93) and Stateline bridge (RM 96); the next most intensively fished reach is between Barker and Sullivan Roads (RM 88-90). (Bailey, 1980).

The nature of the river as it moves through the city of Spokane is not conducive to water contact recreation. Thus the major use is aesthetic appreciation (Fern, 1980). Aesthetics are also quite important downstream at Riverside State Park, where the water is also too swift for swimming, although some wading does occur.

Fishing also occurs in the river between Upriver Dam and Long Lake. The reach between Monroe Street and Upriver Dam (RM 74-80) is planted with rainbow trout, and the reach between Nine Mile Dam and Monroe Street (RM 58-74) is planted with rainbow and German brown trout. Fishing for these fish and the perch, bass, and crappie also present is open year around with no special limits (1980 fishing regulations) (Duff, 1980).

LONG LAKE

Swimming and water skiing are very popular in Long Lake during the summer, particularly in the upstream half of the lake. In general, swimming and skiing occur in front of major housing developments, as well as near the resorts of Tum Tum and Willow Bay (Peters, 1980; Anderson, 1980). Swimming also occurs at the public access points in the downstream half of the lake; however, use is much less intensive than in the upstream portion (Peters, 1980). The areas where swimming and skiing are concentrated, as well as the boat launch areas, are shown in Figure 3-1. Boating occurs along the entire length of the lake, but is more concentrated in the upstream half where waterfront housing developments and resorts give access to a large number of people (Peters, 1980).

Long Lake is a popular lake for spiny ray fisheries (Duff, 1980). Again, use is heaviest during the summer. The lake contains large populations of yellow perch and crappie as well as a substantial number of large bass that are prized by trophy fishermen. Trout are also present in the section between the mouth of the Little Spokane River and Nine Mile Dam; WDG plants german brown trout and eastern brook trout in this section (Duff, 1980).

The lake is very popular with bass fishermen, who fish the lake from March through the end of November (Anderson, 1980). May is considered the best month for bass fishing; however, numerous large bass are taken throughout the season.

Fishing continues even during the winter, after the lake becomes frozen. The large population of yellow perch makes the lake popular with ice fishermen (Anderson, 1980).

The lake is also used by waterfowl, particularly during the fall migration. The presence of some duck blinds near Sportsmen's Paradise, a now defunct resort on the lake, attests to the recreational attraction of the presence of waterfowl (WWP, 1975).

CHAPTER 4

EXISTING CONDITIONS

This section summarizes information on existing water quality conditions, including sources of pollutants, for the three components of the Spokane River/Aquifer System: the Spokane Aquifer, the Spokane River, and Long Lake.

To reduce confusion, the following conventions are used throughout this section. Metric units of concentration are used: milligrams/liter (mg/l), micrograms/liter (ug/l). All phosphate fractions are reported in terms of phosphorus (e.g., PO_4-P). All nitrogen fractions are reported in terms of nitrogen (e.g., NO_3-N). "Total phosphate" and "total phosphorus" are used interchangeably, referring to an analysis in which phosphorus present in other forms is hydrolyzed to phosphate before measurement. "Orthophosphate" refers to a method in which a sample is filtered prior to phosphate determination.

SOURCES OF POLLUTANTS

The glacial outwash deposits overlying the aquifer are extremely permeable; therefore, precipitation, irrigation water, on-site waste disposal leachate, and stormwater runoff may percolate into the aquifer, transporting dissolved constituents from the surface. Similarly, leachate from solid waste disposal sites can transport dissolved constituents into the aquifer. Depth selective sampling conducted during the Spokane 208 program (Esvelt, 1978) indicated that chloride, nitrate-nitrogen, and total dissolved solids concentrations were statistically significantly higher near the aquifer water surface than deeper in the aquifer. Higher dissolved solids concentrations were observed in the vicinity of solid waste disposal sites. As discussed above substantial aquifer/river interchange occurs. In wells that reflect the influence of dilution by water from the Spokane River, higher levels of heavy metals, particularly zinc, and lower levels of total dissolved solids and chloride are observed (Esvelt, 1978).

Spokane River

Heavy metals are added to the river in the Idaho portion of the drainage area. The Kellogg mining district, located along the south fork of the Coeur d'Alene River, is the location of large silver and lead producing mines. Mining and milling activities continue to discharge water containing heavy metals (primarily zinc, but also lead, copper, chromium, cadmium, and others). Metals are also discharged by a large lead smelter, located near Kellogg, Idaho, and by an electrolyte zinc plant (Yake, 1979). As a result, the sediments of Lake Coeur d'Alene, the delta of the Coeur d'Alene River where it enters the lake, and the lowland areas along the south fork of the Coeur d'Alene River all contain high concentrations of heavy metals (e.g., Zinc levels ranging from 2.2 to 32.8 mg/g in the top 10 cm of lake sediment) that will continue to leach into the Spokane River drainage (Funk, et al., 1973, 1975).

Currently, the Coeur d'Alene wastewater treatment plant (RM 110) is the only major municipal source on the Spokane River above Stateline Bridge. It is a secondary plant (trickling filter) in the facilities planning stage for upgrade of the facilities. A proposed plant for the Post Falls area (RM 99), which currently relies on individual subsurface disposal, is also in the facilities planning stage; seasonal land application is being considered for this plant, which is to have an initial flow of 1 MGD and a design flow of 2.4 MGD. Construction of these two facilities will be completed in approximately four years. It is currently not known if phosphorus removal will be required at these two plants (Tinky, Cooney, personal communication, 1980).

As the Spokane River flows through the Spokane Valley and the urbanized Spokane area, pollutants are added by a variety of point and non-point sources. Current and projected point discharges are shown in Figure 4-1 and listed in Table 4-1.

TABLE 4-1

POINT SOURCES - SPOKANE RIVER

Source	RM	Size	Nature
Liberty Lake STP	92.7	1-3 MGD	future municipal
Spokane Industrial Park STP	87.1	0.6 MGD	industrial
Kaiser	86.0	33 MGD	cooling water & some industrial waste
Inland Empire Paper Company	82.6	2.0 MGD	industrial
Millwood STP	82.3	.012 MGD	domestic (package plant)
Spokane STP	65.9	30 MGD	domestic
NW Terrace STP	64.3	0.20 MGD	domestic (package plant)

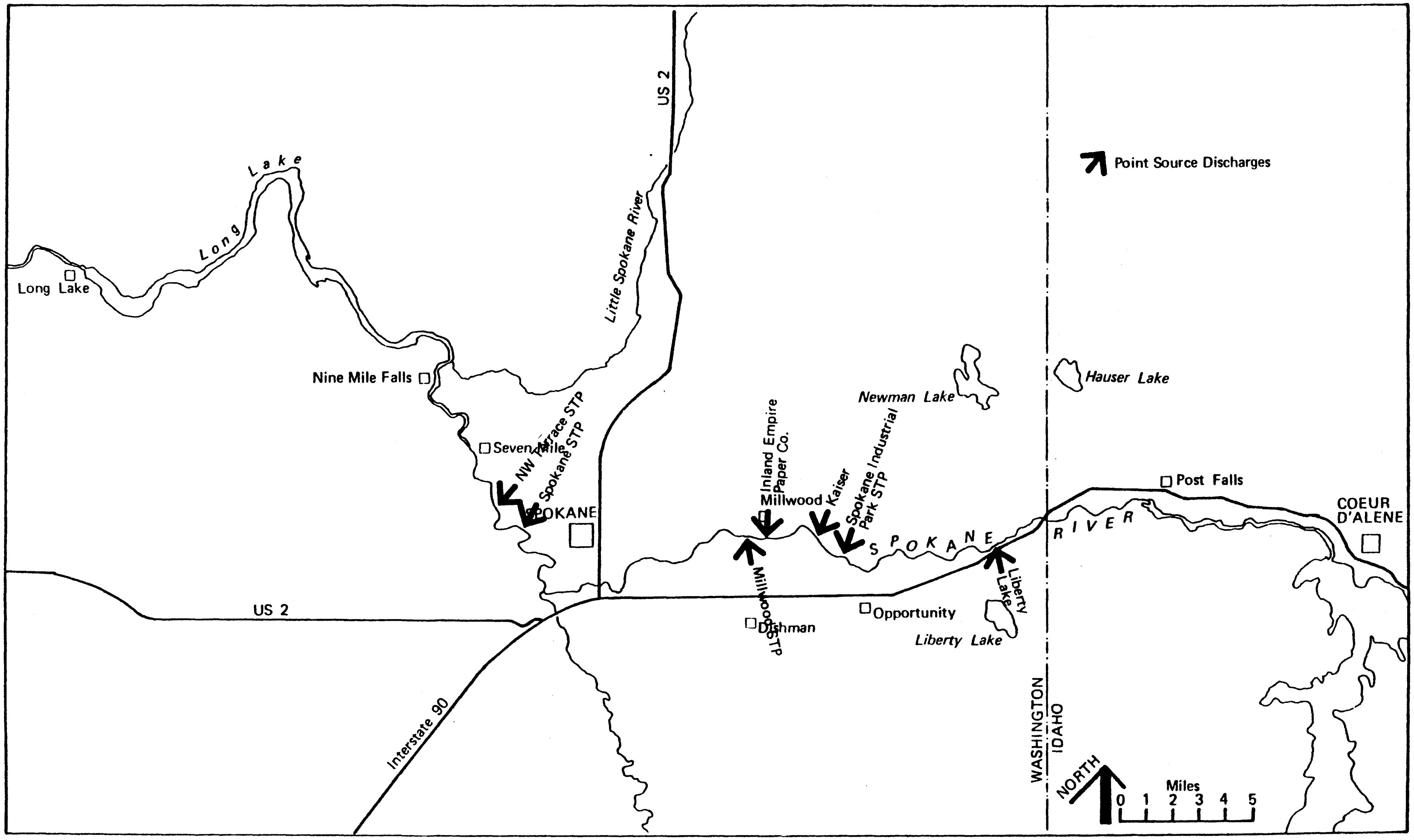


FIGURE 4-1
POINT DISCHARGES TO SPOKANE RIVER

The proposed Liberty Lake wastewater treatment plant is to be a three-phase project to allow for increases in plant capacity as required (Kennedy Engineers, 1979). For Phase 1, an extended aeration activated sludge plant with an average design flow of 1 MGD is to be provided. The plant will be converted to conventional activated sludge for Phase 2. Plant capacity will also be increased to accomodate flows of 2 MGD. Since the draft NPDES permit for the Phase 1 plant requires phosphorus removal when flows exceed 1 MGD, the proposed Phase 2 plant will include such wastewater treatment. Phase 3 expansion will increase plant capacity to 3 MGD. It is estimated that the concentration of total phosphorus discharged from the plant will vary from 6.3 mg/l under Phase 1 to 1.2 mg/l at Phase 3. Several relatively small municipal and industrial discharges enter the river in the Valley. Septic tanks in the urbanizing valley area may also add to the river's pollutants directly to both the Spokane River and the Little Spokane River.

In Spokane itself, the combined sanitary and storm sewer system overflows periodically when stormwater overloads the system, resulting in the discharge of domestic sewage. The Spokane sewer system has 29 different points from which combined storm and sanitary sewage overflows (CSO's) occur to the Spokane River; in addition, two CSO discharges occur to Hangman Creek and eventually reach the Spokane River. Sanitary sewage may be discharged to the river from five bypasses at pump stations and three blowoffs at syphons if a malfunction should occur at these points (City of Spokane, 1977).

Peak overflows in the sewer system tend to occur in the late spring, due to the effects of high groundwater, snowmelt and wet weather (Bovay, 1978). Flow metering at the largest CSOs (Cochran, Hollywood, West Grove, and Sharp Stations) is currently underway.

Since population densities are fairly uniform in the City of Spokane, it has been estimated that the 31 different combined sewer overflows should contain about the same concentration of sewage (City of Spokane, 1977). The actual concentration of the overflows will depend on the intensity and duration of the storm event. The following concentrations were measured in samples collected after the first flush of the combined sewer overflow during stormwater runoff (City of Spokane, 1977):

Parameter	Concentration Range
BOD	20-210
Suspended Solids	76-220
Volatile Suspended Solids	14-35
Phosphorus	0.95-1.9
Kjeldahl Nitrogen	5-12

Annual emission rates were computed by Esvelt Saxton/Bovay, 1972, based on the assumption that interceptor capacity is equivalent to twice the dry weather flow value. The concentration values presented in Table 4-2 were computed based on the assumption that the overflows were proportionate mixtures of average strength sanitary sewage and storm runoff waters.

TABLE 4-2

ANNUAL EMISSION RATES FROM THE SPOKANE COMBINED SEWER OVERFLOW SYSTEM ESVELT & SAXTON/BOVAY, 1972

	Flow MG	SS 1000 lbs.	BOD 1000 lbs.	TKN 1000 lbs.	P 1000 lbs.
CSO	500	1400	430	46	10.5
Sanitary Sewage in Overflows	160	170	190	27	8

Potential alternatives for correction of the combined sewer overflows are presented in the 1977 Facilities Planning Report (City of Spokane, 1977). The recommended alternative for the system was separation of the storm sewers. Phase I of this project involves the elimination of the Hollywood and Cochran overflows, which provide 81 percent of the stormwater flow. No estimated completion date for removal of these two overflows is currently available.

Hangman Creek, which drains the productive agricultural area south of Spokane, enters the Spokane River at RM 72.2. The Spokane STP discharges treated effluent to the system (RM 65.9).

WATER QUALITY

Spokane Aquifer

Existing data reviewed during the Metropolitan Spokane Water Resources Study (Corps of Engineers, 1976) indicated that the aquifer water quality was excellent; however, higher levels of total dissolved solids, conductivity, and nitrates were observed in the aquifer than in the river. In contrast higher levels of heavy metals, especially zinc, color, turbidity, and on occasion, fecal coliform organisms were observed in the river.

During the Spokane County 208 program monitoring, none of the aquifer samples contained any of the contaminants covered by the federal drinking water regulations in concentrations that consistently exceeded limits. Dissolved solids concentrations were higher along the aquifer periphery than in the center of the aquifer, and increased in the aquifer downstream from the state line to the City of Spokane. Bacteriological testing (for total and fecal coliform) of operating water supply well samples resulted in positive findings in 10 of 117 samples; however, only one location exceeded drinking water limitations. Higher salt concentrations were observed in the vicinity of solid waste disposal sites, and cyanide was found downstream from a major industrial site. Organochlorides have been found at low concentrations at various aquifer locations; however, the concentrations are below those deemed hazardous by the EPA. The heavy metals chromium and mercury were found in detectable concentrations. The higher levels of chromium were observed in the central Spokane Valley area. Concentrations of mercury above the detectable limits were observed throughout the aquifer areas but were more numerous in the western valley area. Zinc was observed at higher concentrations in some wells along the river. Concentrations are well below the recommended limits for drinking water supplies (Esvelt, 1978).

Spokane River

Several groups of investigators have studied water quality in the Spokane River. Sampling locations are shown in Figure 4-2. Funk has investigated the reach from the outlet of Lake Coeur d'Alene to a station near Gonzaga University in Spokane (RM 76). Soltero has examined the river downstream from its confluence with Hangman Creek (RM 72.4) to Long Lake (RM 33.9). DOE and USGS also maintain routine monitoring stations on the river.

Spokane River water above Hangman Creek is relatively soft ($CACO_3$ concentrations of 20 to 40 mg/l; Funk, et al., 1973). Specific conductivity increases from 45 to 60 umhos/cm^2 at Stateline Bridge to 70 to 180 umhos/cm^2 at Riverside State Park, below Hangman Creek (Yake, 1979).

River temperature is frequently above 20° C in the Spokane River, particularly between Stateline (RM 96) and the City of Spokane (RM 73) during July and August. The decrease between Stateline Bridge and Riverside State Park (RM 66) probably reflects the influence of groundwater (Yake, 1979).

Summer DO levels are frequently close to 8 mg/l. In the reach between Stateline Bridge and Upriver Dam, minimum DO's of 7.5 mg/l (91 percent saturation) were reported at Upriver Drive (RM 76) in July, 1972 by Funk, et al. (1973). At Nine Mile Dam (RM 58), a minimum of 7.6 mg/l was observed by Soltero, et al. (1979) in 1978.

Funk, et al. (1975) observed mean fecal coliform levels of 7 to 150 organisms per 100 ml between Post Falls (RM 99) and Gonzaga (RM 76). They observed an increase in the ratio of fecal coliforms to fecal streptococci as the river flowed downstream through the Spokane Valley and attributed this increase to increased importance of domestic wastes as the source of bacteria in the river.

Considerable work has been done on levels of nutrients, especially phosphates, in the river; however, the data were collected at different times by different investigators using different techniques and sampling locations. A trend analysis performed by Yake (1979) provides a useful perspective on trends, but is limited by the intermittent data base. Nonetheless, the available data support a few generalizations. Trend analysis (Yake, 1979) shows that total phosphorus concentrations vary inversely with flow in the Spokane River at Riverside Park (RM 66) and directly with flow in Hangman Creek. Funk, et al. (1973, 1975) observed two peaks per year in the river from RM 74 to 92 nutrient concentrations, one during high flow and one during low flow. Total phosphorus varies directly with flow in Little Spokane River because low phosphate groundwater provides the major source of streamflow, particularly in dry years (Yake, 1979).

Some of the results reported are summarized below to provide the reader with an idea of observed concentrations of various parameters.

From RM 74 to 92, orthophosphate values for March to August 1972 ranged from .05 to .12 mg P/L, and were relatively uniform throughout the reach (Funk, 1973). Monthly total phosphate means at Stateline (RM 96) ranged from

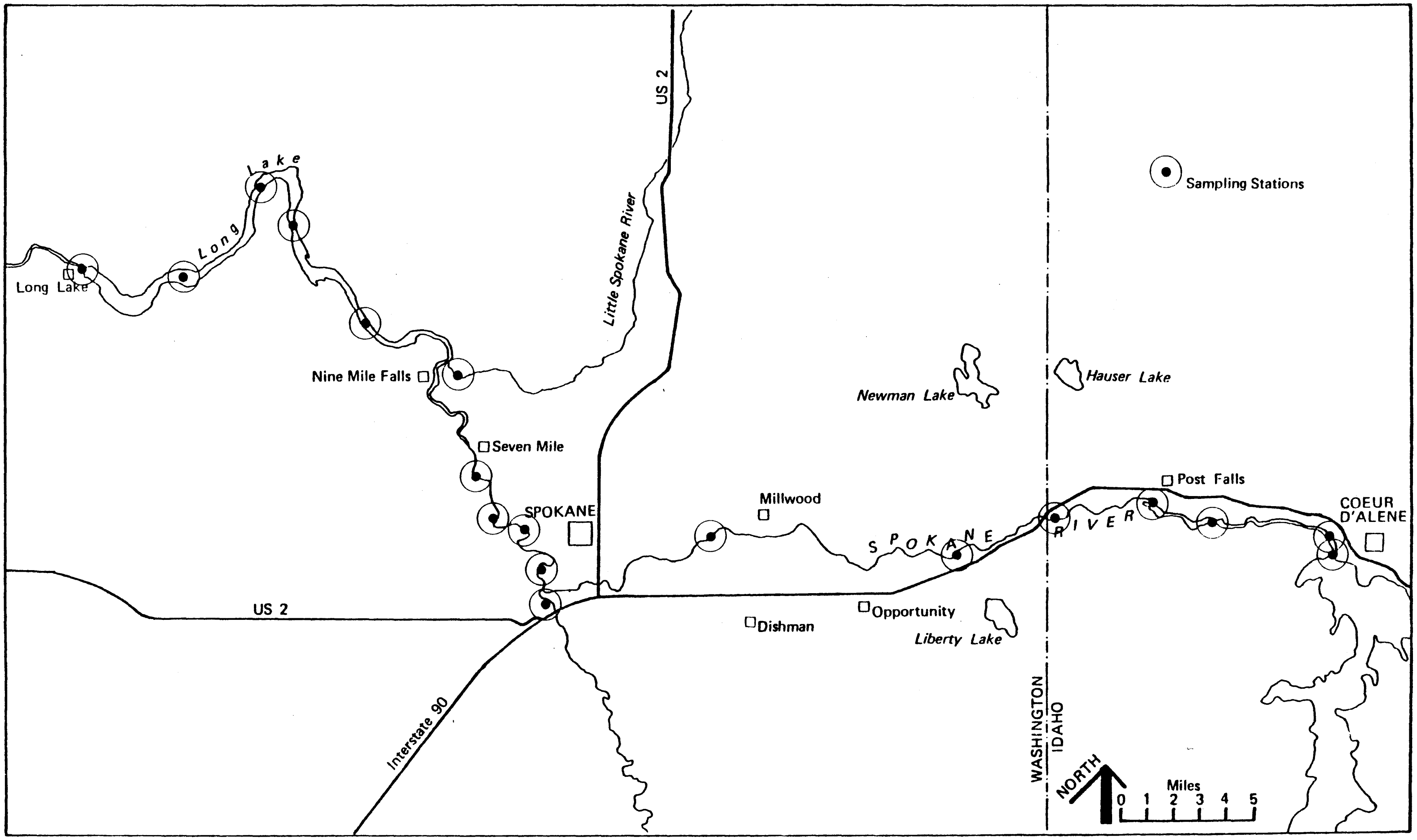


FIGURE 4-2
HISTORIC SAMPLING LOCATIONS

.013 to .70 mg P/L (Yake, 1979). Soltero's post-AWT studies on the river below Hangman Creek show that orthophosphate concentrations ranged from 0 to .065 mg P/L, and total particulate phosphate ranged from 0 to .055 mg P/L (Soltero, et al., 1979).

Studies on nitrogen levels in the river have generally examined nitrate and ammonia concentrations. Funk, et al. (1973, 1975) reported peak nitrate concentrations from RM 74 to 92 of .1 mg N/L in March, July, and August of 1972; in June concentrations of about .02 mg N/L were observed. Yake (1979) calculated mean monthly nitrate concentrations using available data from 1959 to 1973; concentrations ranged from .05 to .13 mg N/L in the upper river (RM 74 to 96).

In the lower river (RM 58 to 72), Soltero, et al. (1979, 1980) reported nitrate concentrations ranging from .06 mg to 1.23 mg N/L and ammonia concentrations ranging from .01 to .56 mg N/L. Monthly means for nitrate concentrations in the Little Spokane River (1970-1978) varied from .59 to 1.84 mg N/L (Yake, 1979).

Yake (1979) reports that mean monthly concentrations of zinc at Riverside State Park (RM 66) ranged from 50 to 270 ug/l for data from 1973 to 1978. The July and August means were lower, ranging from 50 to 120 ug/l. Funk, et al. (1975) reported levels of 78 to 430 ug/l between Harvard Road (RM 93) and Gonzaga (RM 76) from 8/30/72 to 2/26/74.

The total annual zinc loading in the entire drainage system is shown in Table 4-3. Approximately 14 percent of the zinc was lost between Post Falls

TABLE 4-3

TOTAL ANNUAL ZINC MASS BALANCE
SPOKANE DRAINAGE SYSTEM

	Zinc Loadings lbs/d	Sources lbs/d	Sinks lbs/d
Spokane River at Post Falls (RM 98.7)	9625	9625	-
Spokane River - Post Falls to Riverside State Park	-	-	1389
Spokane River at Riverside State Park (RM 66.2)	8236	-	-
Little Spokane River (RM 56.3)	-	48	-
Long Lake Influent	8284	-	-
Long Lake	-	-	607
Long Lake Effluent (RM 33.9)	7677	-	-

Source: Yake, 1979

(RM 99) and Riverside State Park (RM 66), while Long Lake removed about 7 percent of the remainder. Trend analysis of the zinc concentrations revealed a decrease from 1973 to 1978, probably directly attributable to the abatement measures that have been taken in the mining area (Yake, 1979). High levels of zinc have been detected in fish liver (.14 to .46 mg/g) and aquatic insects (.56 to 8.7 mg/g dry weight). Concentrations in the fish flesh are lower (mean value 100 mg/Kg) (Funk, et al., 1975).

Long Lake

Physical Factors - Thermal stratification generally begins to develop in July, and a thermal gradient is usually established by August in the layers immediately above the penstocks (between the 466 and 460 in elevation). By mid-September, the surface water begins to cool, weakening the thermal gradient. Mixing is usually complete within a month.

Chemical stratification during the summer also acts to maintain separation of the surface and deep waters. As peak runoff subsides, warm, high conductivity water enters the upper end of the reservoir and flows downstream to the power penstocks. As a result, lower conductivity waters are isolated in the upper and lower portions of Long Lake. This pattern breaks up when colder water enters the reservoir.

Development of both thermal and chemical stratification are described in considerable detail in Soltero's studies, especially Soltero, et al., 1974a.

Water Chemistry - Since 1959, routine monitoring at the USGS Station below Long Lake Dam (RM 33.8) has frequently detected dissolved oxygen levels less than 5 mg/l. These low concentrations reflect the development of an anoxic hypolimnion in Long Lake. Cunningham and Pine (1969) found that approximately 40 percent of the total lake volume was anoxic in September of 1969. They concluded that this was a result of high nutrient levels, which they attribute to release of nutrients from the sediments and effluent from the Spokane STP upstream. Soltero and his coworkers, conducting longer term studies, observed extensive hypolimnetic anoxia and low pH levels in late summer and early fall, and concluded that intensive respiration was occurring (Soltero, et al., 1974a).

Studies (Soltero, et al., 1979, 1980) subsequent to the initiation of AWT at the Spokane STP reveal a similar pattern of low DO and low pH. The extent of the anoxia observed in 1978 was comparable to that observed during earlier studies (1972-1977), except that in the low flow years (1973 and 1977) a greater portion of the hypolimnion became anoxic (Soltero, et al., 1979). Thus it is apparent that levels of BOD added to the hypolimnion by algal decomposition or present in the inflow are high enough to cause anoxia even at the present nutrient loading rate.

Soltero (Soltero, et al., 1973, 1974a, 1975a, 1976, 1977, 1978) has also studied the nutrient levels in Long Lake. Epilimnetic orthophosphate was less than .003 mg P/L in 1978, in contrast to levels as much as ten times higher in previous years (Soltero, et al., 1979).

Maximum orthophosphate levels were .091 mg P/L for one month in 1978. In contrast, studies before AWT showed levels of .11 to .78 mg P/L that lasted for three months. Particularly high levels were observed in the low flow years, 1973 and 1977. In wetter years, the maximum observed levels ranged from .11 to .13 mg P/L. The orthophosphate concentration observed in 1978 after fall overturn was .016 mg P/L, in contrast to the levels in 1972-1977, which were more than twice as great.

The surface water nitrate concentrations in Long Lake were less than .20 mg N/L from May to mid-August, 1978. Following thermal stratification, hypolimnetic nitrate concentration usually exceeded .5 mg N/L. Following fall turnover, concentrations throughout the reservoir exceeded .30 mg N/L of nitrate nitrogen.

In contrast to the phosphate levels, nitrate concentrations changed relatively little after the beginning of AWT. Concentrations in the euphotic zone in 1978 ranged from .06 to .79 mg N/L. In previous years (1972-1975) nitrate concentrations in the euphotic zone ranged from 0-1.59 mg N/L (Soltero, et al., 1973, 1974a, 1975a, 1976, 1979).

Biological Aspects

Community Assemblage - From the outlet of Lake Coeur d'Alene to Upriver Drive (km 121) the major algal species in 1971-73 included *Melosira* spp., *Aphanizomenon flos aquae*, *Fragilaria* spp., *Ulothrix*, *Tabellaria* spp., *Cyclotella* sp., *Asterionella* sp., *Oscillatoria* sp., and *Cladophora* sp., (Funk, et al., 1973, 1975). Fish present include cutthroat, German brown, and eastern brook, and rainbow trout, long nose suckers, squawfish, perch, and bass.

Periphyton populations below Hangman Creek were 75 to 95 percent diatoms. *Achnanthes* spp., were most abundant. The two most abundant taxa comprised over half of the total cell counts (Williams and Soltero, 1978). German brown trout have been planted in this section of the river.

Long Lake is a productive lake. Extensive growth of water weeds (principally *Nymphoides peltatum*) occur in areas less than 3 meters deep; the seasonal phytoplankton population is large. Among the most abundant species are the diatoms *Melosira italica* and *Fragilaria crotonensis* and the blue-green algae *Microcystis aeruginosa* and *Anabaena* spp. Rotifers and nauplii dominate the zooplankton (Soltero, et al., 1979). Fish present include bass, perch, carp, suckers, crappie, chubb, bullhead catfish, and squawfish; a few northern pike have been reported (Anderson, personal communication, 18 July 1980).

Spatial and Temporal Patterns

Above Upriver Dam, algal populations are dominated most of the year by diatoms; in early fall, blue-green algae are frequently dominant; no particular species was dominant for long (Funk, et al., 1973). Periphyton populations are most luxuriant from Plantes Ferry (RM 85) to Gonzaga (RM 119). From spring to early fall, the dominant genera in this area are *Ulothrix* and *Cladophora*.

A distinct change in algal periphyton abundance was noted by Williams and Soltero (1978) below the Spokane STP outfall, with most species being more abundant above the outfall.

More detailed studies have been carried out on Long Lake. At all lake stations, diatoms form the largest part of the standing crop in spring and early summer. After a small pulse of green and yellow-green algae, diatoms generally become dominant in early fall. In the past several years, blue-green algae have dominated algal population in the upper 12 miles of Long Lake in August and September. In 1976, a toxic bloom of *Anabaena flosaquae* occurred. In 1977, another less toxic bloom of the same species occurred in the upper end of the lake. *Microcystis aeruginosa* was second in dominance at that time. In 1978, a bloom of *Microcystis aeruginosa* occurred in the upper 12 miles of the reservoir; peak productivity of 2.72 g $C/m^2/d$ was observed at station 4 in August (Soltero, et al., 1979).

CHAPTER 5

PROBLEM DEFINITION

CONDITIONS VERSUS PROBLEMS

Several existing and potential concerns have been identified in past studies. Before these concerns are discussed, certain terminology needs to be defined.

To clarify the meaning of the word "problem," two basic points should be considered: (1) determining water quality conditions and assessing whether these conditions constitute a problem are separate matters, and (2) a description of water quality conditions usually is based on scientific or objective criteria. A judgment that a particular set of scientific measurements of water quality conditions constitutes a problem is a matter of opinion, particularly if the water is neither extremely clean nor extremely polluted. This is the case for present water quality conditions in the Spokane River. Thus, judgments that problem conditions exist depend on the perspective of the individual.

Water quality conditions are typically described by evaluating a number of parameters, such as chlorophyll, algal cell volumes, primary productivity, and algal species composition. These scientific parameters provide definitive "criteria" for comparison of different bodies of water and can be analyzed singly or in combination to determine the "trophic" state of a water body.

Limnologists do not agree on a single definition of trophic state due to differences in regional perspectives and the criteria used. For example, trophic state can be defined with criteria describing the causes of algal abundance (e.g. phosphorus, nitrogen) or it may be defined with criteria describing the effects of algal abundance (e.g. chlorophyll, transparency). Scientists do not necessarily agree upon which "criteria" to use or what levels of a given parameter constitute a problem.

The transition from describing a water quality condition to declaring it a problem moves one into the area of subjectivity. Public opinion will not necessarily agree, especially when existing conditions are not extreme.

CRITERIA VERSUS STANDARDS

The development of water quality policies by federal and state agencies has resulted in the specification of water quality criteria, water quality standards and wastewater effluent limitations. To avoid possible misunderstandings, definitions of these terms are presented.

A water quality "criterion" is generally a desired value of a quantitative measure of some aspect of water quality conditions. Criteria should be considered flexible and subject to change as new information is developed.

A water quality "standard" is a specific condition or requirement established by law and subject to administrative enforcement. Water quality standards are established in accordance with desired beneficial water uses and consist of specific limiting values for various constituents. Effluent limitations are legally specified discharge limitations on the quantity and/or concentrating of pollutants in wastewater effluent.

It should be noted that the State of Washington water pollution control regulations (as amended) include water quality criteria and effluent limitations as a part of their water quality standards. The criteria applicable to the Spokane River are shown in Table 5-1.

PROBLEM IDENTIFICATION

A number of the water quality conditions discussed in the preceeding sections have been identified as present or potential problems. These conditions are summarized in Table 5-2.

Spokane Aquifer

No problems in aquifer water quality were documented by the Spokane Co. 208 study (Esvelt, 1978) except for contamination of a few wells by local sources. Of the constituents that are present at higher concentrations in the river than the aquifer (phosphate, turbidity, color, heavy metals, and coliform organisms), only zinc has been shown to be present at elevated levels in wells known to be influenced by recharge from the river. The observed heavy metal levels are well below the maxima permitted by Washington State Drinking Water Standards for all metals except chromium and mercury, which are present at high levels in only a few samples; elevated levels of these metals do not correlate with river influence on the aquifer, as discussed above (Esvelt, 1978).

Spokane River

DO levels below Long Lake (often) fall below 5 mg/l (less than State standards) in the autumn. Levels in the Spokane River near Stateline Bridge are low, occasionally dropping below 8 mg/l in late summer. Increased urbanization of the valley and future industrial development may increase BOD loadings sufficiently that DO standards are more frequently and seriously violated, especially during the low flow, high temperature period. The present low levels are probably due largely to naturally occurring high temperatures, since no major input of BOD occurs in this reach. Low dissolved oxygen levels probably stress most species of fish present; however, no data documenting the effects of low DO on fish populations or productivity in either section of the river are available.

Past monitoring has documented elevated trace metal concentrations in the water and biota of the upper Spokane River (Yake, 1979; Funk, et al., 1973 and 1975). Fish are apparently swimming in waters containing trace metal concentrations at least as high as those necessary to injure them under laboratory conditions (Funk et al, 1973). For example, zinc concentrations are about five times the amount considered to be a median lethal dosage for

TABLE 5-1

WASHINGTON STATE

WATER QUALITY CRITERIA

SPOKANE RIVER

PARAMETER	CRITERION - River	CRITERION - Lake*
Fecal coliforms	Not to exceed median of 100/100 ml with not more than 10 percent of samples exceeding 200/100 ml	Not to exceed median of 50/100 ml with not more than 10 percent of samples exceeding 100/100 ml
Dissolved oxygen	Greater than 8.0 mg/l	No change from natural conditions
pH	6.5 to 8.5; variations due to man-caused activities not to exceed 0.5 units	No change from natural conditions
turbidity	increases not to exceed 5 NTU for background levels less than 50 NTU or 10 percent of background levels greater than 50 NTU	Not to exceed 5 NTU over background
temperature	not to exceed 20°C due to human activities nor shall temperature increases exceed 34/(T+ 9) where T = ambient temperature, or 0.3°C when natural conditions exceed 20°C.	No measurable changes from natural conditions
toxics	concentrations below those of public health significance, or which may cause acute or chronic toxic conditions to aquatic biota, or which may adversely affect any water use	same as river
aesthetics	not to be impaired	not to be impaired

* Spokane river standards (Class A, with special conditions) apply to Long Lake when the residence time is less than 15 days.

TABLE 5-2

WATER QUALITY CONDITIONS IDENTIFIED AS PROBLEMS

System-Condition	Status[a]	Use Conflict	WQ Criteria	References[b]
AQUIFER				
Toxicant pollution	F	Potential drinking water degradation	Non-degradation policy	15
SPOKANE RIVER				
Contamination by toxicants, especially Zn	E, A	Fish habitat (probable)	EPA criteria	
Low D.O.:				
1) <5 mg/l below Long Lake Dam	E	Fish habitat (probable)	State D.O.	6
2) <8 mg/l in River	E, F	Fish habitat (probable)	State D.O.	6
Contamination by raw sewage during CSO events	E, P	swimming, wading aesthetics	State fecal coliform State aesthetic	4,14
LONG LAKE				
Algal blooms during late summer (chl a > 10 ug/l)	E	swimming when posted, skiing, aesthetics	State toxics (when toxic) state aesthetics	1,7,8, 9,10
Aquatic weeds in shallow areas	E	boating, swimming	None	4,8,11
Low D.O. levels in hypolimnion (<1 mg/l)	E	Fish habitat (probable)	State D.O.	12,13

NOTES FOR TABLE 5-2

[a] STATUS

E Existing

F Future

A Ongoing abatement program

P Abatement in planning stages

[b] REFERENCES

1 Yake, 1979

2 Funk, et al., 1973, 1975

3 EPA as cited by Greene, et al., 1978

4 Williams, 1980

5 Angov, 1980

6 Department of Ecology, 1980

7 Soltero, et al., 1975a

8 Peters, 1980

9 Soltero, et al., 1979, 1980

10 Soltero & Nichols, 1980

11 Greene, et al., 1978

12 Cunningham & Pine, 1969

13 US Army Corps of Engineers, 1976

14 City of Spokane, 1977

15. Spokane County Eng., 1979

cutthroat trout (Funk, et al., 1975; Sappington, 1969). Table 5-3 summarizes recent Spokane River toxicant concentrations in relation to present federal criteria. Criteria exceedance for zinc, copper, and cadmium are more common for "total" toxicant fractions and appear to be related to high river flow conditions. Problem definition should be considered in relation to bio-available toxicant fractions (in this case, dissolved trace metals). Existing data for mercury demonstrate a need for using analytical techniques which have a detection limit at least as low as the proposed criterion.

The levels of dissolved zinc, copper and cadmium in the upper Spokane River are generally above the "24-hour average" criteria (EPA, 1978). However, with the exception of zinc during high flows, levels of dissolved copper, lead, cadmium and mercury are generally within the "not-to exceed" criteria for protection of aquatic life. As discussed above, however, no adverse effects on the fish in the river due to these high levels have been documented. Funk, et al. (1975) hypothesize that either fish have become acclimated to high zinc concentrations or past monitoring efforts have measured primarily nontoxic forms of zinc, perhaps bound to colloidal particles or organic matter.

Although no evidence is available to indicate that levels of chlorine residuals or un-ionized ammonia currently present are harmful to fish, these toxicants are discharged in municipal and industrial treatment plant effluents and were therefore evaluated to determine whether they are likely to cause problems.

No data on chlorine residuals in the river are available; however, assuming a typical residual of 0.5 mg/l in the Spokane AWT effluent, a river discharge of 11,500 cfs would be required to maintain a concentration no greater than the EPA recommended level (0.002 mg/l); river discharge was lower than 11,500 cfs throughout the low flow year of October 1972 to September 1973. Thus, it seems likely that levels greater than those recommended occurred below the outfall for the entire year, and probably do so during most low flow periods. Nonetheless, no fish kills or other adverse impacts on fish populations have been documented. Thus, additional studies would be required to determine whether chlorine residuals are actually a problem.

Data on levels of un-ionized ammonia in the river do not suggest a serious problem (DOE 1980). Levels below the Spokane Treatment Plant exceeded EPA's (1976) criterion (0.020 mg/l) in July or August in several years prior to institution of AWT; however, generally lower values (well below the criterion) have been recorded since 1978 (DOE, 1980). Because the additional treatment plant (Liberty Lake) will use an activated sludge process, expect to produce a highly nitrified effluent, no problems are expected when that plant comes on line. No other major ammonia sources are projected; therefore, no problems are expected.

Long Lake - Comparison of water quality conditions with beneficial use identifies algal blooms in Long Lake in the late summer and early fall as a definite problem. Such blooms are aesthetically displeasing and limit water contact recreation, particularly when a lake is posted by the health department due to toxicity. The extensive macrophyte growth in Long Lake is also considered a problem by lakeside residents, since it interferes with boating

TABLE 5-3

COMPARISON OF 1978 SPOKANE RIVER TOXICANT LEVELS TO EPA CRITERIA(1)

River Flow Conditions(2)	River Location	Zinc Dissolved	Zinc Total	Copper Dissolved	Copper Total	Lead Dissolved	Lead Total	Cadmium Dissolved	Cadmium Total	Mercury Dissolved	Mercury Total
Low	State Line Bridge (RM96.5)	100 / 0	100 / 17	33 / 0	33 / 6	0 / 0	67 / 0	0 / 0	100 / 0	33* / 0	100 / 0
Low	Mission St. Bridge (RM76.8)	100 / 0	100 / 0	67 / 5	100 / 16	0 / 0	100 / 5	33 / 0	66 / 13	* / 0	100 / 0
High	State Line Bridge(RM 96.5)	100 / 100	100 / 100	100 / 0	100 / 14	20 / 0	80 / 0	100 / 0	100 / 43	* / 0	100 / 0
High	Mission St. Bridge(RM 76.8)	100 / 100	100 / 100	100 / 0	100 / 44	0 / 0	67 / 11	100 / 0	100 / 0	* / 0	100 / 0

* = Analysis Lower detection limit higher than criterion for most or all results

EPA CRITERIA(4)

A / B	Parameter	Zinc(5)	Copper(5)	Lead(5)	Cadmium(5)	Mercury(5)
A	A -24-hour Average ug/l	16	1	4	0.2	0.64
B	B -Not to exceed ug/l	89	6	30	1.2	3.2

Footnotes:

(1) Spokane River Data from EPA Synoptic Surveys, August, 1979; April, 1980. STORET DATA SOURCE

(2) Low flow conditions during August/High flow conditions during April

(3) A = Percentage of days the 24-hour average criteria was exceeded
B = Percentage of samples exceeding the "not to exceed concentration"

(4) References: EPA, 1978, Ambient Water Quality Criteria:

Zinc, PB-296-807; Copper, PB-296-791; Lead, PB-292-437; Cadmium, P13-292-423; Mercury, PB-297-925

(5) Based on conservative total hardness of 24 mg/l as $CaCO_3$; assumed after review of hardness data from USGS (1978) Water Resource Records. Riverside State Park, n = 12, x = 48 mg/l as $CaCO_3$, min. = 29 mg/l as $CaCO_3$; Spokane R. at Post Falls, n = 2, x = 27 mg/l as $CaCO_3$, min. = 24 mg/l.

in the lake. In contrast, no adverse effects of the low dissolved oxygen levels in the hypolimnion of Long Lake on the resident fish population have been reported. Thus, comparison of beneficial uses and water quality conditions suggests that the major existing problems in Long Lake are algal blooms and macrophyte growth.

Low hypolimnetic dissolved oxygen levels do, however, cause frequent violation of DO standards in the Spokane River below the dam in late summer/early fall. Furthermore, although warm water fish species such as large mouth bass and perch are tolerant of lower DO levels than cold water fish such as trout, levels of at least 5 mg/l are considered necessary to maintain good fish populations (EPA, 1976). Thus portions of the lake with lower concentrations are presumably less useful as habitat.

CHAPTER 6

CAUSE/EFFECT ANALYSIS

The present and potential water quality problems in the Spokane system are identified in the previous chapter. To control these problems, it is necessary to determine which factor(s) cause them. When insufficient data are available to define this relationship, data collection is needed, as discussed in Chapter 8.

For each problem certain parameters are associated with the causative factors and others serve as indicators of the problem. Table 6-1 summarizes the cause/effect relationships identified for the problems discussed in Chapter 5.

AQUIFER

Levels of toxicants such as heavy metals and organics such as pesticides in portions of the aquifer recharged by the Spokane River will probably increase if levels in the river increase. The relationship between concentrations in the river and aquifer is not well defined. In addition, few baseline data on concentrations of toxicants in the aquifer, the river, or discharges to the river are available.

SPOKANE RIVER

Toxicants

Although high levels of toxicants are known to harm aquatic organisms, the levels that will constitute a problem vary with the species present, water hardness, and other factors. One approach to predicting the toxicity of materials such as heavy metals has been use of bioassays.

Funk, et al. (1975) reported 96 hour median lethal concentrations of 90 ug/l (total size) for cutthroat fingerlings in water from the north fork of the Coeur d'Alene River, in contrast to literature values of 10 ug/l for trout in soft water. Mean monthly concentrations of total zinc at Riverside State Park have been observed to be 50 to 270 ug/l. Additional study would be needed to determine an appropriate criterion for the river.

Low Dissolved Oxygen

As discussed above, low DO below Long Lake Dam reflects oxygen levels in the hypolimnetic water released through the power plant. To define a cause/effect relationship, data on DO levels in both the lake and the river would be needed, as would data on the recreation rate and information on mixing behavior within the lake near the outlet. Additional cause/effect analysis of this problem is discussed in connection with the reservoir.

TABLE 6-1

DEFINITION OF CAUSE/EFFECT RELATIONSHIPS

System - Problem	Causal Parameters	Indicator	Sufficient Data?
AQUIFER			
Toxicant pollution	Heavy metals	Higher toxicant levels	No
SPOKANE RIVER			
Contamination by toxicants, especially Zn	Heavy metals, NH_3, chlorine residual	Fish toxicity	No
Low D.O.: 1) <4 mg/l below Long Lake Dam	Low Hypolimnetic D.O. in Long Lake	D.O.	No
2) <8 mg/l in River	Temperature, BOD, NH_3, organic N	D.O.	No
Contamination by raw sewage during CSO events	Pathogens, suspended solids	Fecal coliforms, floatables, BOD, SS	No
LONG LAKE			
Algal blooms during late summer (chl *a* > 10 ug/l)	PO_4, other nutrients	Chl*a*, transparency	Yes
Aquatic weeds in shallow areas	Temperature, light nutrients	Species, Standing crop	No
Low D.O. levels in hypolimnion (<1 mg/l)	BOD (algal biomass, benthic oxygen demand, river inflow), organic N, NH_3	D.O.	No

The DO levels in the rivers are typically influenced by water temperature and levels of BOD and reduced nitrogen compounds (such as organic nitrogen and ammonia). Data taken during several complete diel cycles during the low flow period are needed to define the extent and magnitude of the problem in the Spokane River. Additional data on BOD and nitrogen loads from discharges and within the river would also be needed to model the relationship accurately.

Combined Sewer Overflows

Combined sewer overflows (CSOs) result in contamination of the river by raw sewage. Pathogenic organisms (bacteria, viruses, etc.) enter the river during CSOs, resulting in temporary increase in fecal coliforms below the overflow. Floatable materials in the sewage create a temporary aesthetic problem. Concentrations of BOD, toxicants (lead, cadmium, oil and grease), and nutrients (phosphorus and nitrogen) in CSO discharges are generally high; however, if the stormwater is discharged to the river directly, total loads may not be significantly lower since all phosphorus in combined sewer is treated except during CSO events. Monitoring programs would be needed to characterize the effluent as to quantity and quality and to determine its effect on the river, such a program has been proposed for two major CSOs (see Chapter 8).

LONG LAKE

Algae and Phosphorus

As discussed in Chapter 4, extensive studies of Long Lake have been carried out to characterize the lake's water quality and define the factors affecting algal growth. Approaches discussed here include algal assays, analysis of zooplankton grazing, and examination of the lake's phosphorus budget, and phosphorus loading relationships.

Algal Assays - The Algal Assay Procedure Bottle Test was used to determine which nutrient was limiting to algal growth in Spokane River and Long Lake euphotic zone water. Tests in 1978 using *Selanastrum capricornutum* showed that after heavy metal inhibition was eliminated by the addition of EDTA, phosphorus was the primary growth limiting nutrient, both above and below the Spokane STP and in 80 percent of the lake samples. Phosphorus and nitrogen were colimiting in the remaining samples. Prior to AWT, nitrogen was limiting below the outfall (during 1974 and 1975) and in Long Lake (during 1975 and 1977) (Soltero, et al., 1979).

Separate studies (Greene, et al., 1978) have shown that bioassays using this test alga accurately predict the indigenous phytoplankton standing crop in Long Lake. Algal assays also demonstrate that zinc inhibits the growth of *Anabaena* spp., but not that of *Sphaerocystis schroeteri*, a green algae that has often been dominant in Long Lake.

Zooplankton Grazing Pressure - In some ecosystems, zooplankton grazing controls algal abundance and influences successional patterns. Little relationship between zooplankton and algal standing crop in Long Lake was apparent during most of the year. During fall blue-green algal blooms, zooplankton numbers drop substantially, which probably reflects inhibitory effects of the algae on the zooplankton. The absence of grazing pressure at other times may be due to the abundance of predatory zooplankton or to the presence of plantivorous fish such as perch and crappie (which feed zooplankton) (Shapiro, 1980).

Phosphorus Budget - Since algal assays have shown that phosphate is the primary limiting nutrient for algae in Long Lake, it is useful to describe its sources and sinks in the Lake. As shown in Figure 6-1, sources of phosphorus include:

Spokane River - surface water discharge

Little Spokane River - surface water discharge

Non-point sources - septic tanks

Atmosphere - Precipitation and dryfall

Sediment - net flux, determined by biological, chemical, and physical factors

Biological cycling - waterfowl, nutrient turnover

Surface Water Discharge - Yake (1979) developed estimates of phosphorus loading to the river prior to AWT, which are listed in Table 6-2. These estimates are based on data for 1970 to 1978. Data on the 1978 total phosphate levels in the Spokane and Little Spokane Rivers has been gathered by Soltero, et al. (1979); loading estimates were be obtained from these data.

TABLE 6-2

TOTAL PHOSPHATE LOADINGS - SPOKANE DRAINAGE SYSTEM
PRIOR TO AWT

	Annual Average		July, Aug., Sept., Oct. Avgs.	
Source	lbs/d	% of Total Load	lbs/d	% of Total Load
Spokane R. at Stateline	975	28.1%	291	18.7%
Other Sources*	930	26.8%	25	1.6%
Hangman Creek	267	7.7%	25	1.6%
Spokane Sewage Treatment Plant*	1150	33.1%	1150	73.9%
Little Spokane R.	150	4.3%	66	4.2%
Total	1375	100%	706	100%

*Estimated

Source: Yake, 1979

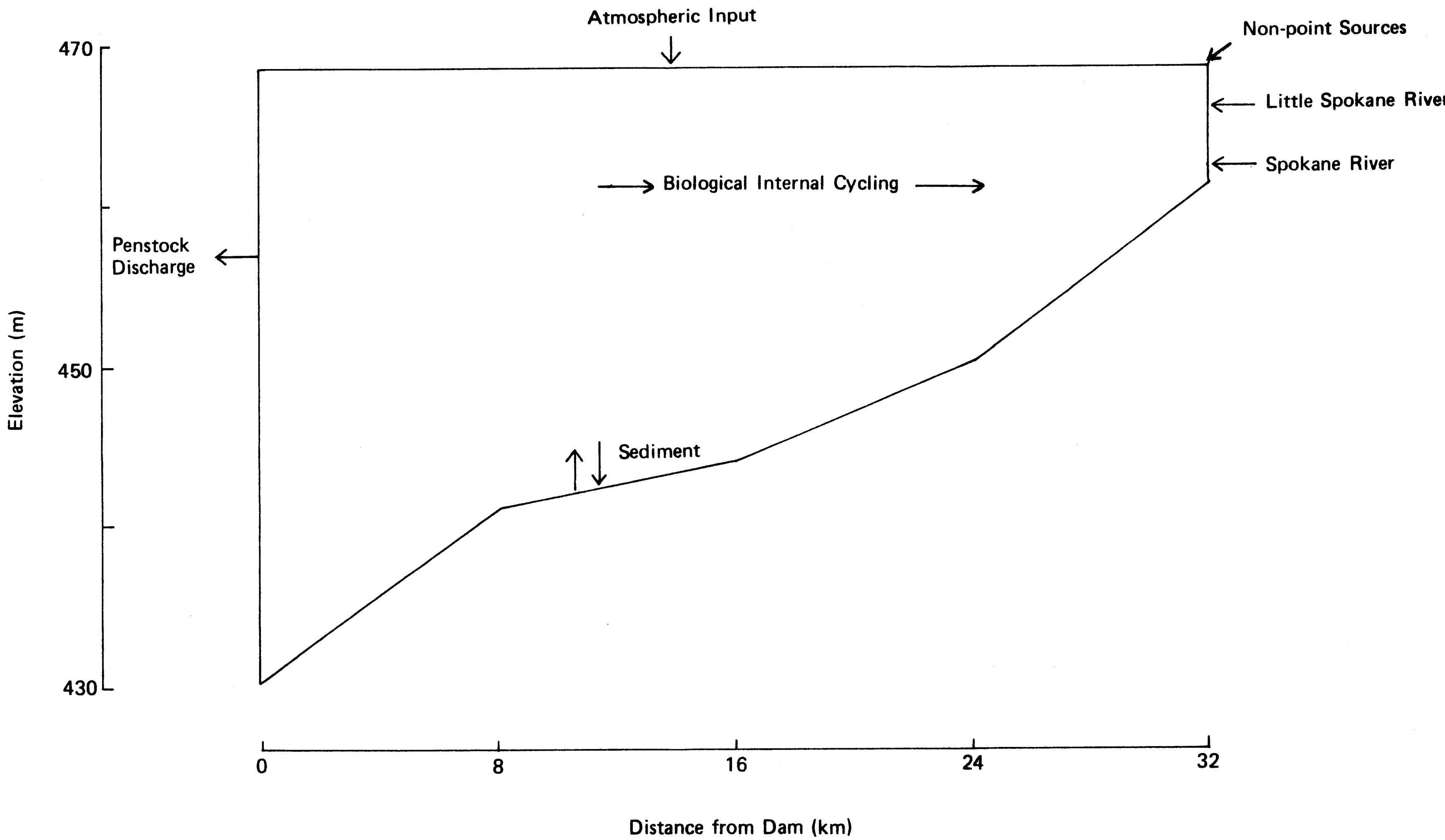


FIGURE 6-1
Long Lake Phosphorus Budget

Non-Point Sources - On-site sewage disposal systems around the lake constitute a possible source of phosphorus input. A survey by the Spokane County Health District found 28 problems (cesspools, outhouses, direct discharges to lake), 131 substandard systems, and 110 approved systems around Long Lake. Dillon and Rigler (1975) estimated septic tank effluent to provide a per capita loading of 1.8 lbs P/yr. Assuming 2 people per system and soil retention of 0 percent, 75 percent and 85 percent for problems, substandard and approved systems respectively, the estimated loading to the reservoir would be 0.73 lbs P/d, quite low in comparison to surface water discharges.

Atmosphere - Precipitation transfers particulate matter from the atmosphere into the lake system. Previous studies (Eisenreich, et al. [1977] and Murphy and Doskey [1975]) have shown that precipitation can be a significant factor in a lake's phosphorus budget. Murphy and Doskey (1975) estimated that precipitation accounts for about 18 percent of the annual phosphorus budget for Lake Michigan. Spokane receives much less precipitation during the algal growth season, hence its influence may be considerably less. Possibly more important is the dryfall atmospheric input. Atmospheric particulates are probably introduced into Long Lake constantly. Eisenreich, et al. (1977) stated that wind blown soil and re-entrained dust are believed to be the major source of atmospheric phosphorus addition to Lake Michigan.

No nutrient data for precipitation or dryfall in the Spokane area was available. Measurements made around Lake Michigan by Eisenreich, et al. (1977) and Murphy and Doskey (1975) indicate an atmospheric deposition rate of total phosphorus of 2.2 ug $P/cm^2/yr$ (including precipitation and dryfall). Since specific data for Long Lake are unavailable, this rate is used as a preliminary estimate. The actual loading rate for Long Lake is probably much lower, since the Spokane area is not heavily industrialized.

Sediment - Thomas and Soltero (1977) examined the recent sedimentary history of Long Lake from 1958-1973. They calculated that the average annual sedimentation rate was 26 mm/yr. A seven fold increase in diatom production was observed between 1958, when Spokane's primary STP went on line, and 1973 when daily flows were 1.4 times 1958 daily flows. Parallel increases in nitrogen and phosphorus concentrations in the sediments were observed. Manganese, iron, phosphorous profiles were not closely related; therefore, the researchers concluded that iron and phosphorous precipitation are probably unrelated in Long Lake.

They also found that clay particles are an important structural component of the sediments in Long Lake. The large quantities of clay particles, which enter Long Lake during spring runoff (March-May), apparently seal off the sediment water interface. Thomas and Soltero conclude that mixing and vertical migration of phosphorous are therefore unlikely, and find support for this argument in the close relationship between sedimentary phosphorus and diatom horizons in all cores. Thus, based on this work, it would appear that the sediment input would be zero.

Some mixing or release from anaerobic sediments may occur. McDonnell (1975) measured phosphate release from anoxic lake sediment and observed a rate of 2.5 to 5 mg P/m^2/day. If one assumes that one third of Long Lake sediments become anoxic for 1 month and release phosphate at a rate of 2.5 mg P/m^2/d, which seems a conservative estimate in light of Thomas and Soltero's work, an average daily loading rate during the growing season of 6.6 lbs P/day is obtained.

Biological/Chemical - Anderson, et al. (1978) and Lamarra (1974) have demonstrated that certain types of fish can indirectly influence water quality in a lake. Excretions from bottom dwelling carp, which are present in Long Lake, can recycle large amounts of phosphorus to the water column where it is available for algal production. No quantitative estimates of density exist for these fish; therefore, their impact on the lake cannot be estimated.

Sylvester and Anderson (1964) have suggested that nutrient input from resident and migrating waterfowl can be a significant aspect of the nutrient load to a lake. Specific information on numbers of waterfowl using Long Lake is lacking; therefore, their impact cannot be quantified at this time.

Remineralization of falling algal debris may be a significant nutrient source during the growing seasons; however, no data are available to permit assessment of its relative importance in Long Lake.

Summary - Our present knowledge of the nutrient budget for Long Lake is summarized in Table 6-3.

TABLE 6-3

ESTIMATED PHOSPHORUS BUDGET OF LONG LAKE
(JUNE THROUGH NOV) 1978

SOURCE	LOADING lbs P/d	%
Spokane River	412	84 to 93
Little Spokane River	26 to 66	6 to 15
Precipitation/dryfall	0 to 2.9	0 to 0.6
Sediment Release	0 to 6.6	0 to 1.5
Biological cycling	unknown	-
Non-point sources (septic tanks)	0.73	0.1
TOTAL	442.3 to 488.6	

From these preliminary estimates, it is apparent that the Spokane River is the most significant source of phosphate loading. Although the estimation techniques used above probably overestimated the relative importance atmospheric, non-point and sediment sources, together these sources are only 2 percent of the total estimated loading. The range in values for the Little Spokane River depends on how much phosphorus is assumed to be present in the groundwater.

Predictive Relationships - Extensive limnological research during the past two decades has shown that phosphorus loading is frequently a limiting factor in determining the trophic condition of a lake. The importance of phosphorus loading in Long Lake is suggested by the algal assay results discussed above. Table 6-4 shows values for total phosphorus loading (adjusted for flushing rate and for phosphorus retention), orthophosphate, chlorophyll *a*, phytoplankton biovolume, and primary productivity for the June through November season during each year. Examination of these data show that all of the water quality parameters vary directly with phosphorus loading, with the exception of the high phytoplankton concentration in 1978. This anomalous value is probably a result of the *Microcystis* bloom that occurred during that year. The problem is probably exaggerated by the difficulty in estimating the percentage of vegetative cells in relation to mucilaginous matrix and the irregular shape of the colonies, which probably lead to overestimation of biovolumes (Soltero, et al., 1979).

A number of investigators, using data gathered on a large number of lakes, have examined relationships between parameters such as summer mean chlorophyll *a* concentration, winter phosphorus concentration, and phosphorus loading (adjusted in various manners for phosphorus retention, lake depth, and flushing rate). Dillon's (1975) method for calculating a regression equation to predict mean summer chlorophyll *a* was applied to the data gathered on Long Lake. The relationship* was calculated to be:

$$\text{chl } a = 9.93 \times Lp + 6.04 \qquad r^2 = .944$$

Lp = areal loading rate; L(1-R)/

L = total surface loading rate, $g\text{-}p/m^2$

R = phosphorus retention coefficients

= lake volume replacement times

As indicated by the high variance and shown in Figure 6-2, the relationship is excellent.

Vollenweider (1976) developed an equation for critical phosphorus loading, which he defined as the maximum allowable phosphorus load to a system that would result in a total phosphorus concentration at spring overturn less than a specified value. Other limnologists have established that, for most lakes, total phosphorus concentration at spring overturn greater than 10 ug P/l can promote summer phytoplankton standing crops (as measured by chlorophyll *a* concentrations) indicative of eutrophic waters.

* This regression equation is changed from the one reported in Soltero (1980) after some corrections were made on the original data (due to wrong placement of decimal points in the calculations)

TABLE 6-4

TOTAL AREAL PHOSPHATE LOADING IN RELATION TO MEAN ORTHOPHOSPHATE AND CHLOROPHYLL A CONCENTRATIONS, PHYTOPLANKTON BIOVOLUME AND PRIMARY PRODUCTIVITY IN LONG LAKE, WA FOR ALL STUDY YEARS DURING THE PERIOD OF JUNE THROUGH NOVEMBER.

Year	$L(1-R)p^{-1}$ ($g\ P\ m^{-2}$)	Orthophosphate ($ug\ P\ L^{-1}$)	Chlorophyll a ($mg\ m^{-3}$)	Phytoplankton ($mm^3\ 1^{-1}$)	Primary Productivity ($g\ C\ m^{-2}\ day^{-1}$)
1972	0.71	46	12.34	6.22	1.61*
1973	1.31	98	19.86**	10.56**	2.10
1974	0.52	36	10.90	6.58	0.82
1975	0.66	33	11.87	7.64	1.05
1977	0.95	82	14.12	8.90	1.45
$\bar{x}$	0.83	59	13.82	7.98	1.41
1978	0.24	16	8.79	42.41	0.94
1979	0.32	13	9.44	4.92	1.32
$\bar{x}$	0.03	16	9.12	23.67	1.13

* July - November
** June - October

Source: Soltero, et al., 1980

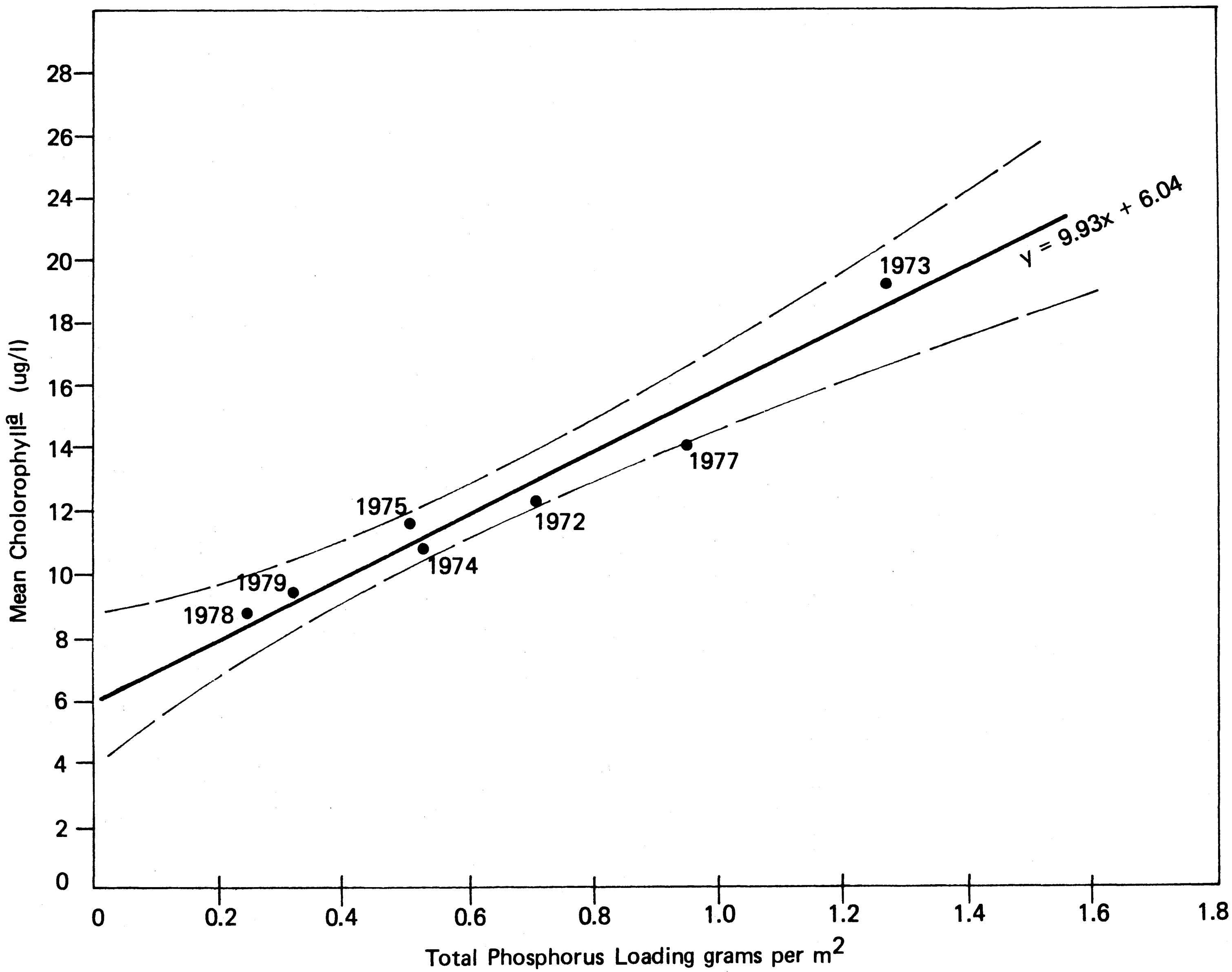


FIGURE 6-2
Total areal phosphorus loading (g p m^2) and mean chlorophyll[a] concentration (ug/l) in Long Lake, for all years of study during the period June through November (1973 chlorophyll[a], June- October). Dashed lines are 95% confidence interval.
Source: Dillon (1975), Soltero, et.al.(1979,1980) modified by URS

Vollenweider suggested an upper limit of 20 ug P/l as a maximum allowable value. Vollenweider's equation for critical loading is given as:

$$L_c = c\ (q_s)\ (1 + (z/q_s)^{1/2})$$

where:

L_c = critical phosphorus loading (maximum allowable)

q_s = hydraulic load = total discharge/lake surface area

z = mean depth

c = maximum allowable concentration of total phosphorus

The closer the surface loading (L_P) is to the calculated L_C value, the more likely it is that the assumed value for critical total phosphorus concentration (c) will occur.

Appendix F provides a detailed comparison of the two models.

Table 6-5 shows the computed values for critical loading for 10 and 20 ug P/l total phosphorus concentrations and the specific surface loading for each year that Soltero studied. For all years prior to 1978, total phosphorus load exceeded the critical loading value. In 1978, the critical total phosphorus load was intermediate between the loads that would result in 10 and 20 ug P/l concentrations.

Relationships of this type do not predict what algal species will be present, or whether toxic blue-green algal blooms will develop. Soltero and Nichols (1980) suggest that the sudden appearance of blue-green algal blooms may have been a result of lower heavy metal concentrations due to abatement programs in the upstream mining areas in Idaho. As discussed above, Yake (1979) has shown that Zn concentrations have decreased significantly since 1973 when abatement programs were instituted. They also postulate that the dominance of *M.aeruginosa* over *Anabaena* sp. observed in 1978 may be due to higher N/P ratios, which have been shown to favor the former.

Low Dissolved Oxygen

The low dissolved oxygen levels in lower Long Lake hypolimnion during the summer have been attributed to decomposition of algal detritus (Cunningham and Pine, 1969; Soltero, et al., 1979). It should be possible to prevent oxygen depletion during the summer by controlling phosphate levels in the lake. Since low DO levels (less than 1 mg/l) were observed in 1978 and 1979 when AWT was operating, a further reduction in phosphate input to Long Lake may be required to eliminate this problem. Alternatively, BOD or nitrogeneous compounds in the inflow to the lake may contribute significantly to the hypolimnetic anoxia. More data will be needed to resolve this question.

TABLE 6-5

MEAN DAILY TOTAL PHOSPHORUS LOAD (METRIC TONS), HYDRAULIC LOAD (q_s), SPECIFIC SURFACE LOADING (L_p) AND CRITICAL LOADING (L_c; USING 10 AND 20 TOTAL PHOSPHORUS AS THRESHOLD VALUES) TO LONG LAKE, WA FOR ALL STUDY YEARS, DURING THE PERIOD OF JUNE THROUGH NOVEMBER (183 DAYS).

Year	Mean daily total P load to Long Lake (metric tons)	q_s (m)	L_p ($g\ P\ m^{-2}$)	$L_c(10)$ ($g\ P\ m^{-2}$)	$L_c(20)$ ($g\ P\ m^{-2}$)
1972	1.00	128.3	8.78	1.72	3.43
1973	0.91	56.8	7.99	0.86	1.71
1974	0.88	165.8	7.73	2.14	4.30
1975	1.06	138.3	9.31	1.83	3.66
1977	0.68	54.5	5.97	0.83	1.65
1972-1977 Mean	0.91	108.7	7.96	1.48	2.95
1978	0.20	80.7	1.76	1.15	2.30
1979	0.22*	73.4	1.94*	1.06	2.12
1978-1979 Mean	0.21*	77.1	1.85*	1.11	2.21

* connected values

Source: Soltero, et al., 1980

Aquatic Weeds

Factors affecting macrophyte growth in Long Lake are not sufficiently well known to predict the effect of phosphorus control on water weeds. Nonetheless, since macrophyte growth is normally limited by light penetration, improvements in water clarity due to reduction of algal growth are likely to increase the area where macrophyte growth is possible. Since many aquatic plants can obtain nutrients from sediments as well as from the water column (Hutchinson, 1975), the effect of control of nutrient loading on weed growth cannot be predicted. Additional studies on factors controlling macrophyte growth in Long Lake would be needed to identify a feasible, cost-effective method for control.

CHAPTER 7

SYSTEM MODEL

This chapter describes the system model developed for use in allocating the phosphorus load in the Spokane River/Long Lake System. Suitable computer models are also described here for allocation of other parameters if it becomes necessary.

A number of present and potential water quality problems in the Spokane system were identified in Chapter 5. In Chapter 6 (Table 6-1) cause and effect parameters for each of these problems were defined. "Cause" here refers to the wasteloads, "effect" refers to the receiving water quality.

Table 7-1 identifies the analytical schemes needed to represent the cause/effect relationships for the identified water quality problems in the Spokane system. One function of the analytical schemes not shown in the table but common to all is computing the permissible loads controllable of the cause parameters. These analytical schemes are referred to as system models. In the wasteload allocation process, the system models are used to analyze the effect of a given wasteload.

Because the system models will be used repeatedly in the wasteload allocation process, it is essential that they be easy to use in addition to being representative of actual system behavior.

SYSTEM MODEL DEVELOPMENT

The modelled system consists of three different but inter-related water systems: the aquifier, river and lake. Conceptually, one system model could be developed to represent all three water systems and to cover all cause/effect parameters. Such a generalized system model would, however, be too cumbersome and costly to use. It is more efficient to develop a model for each water system, and to tailor each model to corresponding cause/effect parameters. Budget constraints require the use of existing models as much as possible rather than development of elaborate new models. Furthermore, insufficient data on most of the cause/effect relationships precludes the development of any new--simple or elaborate--model just for this system.

The cause/effect models identified in Table 7-1 are normally presented as submodels of large and complex river or lake models. In the course of river basin studies (303e), water quality management studies (208), and clean lake studies (304), a large number of generalized river and lake models have been developed and validated. Most of these are available and could be applied to the Spokane system. There are, however, some drawbacks in applying these models for waste load allocation purposes:

1. Costly to use: some models automatically calculate values for all parameters simulated regardless of whether they are subject to allocation;

TABLE 7-1

ANALYTICAL SCHEMES REQUIRED FOR
CAUSE/EFFECT MODELS

System - Problem	Controllable Casual Parameters	Analytical Scheme Required to Compute
LONG LAKE		
Algal blooms during late summer (chl a > 10 ug/l)	Total - P wasteloads	existing and future (with and without control measures) total-phosphorus loads to Long Lake during growing season resultant chl a concentrations in Long Lake.
Algal blooms-feasibility of control by seasonal P removal	Total - P wasteloads from municipal STPs	existing and future (with and without control measures) total-phosphorus loads to Long Lake prior to growing season, using a shorter time step. the resultant in-lake total-phosphorus concentration
Low D.O. levels in Hypolimnion (<1 mg/l)	BOD, NH_3, organic N wasteloads carried by river; algal biomass in Long Lake	existing and future (with and without control measures) loads to Long Lake of deoxygenation* parameters. resultant in-lake deoxygenation* loads including algal respiration. resultant hypolimnetic DO concentrations in Long Lake

TABLE 7-1 (CONT'D)

System - Problem	Controllable Casual Parameters	Analytical Scheme Required to Compute
SPOKANE RIVER		
Contamination by toxicants, expecially Zn	Wasteloads containing heavy metals, NH_3, chlorine residuals	existing and future (with and without control measures) heavy metal loads in the Spokane River resultant in-stream heavy metal concentrations
Low D.O.:		
1) <5 mg/l below Long Lake Dam 2) <8 mg/l in River above Spokane	Low Hypolimnetic D.O. in Long Lake BOD, NH_3, organic N wasteloads	See Long Lake problem existing and future (with and without control measures) deoxygenation* loads in the Spokane River. resultant in-stream DO concentrations.
AQUIFER		
Toxicant pollution	Concentration of heavy metals in Spokane River	existing and future (with and without control measures) heavy metal loads in the Spokane River. resultant in-stream heavy metal concentrations. resultant heavy metal concentrations in wells.

* deoxygenation parameters include all biological and chemical oxygen demands, such as BOD, nitrogenous oxygen demand, sediment oxygen demand, algal respiration

2. Cumbersome to modify: Massive and elaborate input/output features are built-in to some models and means of modifying the algorithm without modifying the program codes are limited.

3. Difficult to calibrate; Calibration of some models involves many rate coefficients and thus requires a large volume of data.

EPA/QUAL-II and Battelle's Long Lake Reservoir models are two of the better models of this type, and represent state-of-the-art water quality models for the Spokane River and Long Lake systems, respectively. Because of the above mentioned drawbacks, they should be used to model the dissolved oxygen effects in the Spokane system only if an available simpler model is not sufficient. Both models have a sophisticated dissolved oxygen sub-model which simulates complicated interactions between supplies and demands from a number of deoxygenation parameters, e.g. BOD, ammonia-nitrate-nitrite reactions, sediment and benthic oxygen demands, and photosynthesis.

Because of the algal problem in Long Lake and the follow-up monitoring related to advanced waste treatment at the Spokane STP, a large volume of data on the cause/effect parameters (phosphorus and chl a in particular) in Long Lake is available. The abundance of data enables development of a simple regression equation, between the phosphorus load from the river and mean chl a concentration in the lake (Soltero, et al., 1979). This relationship is described in Chapter 6.

To facilitate repeated computations of the total-phosphorus loads in the Spokane system, URS has modified an existing steady-state mass balance model into the URS/Spokane River Model (SRM). Because the structure of the model is very simple, additional parameters such as heavy metals and BOD/Temperature/DO can be added to the model to allow preliminary evaluation of the cause-effect relationships for these parameters. It will be shown in the section on model application that this simple river model is adequate for modeling the heavy metal parameters and simulation of the DO in the river above the Nine Mile Dam. The river below Long Lake Dam was not modelled because the models used cannot predict the quality of water released from Long Lake.

In contrast to model development for rivers and lakes, generalized aquifer quality models are not available. The development of an aquifer quality model is highly dependent on the specific conditions of the system to be simulated and requires adequate monitoring data. USGS/Tacoma district has developed a flow model for the Spokane Aquifer (Bolke and Vaccaro, 1979). The model is capable of simulating the groundwater movement, water elevation at various well sites, and the flow exchange between the aquifer with the Spokane and Little Spokane Rivers. It allows for both steady-state and transient-state simulations with a time interval of 5 or 10 days.

The flow model has been calibrated for the May 1977 to April 1978 period with streamflow data for the Spokane and Little Spokane Rivers and Hangman Creek, and water level measurements at 142 well sites. The reliability of the model calibration was checked in two ways. First, the discharge of the Spokane River at three sites (Post Falls, Liberty Bridge, and Spokane) was compared to the discharge calculated by the model. Second, the net contribution of groundwater inflow to the flows measured at the gaging station below Long Lake Dam as determined by mass balance was compared to that calculated by the model. The test results were good for the medium and low flow periods (± 5 percent deviation), but the deviations were quite large for the high flow period. This may be due to the use of 5 to 10 day time increments in the model; since large fluctuations in flows have been observed within one day, use of longer time intervals may have resulted in incorrect averaging of flow.

Since a low flow regime is usually used for wasteload allocation study, the accuracy of the aquifer model demonstrated by the model test in the low and medium flow periods should be adequate for river modeling use (e.g. modeling the rate of flow interchange between the aquifer and the river). In the modeling application section of this chapter, details will be given on the coupling of the aquifer and the river system.

Although USGS/Tacoma has developed a solute-transport model for the Spokane Aquifer System (Vaccaro, et al., 1979), the modeling effort was limited to chloride. Algorithms for computing the fate of other pollutants (heavy metals or conventional parameters) have not been evaluated for this application and would have to be developed from an analysis of monitoring data.

Table 7-2 gives a list of selected cause-effect models for each type of cause-effect analysis. For example, Soltero's Regression Model and URS/SRM model are used together for computing the causes and effects of the phosphorus and chl a relationship. Each model is described in Appendix C.

TABLE 7-2

SELECTED CAUSE-EFFECT MODELS

Type of Cause-Effect Model Needed	Parameter for Allocation	Selected Model(s)
1. Lake ecosystem model	total-phosphorus	Soltero's Regression Model + Spokane River Model (URS)
2. lake phosphorus model	total-phosphorus	Seasonal Phosphorus Removal Model (URS) + Spokane River Model (URS)
3. river mass balance model	heavy metals	Spokane River Model (URS) or QUAL-II (EPA)
4. river dissolved oxygen model	deoxygenation parameters	Spokane River Model (URS) or QUAL-II (EPA)
5. lake dissolved oxygen model	deoxygenation parameters	Battelle's Long Lake Reservoir Model (with modification)
6. groundwater heavy metal model	Heavy metals	model need to be developed

MODEL APPLICATION

Before any of the models can be applied, four preparatory steps must be taken:

1. Schematize the modelled system
2. Set the design conditions
3. Compile flow and concentration data for each source
4. Calibrate and verify the model

Model Schematization

Figure 7-1 shows a simplified version of the system model. Post Falls, Idaho and Long Lake Dam are the respective upstream and downstream boundaries. By treating the interchange between the Spokane Aquifer and the river as either source or sink for the river, the two systems are coupled. Table 7-3 summarizes the schematics of each model selected for the allocation study.

TABLE 7-3

MODEL SCHEMATIZATION

Model Name	Type of Allocation Use	Modelled Boundary	System Representation
1. Soltero's Regression Model	total-phosphorus	inlet/outlet of the Long Lake	- treat the lake as a well-mixed box
2. URS/Spokane River Model	total-phosphorus	upstream - Post Falls	- plug flow
		downstream - Nine Mile Dam and confluence with L. Spokane River	- system responses are modelled as snapshots of the plug, taken at various river stations
		Spokane aquifer	- incoming loads from the sources are added and exiting loads (to the sink) are subtracted
3. URS/Spokane River Model	heavy metals	same as above	- same as above (2)
4. URS/Spokane River Model	deoxygenation parameters	same as above	- same as above (2) - BOD decays exponentially with travel time

TABLE 7-3 (CONT'D)

MODEL SCHEMATIZATION

Model Name	Type of Allocation Use	Modelled Boundary	System Representation
5. QUAL-II (EPA)	deoxygenation parameters (BOD, nitrogenous oxygen demand, sediment oxygen demand, algal respiration)	same as above	- in each river segment mass transportation through advection and dispersion processes - system responses are modelled as a sequence of pictures taken from the initial to the last segments - a system of differential equations is written for the mass balance of each parameter
6. Battelle's Long Lake Reservoir Model	deoxygenation parameters	inlet/outlet of the Long Lake	- in each lake layer (horizontal) and segment (vertical) mass is being transported through advection, convection and dispersion processes - Others are same as QUAL-II representation

URS/SRM models the river as many stations, each station designated by an index (e.g. river miles). The water quality condition at each of the assigned stations is simulated by the model. Sources/sinks in the model are assigned as stations based on location. For example, if a system has only one input source and a control point downstream, the model needs only to designate four stations for up-and downstream boundary, the source and the control point.

EPA/QUAL-II divides the river into many segments. The water quality condition in each segment is simulated under the assumption that the quality is uniform within each segment. To reduce computation time, only those stations or segments which represent a major change in water quality conditions need to be specified.

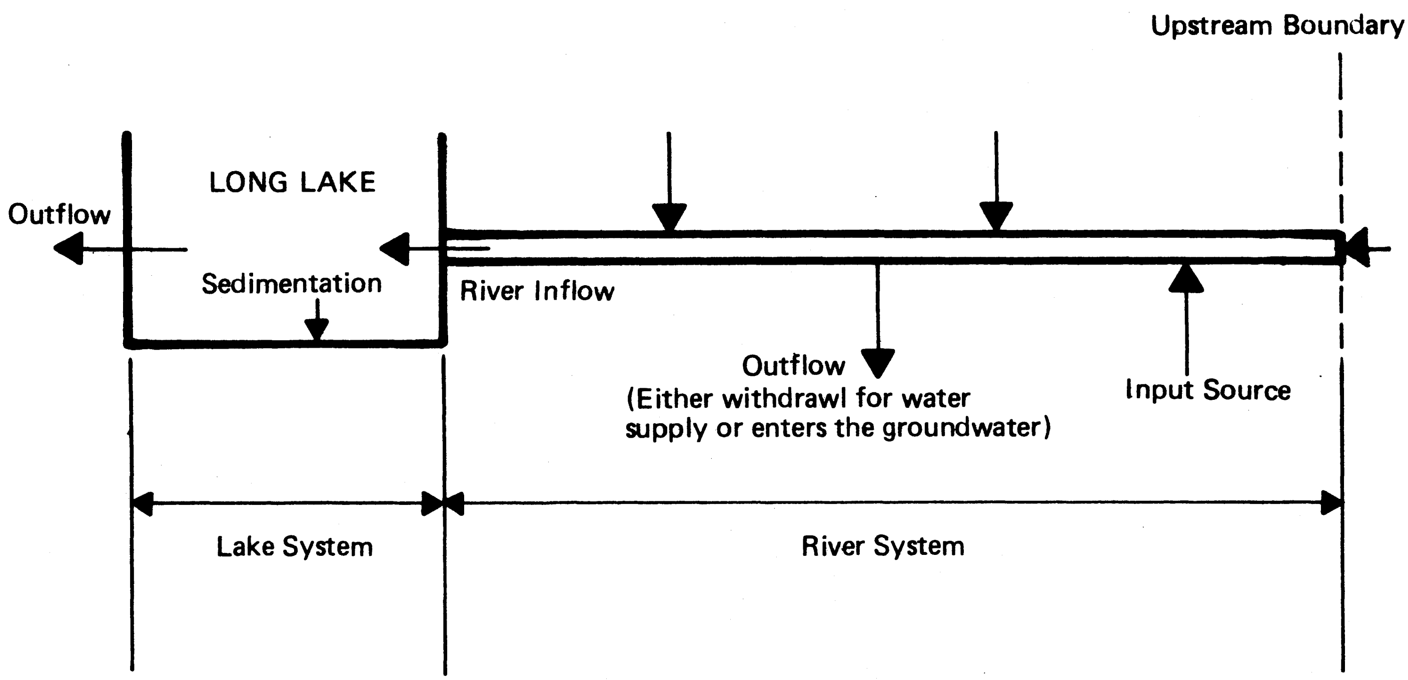


FIGURE 7-1
Schematic of the System Model

Basically, either a station (for URS/SRM) or a segment (for QUAL-II) should be specified only for the following:

- o boundary
- o source/sink
- o location of major change in river hydraulics
- o gaging and sampling stations
- o major charges in shoreline land use

Batelle's Lake Model divides the lake into vertical segments and horizontal layers--top layer (well-mixed) and many discrete lower layers.

Design Condition

The "design condition" is defined as the condition upon which the allocation is based. To minimize the frequency of water quality violations, a critical or worst case condition is usually selected as the design condition for the allocation calculations.

Permissible phosphorus loadings to Long Lake are directly related to the flushing rate of the lake; therefore, a low flushing rate (low flow) should be used as the design condition. Low flow conditions are also critical for dissolved oxygen calculations because dissolved oxygen content in the river is lowest during the summer (high temperature, low saturation dissolved oxygen concentration) low flow period, and the hypolimnetic dissolved oxygen concentration in the lake is also at its lowest level because of the summer stratification (little contact with the atmosphere). Examination of the USGS aquifer model results shows that the amount of the flow exchange between the aquifer and river is relatively constant during the low and medium flow regimes; therefore, the effects of the aquifer should not affect the selection of the design conditions.

For heavy metal allocation calculations, enough data are not available to set the design condition. It is possible that the critical condition is in the high flow period when the aquifer is gaining water from the river. For the evaluation of the concentrations in the river discussed below, a low flow regime was used.

Wasteload Generation

Table 7-4 gives the data sources for the existing and future wasteload estimations of all point and non-point sources in the Spokane River/Long Lake system. Point sources include discharges from municipal sewage treatment plants and industrial plants, tributary flows and groundwater inflows. Non-point sources include combined sewer overflows, urban runoff.

TABLE 7-4

WASTELOAD ESTIMATION - DATA SOURCES

Wasteload Source	Present Conditions	Future Conditions (1990)
Spokane River at Post Falls	Yake, 1979	Boundary condition assumed to remain unchanged
Coeur d'Alene & Post Falls STPs	EPA survey data (9/79)	Flow estimated to be 3 mgd greater greater than present based on Idaho Div. of Environment, 1978. Staff evaluation on effluent limitations for the City of Coeur d'Alene and City of Post Falls. Concentration assumed to be the same
Liberty Lake Wastewater Treatment Facility	Facility not in operation	Kennedy Engineers, 1978. Addendum to Facilities Plan - Prepared for the Liberty Lake Sewer District
Spokane Industrial Park Wastewater Treatment Facility	DOE Sampling Data; Spokane River Point Sources-3/31/80 to 4/01/80*, 6/10,11/80	Eastern Regional Office Dept. of Ecology
Kaiser Aluminum	DOE Sampling Data; Spokane River Point Sources-3/31/80 to 4/01/80*, 6/10,11/80	Eastern Regional Office Dept. of Ecology
Inland Empire Paper Co.	DOE Sampling Data; Spokane River Point Sources-3/31/80 to 4/01/80*, 6/10,11/80	Eastern Regional Office Dept. of Ecology
Millwood Wastewater Treatment Facility	DOE Sampling Data; Spokane River Point Sources - 6/10,11/80	Eastern Regional Office Dept. of Ecology
Hangman Creek	Yake, 1979	Same as the present
Combined sewer overflows/ Urban Runoff	Esvelt and Saxton/Bovay Engineers, Inc., 1972 Spokane Wastewater Study.	City of Spokane, 1977. Facilities Planning Report for Sewer Overflow Abatement.
	Corps of Engineers, 1976. Metropolitan Spokane Region Water Resources Study - Technical Report	Corps of Engineers, 1976. Metropolitan Spokane Region Water Resources Study - Technical Report.

TABLE 7-4 (CONT'D)

WASTELOAD ESTIMATION - DATA SOURCES

Wasteload Source	Present Conditions	Future Conditions (1990)
Spokane Advanced Wastewater Treatment Facility	1979 Treatment Plant Data	Esvelt and Saxton/Bovary Engineers, Inc., 1972. Spokane County Comprehensive Wastewater Management Plan Phase II Report--Future Needs, 1980. 1979 Treatment Plan Data.
NW Terrace Wastewater Treatment Facility	DOE Sampling Data; Spokane River Point Sources - 6/10,11/80	Eastern Regional Office, Dept. of Ecology
Little Spokane River	Yake, 1979	Same as the present

* Additional data regarding effluent concentrations of total phosphorus is needed. Sampling is conducted at these facilities to determine phosphorus discharge; however, data is collected for orthophosphorus concentrations only.

These data are taken from special surveys, routine monitoring reports by various agencies, and NPDES permit limits. Flow, phosphorus and BOD concentration data are the only parameters that have adequate data. The data for most of the other parameters are either missing or taken from one time survey.

Water withdrawals from the river (e.g. water supply for Kaiser Aluminum) and river flow to the aquifer are modelled as negative flows with concentrations equivalent to the in-stream concentrations at the withdrawal sites.

Discharge data from municipal sewage treatment plants, although showing large fluctuations in daily or instantaneous samples, are fairly constant within each month. Flow exchange between the aquifer and the river are taken from the calibrated USGS aquifer model. Concentrations of most parameters in the groundwater inflow are very low. Total phosphorus data measured in several wells near the river are given simply as less than 0.01 mg/l. For modeling purposes, this upper concentration value is used as the actual concentration because no other estimate is available.

Flow and concentration data for urban runoff are available from the 208 and Corps of Engineers' urban study reports (Esvelt, et al., 1972 and COE, 1976) but the inlet locations at the river and subdrainage areas are not specified. The City of Spokane has 559.22 miles of sanitary and combined sewers. Separate storm sewers are present in northwest Spokane, west of the central business district and east of Division and along the river, totaling 57.44 miles of sewers. The construction of separate storm sewers is required in all new developments. Future plans include the separation of storm and sanitary sewers throughout the City.

The North Spokane suburban area contains a limited storm drainage system that includes both sewers and roadside ditches. The ultimate point of discharge is the Little Spokane River. There are no combined sewers in the North Spokane suburban area. The area in general slopes directly toward the Little Spokane River.

The Spokane Valley suburban area contains practically no storm drainage systems. All drainage is essentially by percolation, either from "dry wells" dug for this purpose or by simple infiltration into the ground surface. The ground surface slopes to the Spokane River so that the Spokane River would be the recipient of any collected storm drainage.

Table 7-5 shows the forecasted urban runoff quantity, in annual volume, for the City, North Spokane and Spokane Valley as it was reported by the Corps of Engineers' Urban Study in 1976. An annual average discharge rate, in cfs, is computed from the annual flow volume.

TABLE 7-5

URBAN RUNOFF FORECASTS

		Forecast by Years					
		1980		1990		2000	
Area		Annual* Volume (AC-FT)	Average Discharge (cfs)	Annual* Volume (AC-FT)	Annual Discharge (cfs)	Annual* Volume (AC-FT)	Annual Discharge (cfs)
City of Spokane	Max[1]	8504	11.7	8722	12.0	9046	12.4
	Min[1]	6047	8.3	6202	8.5	6433	8.9
North Spokane	Max[2]	698	1.0	1563	2.2	1809	2.5
	Min[2]	446	0.6	999	1.4	1155	1.6
Spokane Valley	Max[3]	2436	3.4	2947	4.1	3456	4.8
	Min[3]	1664	2.3	2013	2.8	2360	3.2

1 At mean rainfall 18.2 inch/yr and 0.7 runoff coefficient (1.062 Ac-Ft/Ac. Yr).

2 At mean rainfall 19.3 inch/yr and 0.7 runoff coefficient (1.126 Ac-Ft/Ac. Yr).

3 At mean rainfall 19.5 inch/yr and 0.7 runoff coefficient (1.138 Ac-Ft/Ac. Yr).

* Taken from Corps of Engineers' Water Resources Study/Metropolitan Spokane Region, Technical Report, P. 251, January 1976.

Table 7-6 gives the precipitation distribution by month in the Spokane area. The percentage of the annual precipitation in the growing season (June-November) is 41 percent. This percentage is used to scale the runoff volume in the growth season from the annual volume. For example, the annual urban runoff volume of the City of Spokane, on Table 7-5, is 8,504 ac-ft (11.67 cfs). The corresponding runoff volume in the growth season is 8504 x 0.41 = 3,487 ac-ft or 1,145 million of gallons. The mean seasonal runoff volume on a daily scale (divided by 183 days), is 6.26 MGD or 9.7 cfs. Presently, for the City of Spokane, the total contributory area is 33,626 acres, of which 16,239 acres are in the combined sewer service area and 17,387 acres are in the separated area. The runoff volume from the separated area is 9.7 cfs x 17,387/33,626 = 5.0 cfs.

TABLE 7-6

MONTHLY DISTRIBUTION OF PRECIPITATION FOR THE CITY OF SPOKANE AREA (ESVELT, ET AL., 1972)

Month		Percent
January		13
February		10
March		8
April		6
May		8
June		8
July		3
August		4
September		5
October		8
November		13
December		14
	TOTAL	100

Total annual overflows from the 10 combined sewer overflows from the 10 combined sewer overflow (CSO) zones were reported as 500 million gallons. The volume of overflow in the growing season (again scaled by 0.41), is 50 x 0.41 = 205 MG, and averaged to 1.12 MGD (or 1.74 cfs).

Data on average phosphorus concentration of urban runoff are given in Table 7-7.

TABLE 7-7

TOTAL P CONCENTRATION OF URBAN RUNOFF

Source of Data	Concentration of P in mg/l	
	Storm Sewer	
EPA	mean	standard deviation
	5	0.4
Draft EIS	Urban Runoff	
City of Spokane	mean	standard deviation
CSO Project	0.2	4.3
Unpublished 208 data	0.89	1.62
	Combined Sewers	
Spokane	0.95	1.9
EPA	2.8	2.9

Source: Spokane County, 1979

The mean concentration of 0.89 mg/l (208 data, unpublished) gives an annual phosphorus loading from the urban runoff of,

11.67 cfs x 0.89 mg/l x 5.394 (conversion factor)

= 56.17 lb-P/day, or

20,501 lb-P/yr

This loading rate gives a unit mass areal loading rate of,

$$\frac{20,501}{33,626} = 0.61 \text{ lb-P/acre/yr.}$$

This value is well within the loading value observed in the Seattle area, 0.5 to 2.37 lb-P/acre/yr (Table 7-8). Rast and Lee (1978) estimated an export coefficient of 0.1 $g/m^2/yr$ or 0.89 lb/acre/yr of total phosphorus from the urban watershed.

TABLE 7-8

PHOSPHORUS AREAL LOADING FACTORS
IN THE SEATTLE AREA

Land Use Type	Total PO_4-P (lb/acre/yr) (Stable Site Estimates)
Industrial	2.34
Commercial	1.64
High Density (Mult. Family)	2.37
Med. Density (Mult. Family)	0.51
Low Density (Single Family)	0.50

Source: Buffo, 1979

Table 7-9 summarizes the urban runoff loading characteristics (flow and total-phosphorus concentration) in the Spokane River Basin.

TABLE 7-9

URBAN RUNOFF LOADING CHARACTERISTICS -
FLOW AND TOTAL-P CONCENTRATION

I. Present

Source	Flow	P-concentrations	P-Load
Combined Sewer Overflows (CSO)	1.74 cfs	2.80 mg/l	26.28 lb/day
City Urban Runoff (URO)	5.01 cfs	0.89 mg/l	24.05 lb/day
North City URO	0.80 cfs	0.89 mg/l	3.84 lb/day
Valley URO	2.78 cfs	0.89 mg/l	13.35 lb/day

II. Future (1990)

Source	Flow	P-concentrations	P-Load
CSO	0.	0.	0.00
City URO	9.95 cfs	0.89 mg/l	47.77 lb/day
North City URO	1.78 cfs	0.89 mg/l	8.55 lb/day
Valley URO	3.36 cfs	0.89 mg/l	16.13 lb/day

Tables 7-10 and 7-11 summarize the existing and future sources and the respective wastewater characteristics. Zeros or blanks indicate no data are available or that a plant is not currently on-line.

Model Calibration and Verification

Model Calibration is the process of adjusting the model coefficients so that the deviation from measurements can be minimized. Model verification is testing a model by determining how well the results of the calibrated model match an independent set of observations. Table 7-12 lists the parameters and coefficients to be adjusted during calibration and the parameters to be checked during verification for each model for specific application to wasteload allocation calculations.

As mentioned above, simple models such as URS/SRM, Soltero's regression model and the seasonal phosphorus removal model were tested first. The results of the tests of these three models are presented in the next section--sample model application for phosphorus load allocation.

TABLE 7-10

INPUT DATA TO URS/SRM MODEL FOR THE YEAR 1980

RM	SOURCE NAME	Q cfs	BOD (mg/l)	P (mg/l)	ZN (ug/l)	CL (ug/l)	PB (ug/l)	CU (ug/l)	DO (ug/l)	TEMP (°C)
98.7	POST FALLS	1600.	1.3	.014	100.		21.	9.	7.3	20.7
98.6	COEUR D'ALENE STP	3.1	30.	7.5						
87.0	GROUNDWATER 1	-28.								
86.1	WITHDRAWAL	-42.								
92.7	LIBERTY LK STP									
87.1	SPOKANE IND PARK	1.06		2.9	190.		73.	3500.	8.3	18.1
84.0	GROUNDWATER 2	219.		0.01						9.5
85.3	SPOKANE VALLEY URO	2.78	35.	0.89						
86.0	KAISER	42.	8.	0.1	60.	0.1	3.	7.	8.8	22.2
79.8	GROUNDWATER 3	-46.								
82.6	INLAND EMP PAPER	3.3	160.	0.8	30.		1.	5.	3.5	23.3
82.3	MILLWOOD STP	0.104	30.	16.	210.		3.	65.	3.0	18.1
78.0	GROUNDWATER 4	241.		0.01						9.7
74.0	GROUNDWATER 5	-208.								
72.9	GROUNDWATER 6	120.		0.01	3.2					11.0
71.0	GROUNDWATER 7	-12.	0.	0.	0.	0.	0.	0.	0.	0.
72.4	HANGMAN CK	14.	0.	0.44	0.	0.	0.	0.	0.	17.4
69.7	GROUNDWATER 8	21.		0.01						12.0
69.8	CITY CSO	1.74	35.	2.80						
65.0	GROUNDWATER 9	-23.	0.	0.	0.	0.	0.	0.	0.	0.
67.3	SPOKANE STP	51.	8.5	0.66	30.	0.8	50.	30.	9.7	
67.0	URBAN RUNOFF	5.01	35.	0.89	0.	0.	0.	0.	0.	0.
61.9	GROUNDWATER 10	45.	0.	0.01	0.	0.	0.	0.	0.	10.9
64.3	NW TERRACE	0.18	10.	8.3	60.	1.5	50.	20.	0.	0.
58.1	GROUNDWATER 11	-41.	0.	0.	0.	0.	0.	0.	0.	0.
56.4	NO. CITY URO	0.8	35.	0.89						
56.3	L. SPOKANE R	380.	0.	.024	0.	0.	0.	0.	0.	0.
56.2	SW. BOUNDARY FLOW	110.		.01						

TABLE 7-11

INPUT DATA TO URS/SRM MODEL FOR THE YEAR 1990

RM	SOURCE NAME	Q cfs	BOD (mg/l)	P (mg/l)	ZN (ug/l)	CL (ug/l)	PB (ug/l)	CU (ug/l)	DO (ug/l)	TEMP (°C)
98.7	POST FALLS	1600.	1.3	.014	100.		21.	9.	7.3	20.7
98.6	COEUR D'ALENE STP	7.7	30.	7.5						
87.0	GROUNDWATER 1	-28.								
86.1	WITHDRAWAL	-42.								
92.7	LIBERTY LK STP	3.10	9.	6.3						
87.1	SPOKANE IND PARK	1.06	30.	2.9	190.		73.	3500.	8.3	18.1
84.0	GROUNDWATER 2	219.		0.01						9.5
85.3	SPOKANE VALLEY URO	3.36	35.	0.89						
86.0	KAISER	42.	8.	0.1	60.	0.1	3.	7.	8.8	22.2
79.8	GROUNDWATER 3	-46.								
82.6	INLAND EMP PAPER	3.3	160.	0.8	30.		1.	5.	3.5	23.3
82.3	MILLWOOD STP	0.104	30.	16.	210.		3.	65.	3.0	18.1
78.0	GROUNDWATER 4	241.		0.01						9.7
74.0	GROUNDWATER 5	-208.								
72.9	GROUNDWATER 6	120.		0.01	3.2					11.0
71.0	GROUNDWATER 7	-12	0.	0.	0.	0.	0.	0.	0.	0.
72.4	HANGMAN CK	14.	0.	0.44	0.	0.	0.	0.	0.	17.4
69.7	GROUNDWATER 8	21.		0.01						12.0
69.8	CITY CSO	0.	0.	0.						
65.0	GROUNDWATER 9	-23.	0.	0.	0.	0.	0.	0.	0.	0.
67.3	SPOKANE STP	76.6	8.5	5.00	30.	0.8	50.	30.	9.7	
67.0	URBAN RUNOFF	9.95	35.	0.89	0.	0.	0.	0.	0.	0.
61.9	GROUNDWATER 10	45.	0.	0.01	0.	0.	0.	0.	0.	10.9
64.3	NW TERRACE	0.18	10.	8.3	60.	1.5	50.	20.	0.	0.
58.1	GROUNDWATER 11	-41.	0.	0.	0.	0.	0.	0.	0.	0.
56.4	NO. CITY URO	1.78	35.	0.89						
56.3	L. SPOKANE R	380.	0.	.024	0.	0.	0.	0.	0.	0.
56.2	SW. BOUNDARY FLOW	110.		.01						

TABLE 7-12

MODEL CALIBRATION/VERIFICATION REQUIREMENTS

Modelled System	Model Name	Parameter To Be Simulated	Calibration Parameters/ Coefficients (Model Inputs)	Verification Parameters (Model Results)
A. River	URS/SRM	a. phosphorus	a-1 groundwater/ river exchange	a-1 flow
			a-2 input loads	a-2 in-stream concentration
		b. heavy metals	b-1 groundwater/ river exchange	b-1 flow
			b-2 input loads	b-2 instream concentration
		c. deoxygenation parameters	c-1 reaeration rate	c. dissolved oxygen concentration
			c-2 temperature	
			c-3 input loads (BOD only)	
	EPA/ QUAL II	a. phosphorus	a-1 groundwater/ river exchange	a-1 flow
				a-2 in-stream concentration
			a-2 input loads	
			a-3 sedimentation amount	
			a-4 dispersion coefficient	
		b. heavy metals	b-1 groundwater/ river exchange	b-1 flow
				b-2 in-stream concentration
			b-2 input loads	

TABLE 7-12 (CONT'D)

MODEL CALIBRATION/VERIFICATION REQUIREMENTS

Modelled System	Model Name	Parameter To Be Simulated	Calibration Parameters/ Coefficients (Model Inputs)	Verification Parameters (Model Results)
		c. deoxygenation parameters	c-1 reaeration rate c-2 temperature c-3 BOD, nitrogenous & benthic oxygen demand c-4 deoxygeneration rates c-5 algal respiration & photosynthesis	c. dissolved oxygen
B. Lake	Soltero's regression	a. phosphorus	a-1 retention coefficient a-2 flushing rate a-3 input loads	a. chl a
	Seasonal phosphorus removal model	a. phosphorus	a-1 retention coefficient a-2 flushing rate a-3 input loads	a. in-lake mean total P concentration
	Battelle's Long Lake Reservoir Model	b. deoxygenation parameters	b-1 input loads (carbonaceous, nitrogenous and benthic oxygen demands) b-2 deoxygenation rates	b. hypolimnetic dissolved oxygen

EPA-QUAL-II has been tested in many river systems. The difficulty encountered in calibration is usually related to benthic oxygen demand--its area/coverage and strength in each modelled segment. However, a carefully planned sampling program should be able to overcome this problem. One of the anticipated calibration problems for the Battelle model is determining internal load transformation (from algal biomass to carbonaceous oxygen demand or to benthic oxygen demand). The results of the previous model application on Long Lake (Gasperino and Soltero, 1977) have shown that the lake temperature profile and stratification depth were adequately modelled. One major problem for the testing of all models is lack of synchronous data for the input loads and the in-stream concentrations for the entire system.

Application to Wasteload Allocation

In this section, application of the cause/effect models for the phosphorus load allocations is described. Application for allocation of other wasteload parameters is also discussed.

1. Allocation of phosphorus loads

Figure 7-2 shows the process that applies to phosphorus allocation. The modeling process involves three cause/ effect models--Soltero's regression model, URS/SRM, and seasonal phosphorus removal model.

Step 1 - Data Analysis

First a data analysis computer program (Appendix B) was used to perform the loading calculations on the historical data for the verification of the reported Soltero's regression model. All relevant data used in the calculations, such as the inflow data (for both the Spokane and the Little Spokane Rivers) to the Long Lake, the outflow data measured at the Long Lake Dam and the corresponding total phosphorus concentrations were obtained from previous studies. The program computes the total-phosphorus (PO_4) load to the lake from the two rivers, in terms of the instantaneous, average monthly and total seasonal loads (June-November), and the load carried by the lake outlet, as well as the retention coefficient, sedimentation factor, and lake flushing rate. Then the program computes the areal phosphorus load, which is the loading parameter used in Soltero's regression model and calculates the chl a concentrations using the regression equation.

These calculations were carried out for the 1972, 1973, 1974, 1975, 1977, 1978, and 1979 data (see Appendix B2-B9). The results substantiated that, as has been reported by the previous investigations (Soltero et al., 1979, 1980) the correlation coefficient between mean seasonal chl a concentration in the lake and the areal total-phorphorus load is well above 0.90. This data analysis program can be used to analyze future monitoring data.

Step 2 - Cause/Effect Modeling Approach

The permissible phosphorus load in the growing season (June-November) can be obtained by using the regression model with the input of the

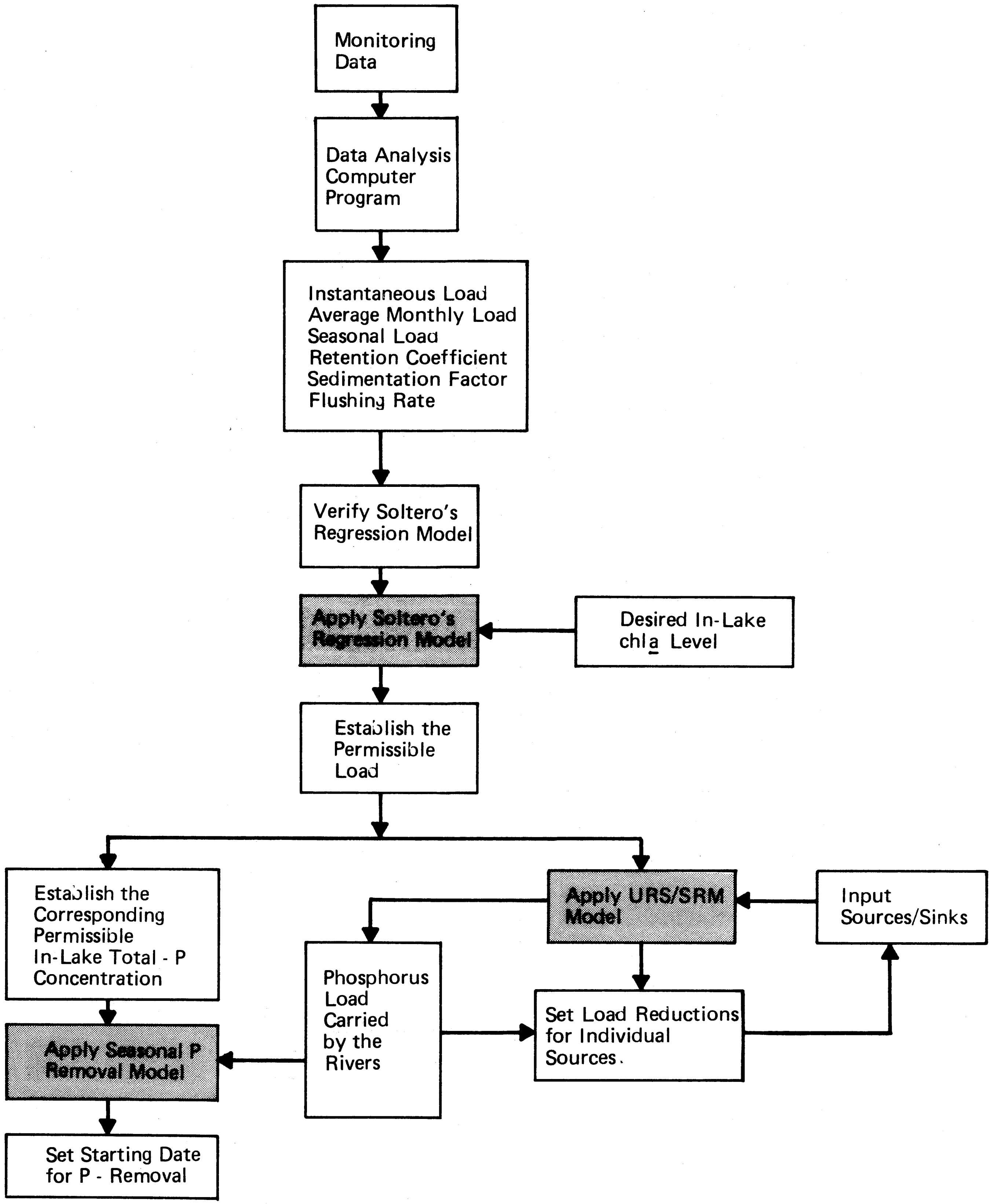


FIGURE 7-2
Modeling Process for Phosphorus Allocation

desired chl a concentration level. Once the permissible load value, Lp, is known, it is used as follows:

1) dividing Lp by the mean depth of the lake, we get the permissible mean lake phosphorus concentration. This concentration value is used as the target to derive the starting date for the seasonal phosphorus removal by the application of the seasonal phosphorus removal model (for details see Appendix A)

and 2) to compute the required load reduction, as described in Chapter 9.

Step 3 - Model Verification

The URS/SRM model was verified using data for August 15, 1979, collected during an intensive EPA survey of the Spokane River from Post Falls, Idaho, to Hangman Creek.

Figure 7-3 shows the schematic of the Spokane River System depicted by the URS/SRM model.

The first step of the model verification was to balance the flow in the system, which involves primarily the exchange between the aquifer and the river.

This was accomplished in the following manner:

1. The measured flow at Post Falls is 690 cfs (personal communication, John Yearsley).

2. A similar flow regime occurred in August, 1977, a period that has been simulated by the USGS aquifer model.

3. Table 7-13 presents the rate of flow exchange between the aquifer and the river at various locations in the river from the transient-state modeling results, averaged for the month of August, 1977.

4. These gains and losses by the river are entered into the model along with the flows of other sources and tributaries.

Figure 7-4 presents the results of flow profile of August 15, 1979 computed by URS/SRM model and the range of the flows that were measured on the same day at three locations - Trent Road Bridge, Green Street Bridge and Spokane Gage. The results show that by coupling the results of the aquifer model with the river model, the river flows (especially during the low flow period) in the Spokane River can be appropriately balanced.

The next step is to do a mass balance. Table 7-14 gives the flow and the phosphorus concentration of each input source and the flow of each sink. The phosphoprus concentration of each sink flow is equivalent to the river concentration at that site. The model adds the load from each source and subtracts for each sink. The resulting load is then divided by the river flow to get the concentration.

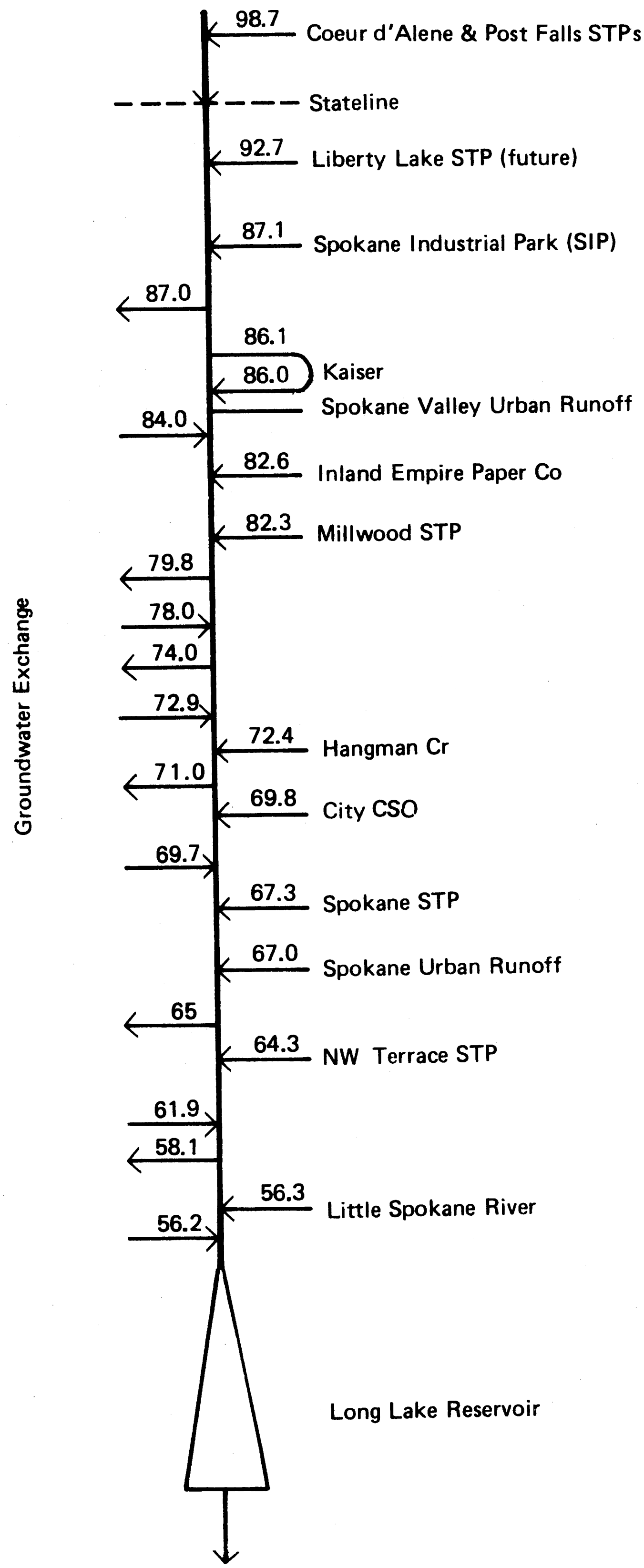


FIGURE 7-3
Schematic of Spokane River System

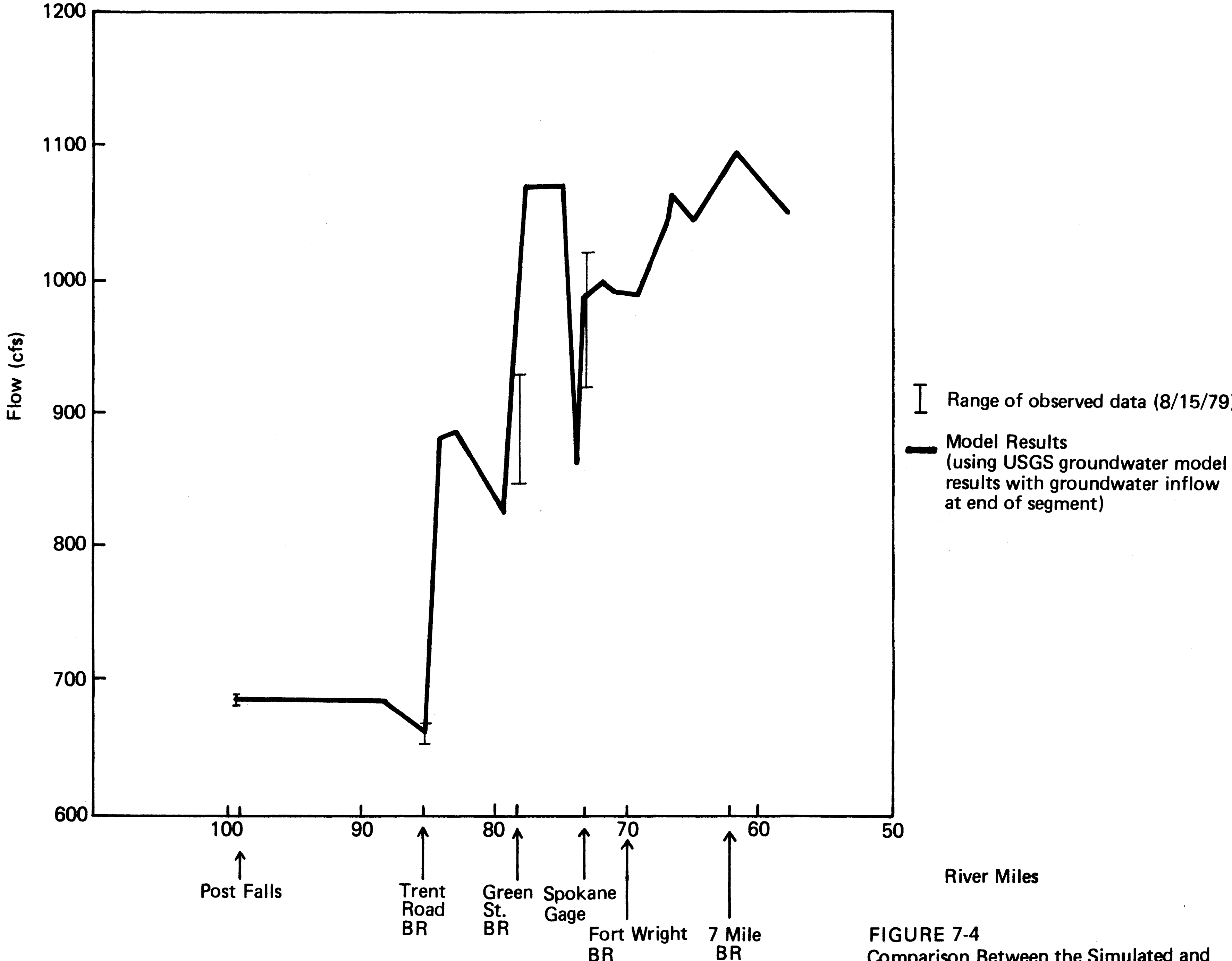


FIGURE 7-4
Comparison Between the Simulated and Observed Flow Profile in the Spokane River, August 15, 1979

TABLE 7-13

FLOW EXCHANGE(1) BETWEEN THE SPOKANE AQUIFER AND THE SPOKANE RIVER

River Miles	Flow (cfs)(2)
87.0 - 96.5	- 17
84.0 - 87.0	214
79.8 - 84.0	- 50
78.0 - 79.8	241
74.0 - 78.0	-208
72.9 - 74.0	120
71.0 - 72.9	- 8
69.7 - 71.0	21
65.0 - 69.7	- 15
61.9 - 65.0	49
58.1 - 61.9	- 41
Little Spokane River	255
Long Lake	110

(1) Simulated by the USGS/Spokane Aquifer Model. Transient-state runs (5 days time step), averaged for the month of August, 1977. Positive flow means the direction of flow is from the Aquifer to the river, or the gains by the river.

(2) Based on preliminary results not approved for release.

Figure 7-5 shows that the total-phosphorus profile produced by the URS/SRM model was similar to that observed during the August 15, 1979 survey. The results simulated by the URS/SRM model closely match the field measurements in the upper portion of the river but are about 20 to 30 percent higher than the measured values in the reaches between river miles 73.0 to 83.0. In that reach the stream bed is relatively flat and the velocity of the stream may be slower (especially in the low flow period); as a result, some of the phosphorus loads may have settled to the streambed. Although no data was taken at the Nine Mile Dam (RM 58.1) for that day, the concentration data collected by Soltero at August 6 and 20, 1979, gave 120 and 80 ug/l respectively, which is fairly close to the modelled value, 105 ug/l.

TABLE 7-14

INPUT DATA TO URS/SRM MODEL-FOR THE AUGUST 15, 1979 EVENT

RM	SOURCE NAME	Q cfs	BOD (mg/l)	P (mg/l)	ZN (ug/l)	CL (ug/l)	PB (ug/l)	CU (ug/l)	DO (ug/l)	TEMP (°C)
98.7	POST FALLS	690.	1.3	.034	100.		21.	9.	7.3	20.7
87.0	GROUNDWATER 1	-17.								
86.1	WITHDRAWL	-42.								
92.7	LIBERTY LK STP									
87.1	SPOKANE IND PARK	.94		1.6	190.		73.	3500.	8.3	18.1
84.0	GROUNDWATER 2	214.								
86.0	KAISER	42.	8.	0.1	60.	0.1	3.	7.	8.8	22.2
79.8	GROUNDWATER 3	-50.								
82.6	INLAND EMP PAPER	3.3	160.	0.26	30.		1.	5.	3.5	23.3
82.3	MILLWOOD STP	0.023	30.	8.	210.		3.	65.	3.0	18.1
78.0	GROUNDWATER 4	241.								
74.0	GROUNDWATER 5	-208.								
72.9	GROUNDWATER 6	120.								
71.0	GROUNDWATER 7	-8.	0.	0.	0.	0.	0.	0.	0.	0.
72.4	HANGMAN CK	7.4	0.	0.44	0.	0.	0.	0.	0.	17.4
69.7	GROUNDWATER 8	21.								
65.0	GROUNDWATER 9	-15.	0.	0.	0.	0.	0.	0.	0.	0.
67.3	SPOKANE STP	51.	30.	1.8	30.	0.8	50.	30	9.7	
67.0	HOLLYWOOD CSO	0.	0.	0.	0.	0.	0.	0.	0.	0.
61.9	GROUNDWATER 10	49.	0.	0.	0.	0.	0.	0.	0.	0.
64.3	NW TERRACE	0.30	30.	8.	60.	1.5	50.	20.	0.	0.
58.1	GROUNDWATER 11	-41.	0.	0.	0.	0.	0.	0.	0.	0.
56.3	L. SPOKANE R	100.	0.	0.1	0.	0.	0.	0.	0.	0.

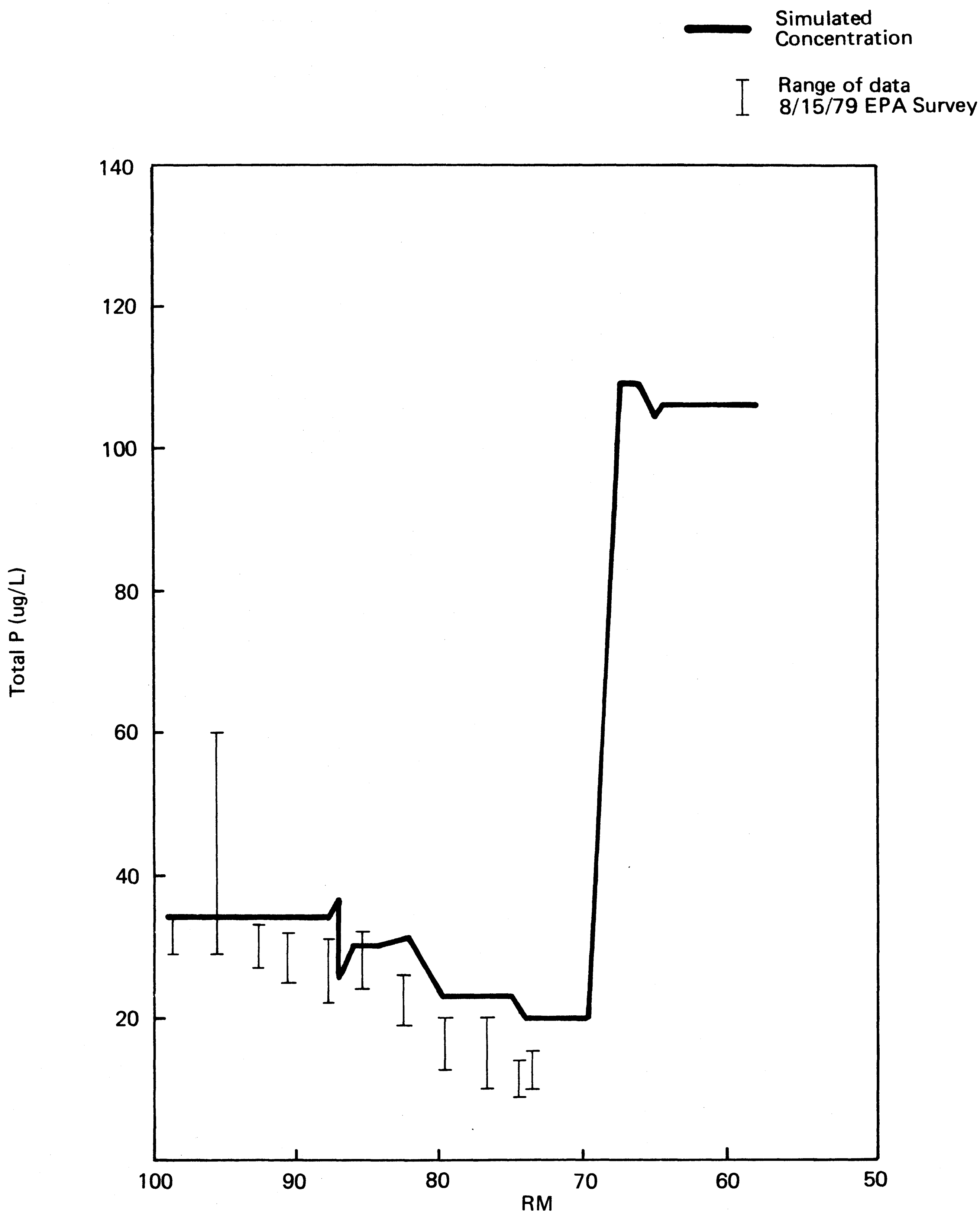


FIGURE 7-5
Comparison of Simulated and Observed Total Phosphorus Concentration Profiles in the Spokane River August 15, 1979

Step 4 - Application to Wasteload Allocation

Data contained in Tables 7-10 and 7-11 are used as input data to URS/SRM to compute the existing and projected future total-phosphorus loads to Long Lake. A loading factor, ranging from 0.0-1.0, can be used to reduce the load as dictated by the applied control measures. Details on the phosphorus allocation are presented in Chapter 9.

2. Allocation of Heavy Metal Loads

Normally, heavy metals are modelled as conservative constituents (i.e., all of the metal added to the system remains in the system). To verify this assumption in the Spokane system and determine the sensitivity of river concentrations to the known heavy metal loads, the URS/SRM model was used to compute the in-stream concentrations. Three heavy metals, zinc, copper, and lead, were studied. The model simply computes the river carrying load and the corresponding concentration value at each specified station in the same manner as in the phosphorus calculations. Again the August 15, 1980 data were used (see Table 7-14) in the analysis.

Figures 7-6, 7-7 and 7-8 plot the computed concentration profiles and the observed range of the concentrations in the Spokane River. The model results match the observed means well for both zinc and copper. Disparities between the modelled and observed lead concentrations occur in the reach between RM 73 to RM 83. It is not certain at this time why the observed concentrations are substantially higher than the modelled concentrations in that reach. It is possible that some sources were not properly accounted for or that the system is too dynamic to be modelled as steady state. Both the observed and the modelled concentrations of all three parameters exceed the EPA criteria (Table 5-3).

The large fluctuations in the observed in-stream concentrations indicate the sensitivity of the input data. Neither instantaneous nor time-composited samples of the effluents, which are the data available, are adequate to determine the actual cause-effect relationships. Although the QUAL-II model has a more elaborate treatment of the mass transport (e.g., features like dispersion and sedimentation) than the URS/SRM, it is still a steady-state mass balance model. Furthermore, because the modelled results are lower than the observed, it is probable that the problem is the input data rather than reaction mechanisms. The results of both models depend heavily on the adequacy of the input data.

Thus none of the available models provides an adequate basis for allocation of heavy metals. Furthermore, as discussed above (Chapter 5), additional work to refine the criteria in the Spokane system is required before allocation would be appropriate.

3. Allocation of Deoxygenation Parameters

The URS/SRM model contains a dissolved oxygen submodel which is designed to be driven by three variables: temperature (saturation dissolved oxygen concentration), BOD, and dissolved oxygen in the inflow. The BOD is decayed exponentially with the travel time; the modelled BOD decay rate, KBOD, is an average value recommended in the literature and is

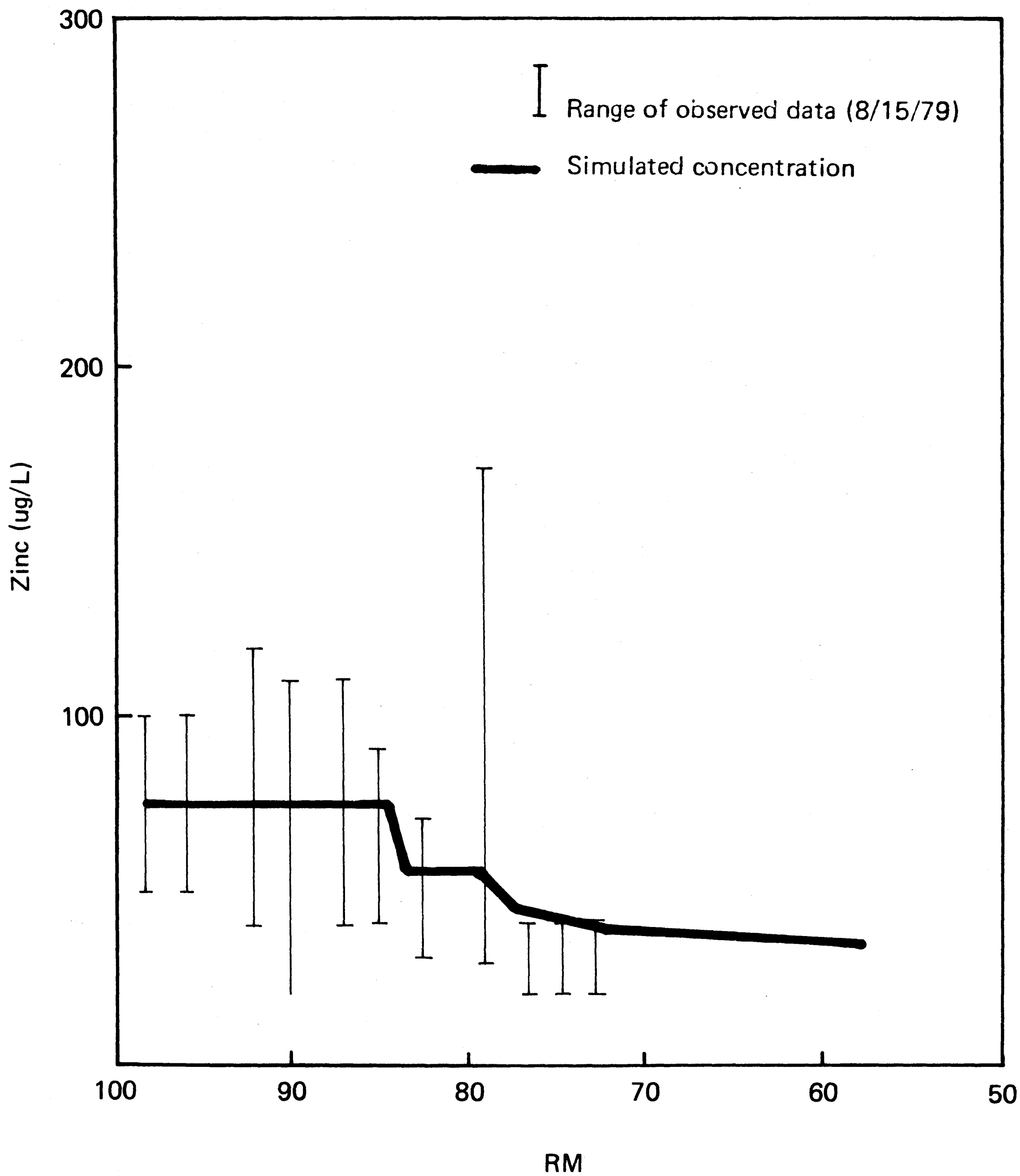


FIGURE 7-6
Comparison of Simulated and Observed Zinc Concentration Profiles in the Spokane River

August 15, 1979

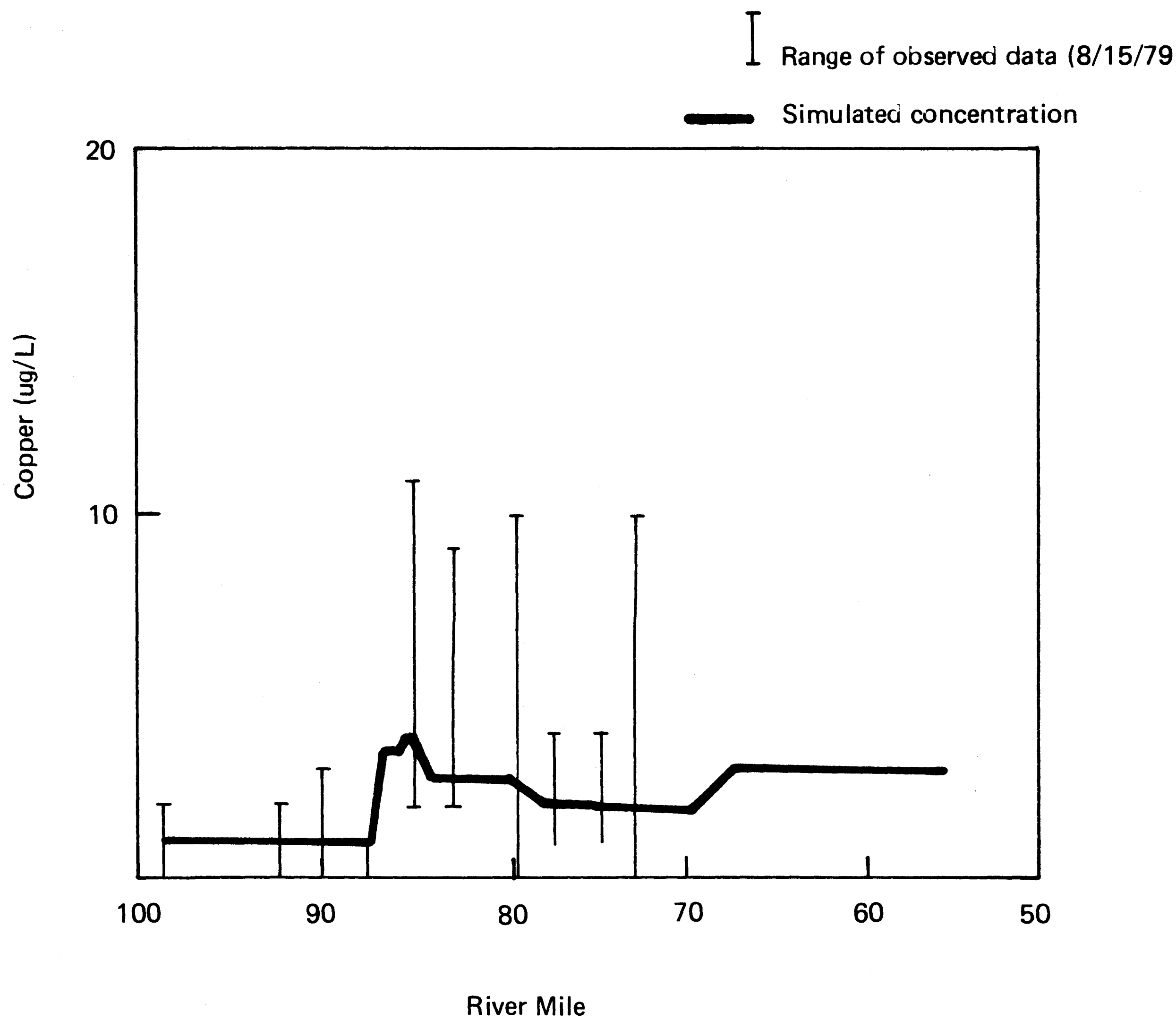


FIGURE 7-7
A Comparison of Simulated and Observed Copper Concentration Profiles in the Spokane River - on August 15, 1979.

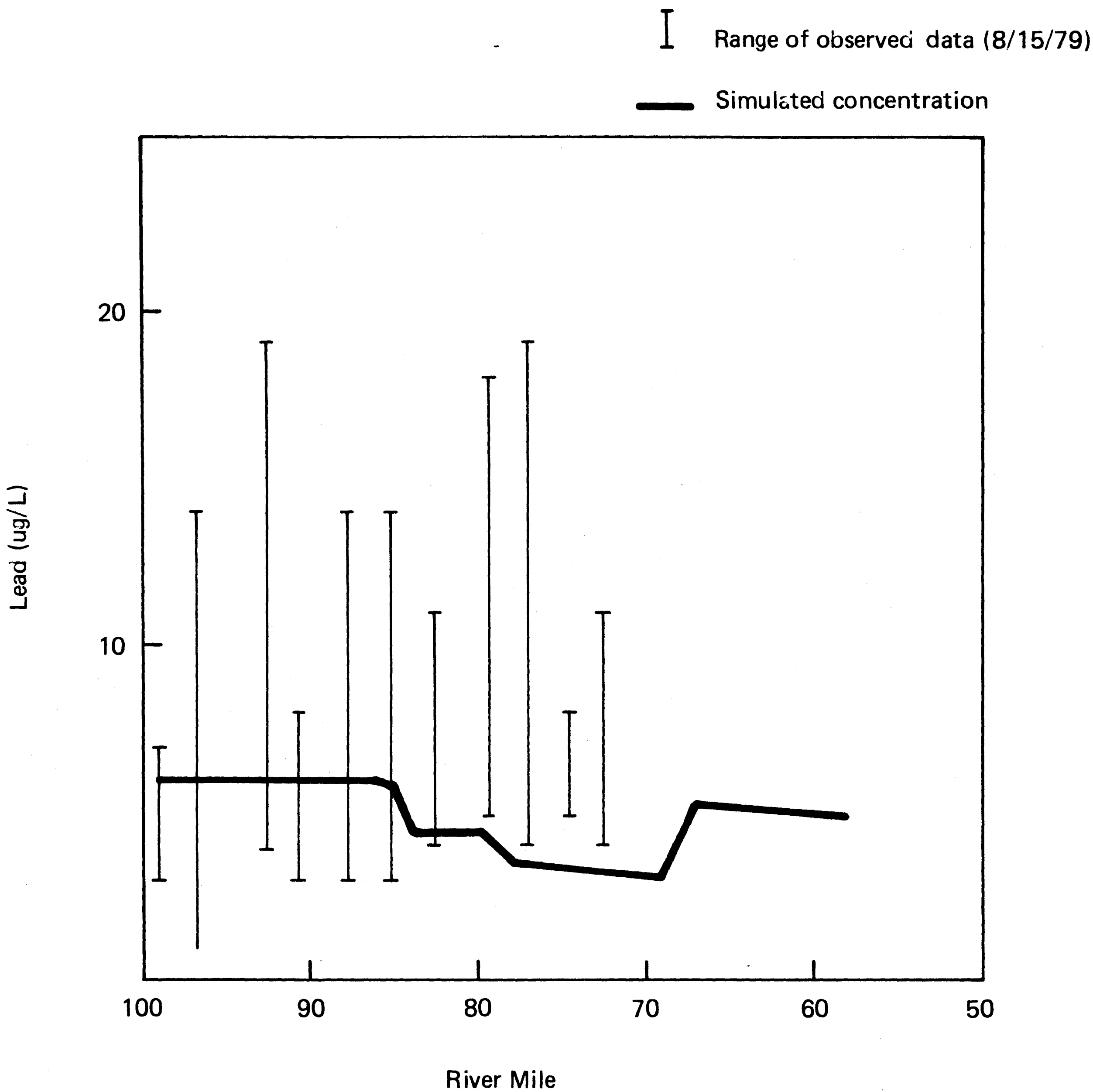


FIGURE 7-8
A Comparison of Simulated and Observed Lead Concentration Profiles in the Spokane River - on August 15, 199 1979.

dependent on temperature. The travel time is taken directly from the results of the DOE dye study (Lynn Singleton, personal communication). In the model, the stream reaeration rate, K2, is dependent on the stream velocity and depth. Both velocity and depth are derived from the rate of the streamflow and the width of the channel. The streamflow rate is computed as part of the flow balance and the channel width is measured from the USGS QUAD map for each specified station. Table 7-15 lists the values of the above parameters, and saturation-oxygen concentrations at each specified station in the Spokane River, for the August 15, 1980 low flow condition.

Figure 7-9 shows the dissolved oxygen concentration profiles in the Spokane River, simulated by URS/SRM model and observed from EPA survey. The modelled results fall within the envelope of the observed data. The dissolved oxygen concentration in the river could be driven primarily by the temperature and the inflow dissolved oxygen concentration from the aquifer. For lack of DO data from the aquifer, no attempt was made to quantify its effect on the river concentration. Another run was made with the future BOD loads (see Table 7-11), and the results show little marked difference in dissolved oxygen concentrations.

Analysis of the sensitivity of other deoxygenation parameters such as nitrogenous oxygen demand, sediment oxygen demand and algal respiration on the dissolved oxygen concentration in the river was not attempted for lack of local data and will require the use of QUAL-II model.

The modeling process for using QUAL-II model is the same as the URS/SRM model.

The effect of the deoxygenation parameters on the Long Lake will be much more severe during the summer lake stratification period as it is shown by the low hypolimnetic dissolved oxygen concentration level.

Battelle's Long Lake Reservoir Model can be used to model the cause-effect relationship. In past applications it has been used to relate the algal growth to the in-lake soluble phosphorus concentration and did not account for the phosphorus from the non-soluble pool. This should be modified to provide a better representation of the relationships between the incoming total-phosphorus loads and the algal biomass, and between the algal biomass and the hypolimnetic DO level.

It is likely that hypolimnetic DO is more sensitive to other deoxygenation loads carried by the river. To analyze this aspect, QUAL-II should be used first to compute all types of the deoxygenation loads carried by the river prior to entering into the lake. These loads will become inputs to the Battelle model to determine the resultant hypolimnetic DO level.

It is possible that the river carrying deoxygenation loads may be regressed against the hypolimnetic DO values through multi-variate regression analysis, such that a simple regression model (a multi-variate model) may be developed. Data used in the regression analysis can be either directly measured from the field or simulated from the QUAL-II model (deoxygenation parameters) and the Battelle model (hypolimnetic DO values). Additional data requirements for this modeling process are listed in Chapter 8.

TABLE 7-15

PARAMETERS USED IN THE URS/SRM MODEL TO SIMULATE DO PROFILE
IN THE SPOKANE RIVER - ON AUGUST 15, 1979 EVENT

STA (RM)	STATION NAME	TEMP DEG-C	KBOD (/DAY)	K2 (/DAY)	TPASS (HOUR)	VELOCITY (FT/SEC)	DEPTH (FT)	O2SAT (MG/L)
98.7	POST FALLS	20.7	0.00	0.00	0.00	0.00	0.	0.00
98.6	COEUR D'ALENE	20.7	.52	8.79	.07	1.96	2.	8.86
96.5	STATELINE BR	20.6	.51	12.75	1.64	1.96	1.	8.88
92.7	HARVARD RD	19.9	.50	15.51	4.48	1.96	1.	9.01
90.4	BARKER RD	20.2	.50	15.59	6.20	1.96	1.	8.95
87.8	SULLIVAN RD	20.2	.50	4.41	8.14	1.96	3.	8.95
87.1	RAILROAD BR	20.2	.50	5.53	8.66	1.98	2.	8.95
87.0	AQUIFER	16.2	.42	.20	8.93	.54	8.	9.72
86.1	WITHDRAWL	16.3	.42	.18	11.37	.54	8.	9.72
86.0	KAISER	16.7	.42	.20	11.64	.54	8.	9.72
85.3	TREND RD BR	16.3	.42	.18	13.54	.54	8.	9.72
84.0	AQUIFER	16.7	.43	.30	17.06	.54	6.	9.64
82.6	ARGONNE RD	17.1	.44	.26	20.86	.54	7.	9.56
82.3	MILLWOOD STP	17.3	.44	.26	21.67	.54	7.	9.51
79.8	UPRIVER DAM	17.5	.45	1.07	28.48	.54	3.	9.47
78.0	GREEN ST BR	16.5	.43	1.69	30.41	1.37	4.	9.68
76.8	MISSION ST	15.5	.41	2.64	31.69	1.37	3.	9.90
74.9	DIVISION ST BR	15.8	.41	2.65	33.72	1.37	3.	9.83
74.0	AQUIFER	16.0	.42	2.66	34.69	1.37	3.	9.79
73.4	SPOKANE	16.0	.44	2.16	35.86	1.37	3.	9.56
72.9	SPOKANE GAGE	17.1	.44	2.16	35.86	1.37	3.	9.56
72.4	HANGMAN CK	17.1	.44	4.09	36.40	1.37	2.	9.56
71.0	AQUIFER	17.1	.44	4.04	37.90	1.37	2.	9.56
69.8	FORT WRIGHT BR	17 1	.44	1.29	39.18	1.37	4.	9.56
69.7	AQUIFER	17.1	.44	2.54	39.29	1.37	3.	9.56
67.3	SPOKANE STP	17.1	.44	1.25	41.86	1.37	4.	9.56
67.0	HOLLYWOOD CSO	17.3	.44	2.53	42 18	1.37	3.	9.51
66.2	BOWL AND PITCHER	17.3	.44	2.01	43.03	1.37	3.	9.51
65.0	LAST RAPIDS	17.5	.45	1.78	44.32	1.37	4.	9.47
64.3	NW TERRACE	17.7	.45	.12	46.22	.54	11.	9.43
61.9	SEVEN MILE BR	17.8	.45	.25	52.74	.54	7.	9.41
58.1	NINE MILE DAM	18.1	.46	.59	63.06	.54	4.	9.35

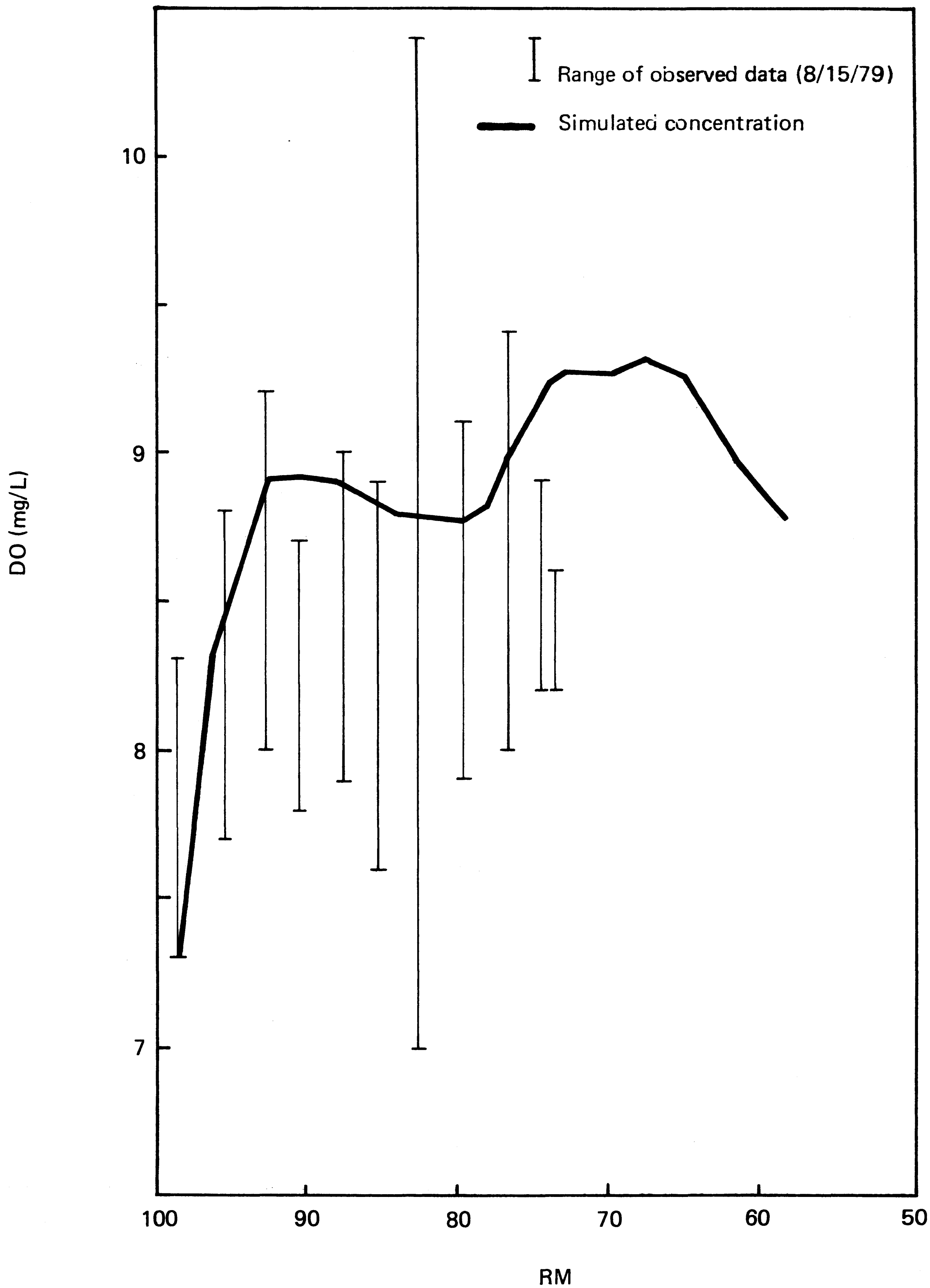


FIGURE 7-9
Comparison of Simulated and Observed DO Concentration Profiles in the Spokane River August 15, 1979

CHAPTER 8

INFORMATION NEEDS AND RECOMMENDATIONS

The purpose of this chapter is to define the technical tasks needed to provide the additional information previously identified as necessary to developing future wasteload allocations. Information needs are discussed in relation to: 1) identifying the water quality problems (Chapter 4) and 2) providing input data for the system model (Chapter 7). Table 8-1 summarizes the information needs by these two categories.

WATER QUALITY PROBLEM IDENTIFICATION

Specific water quality problem definitions are the basis for wasteload allocations. Items 1 through 4 are listed in Table 8-1 because better definitions of the specific problems in this system are needed for toxicants, fecal contamination, and river dissolved oxygen. An important component of problem definition is selection of criteria (Chapter 5). Toxicant criteria have been published by EPA and require further analysis for the Spokane River Basin System before being applied in a wasteload allocation.

Reduction of river fecal contamination is one of the major reasons for eliminating combined sewer overflows from the City of Spokane. Additional data are needed to define the effects of both CSOs and urban runoff on receiving water quality.

Low dissolved oxygen is a concern for the upper river (near the Idaho border) and below Long Lake dam; however, available data do not precisely define the frequency and severity of these problems. Further information is needed to define temporal and spatial effects on water quality conditions.

Aquatic macrophytes in Long Lake may be more effectively controlled by methods other than wasteload allocation. Further analysis is needed to define the problem and solutions since previous studies and available models do not address aquatic macrophytes.

SYSTEM MODEL INPUT DATA

Inputs needed for the system model used as a tool in the wasteload allocation include items 5 through 7 in Table 8-1. Item 5 lists data needed to improve the phosphorus/chlorophyll a model. Data are needed to improve the model including reservoir total phosphorus concentrations and sedimentation rates. Accurate data on existing loadings and concentrations are needed for the steady-state river model. Pollutant loading rates for aquifer and other non-point inputs, including urban runoff and combined sewer overflows, need to be quantified.

TABLE 8-1

INFORMATION NEEDS

Water Quality Problem	Additional Information Needs	Rationale
1. Toxicants in river and aquifer	- Determination of basin - specific criteria for river - Baseline data on sources, distribution, and fate	- Definition of specific problems needed as basis for allocation
2. Fecal contamination of river	- Baseline data on non-point sources (CSO's and urban runoff) and spatial and temporal effects on beneficial uses	- Definition of specific problems needed as basis for allocation
3. Low dissolved oxygen in upper river and below Long Lake	- Baseline data on causes and spatial and temporal effects on beneficial uses	- Definition of specific problems needed as basis for allocation
4. Aquatic macrophytes in Long Lake	- Baseline data on spatial and temporal effects on beneficial uses and control measures	- Definition of specific problems needed as basis for control
Input Data for System Model		
5. Phosphorus/Chlorophyll a Model - Long Lake	- Define effects of trace metal reduction on algal production	- Define "side-effects" of toxicant control
	- Define sedimentation rate of total phosphorus	Improve accuracy of sensitive model input
	- Define total phosphorus concentrations in Long Lake	Improve accuracy of sensitive model input

TABLE 8-1 (CONT'D)

INFORMATION NEEDS

Water Quality Problem	Additional Information Needs	Rationale
6. Steady-state Model-River	- Quantitative relationships (flow and concentration) between aquifer and river needed on seasonal basis	- Allocation should consider these relationships to be effective and to ensure protection of the aquifer
	- Quantitative relationships for non-point sources' pollutant load contributions to river needed on single event, seasonal, and annual basis. Define changes in concentrations from point of discharge to input into Long Lake	- Allocation during low flow should consider these relationships to be effective
7. Dissolved Oxygen Model - Long Lake	- Quantitative relationships between hypolimnetic dissolved oxygen levels and the effects of river flow, reservoir circulations, and sediment oxygen demand	- BOD allocation should consider these relationships to be effective

EXISTING AND RECOMMENDED STUDIES

Four monitoring studies of the Spokane River/Long Lake system are in various stages of completion as summarized in Figure 8-1. Two water quality monitoring studies are being conducted for the Spokane River and Long Lake by Washington State University (WSU) and Eastern Washington University (EWU) respectively. Two synoptic water quality studies are in progress; one monitoring the Spokane combined sewer overflows (City of Spokane/DOE) and the other focusing on water quality conditions in the Spokane River (EPA/DOE). The following discussion describes and prioritizes recommended studies to improve the wasteload allocation methodology. Some of these recommendations may be incorporated into existing studies.

Table 8-2 summarizes the priority and approximate degree of effort for collecting the information listed in Table 8-1. The following discussion defines the objective and scope of each of these studies. Effective coordination of existing and proposed new studies is needed so that resultant data can be jointly used for the allocation methodology. Logistically, coordination of several monitoring efforts is difficult; however, unless the Spokane River system is monitored to determine cause and effect relationships, development of justifiable allocations will be difficult to accomplish.

I. PHOSPHORUS ALLOCATION

I a. Routine Survey

Objective - The objective is to provide additional Long Lake data to improve the phosphorus/chlorophyll *a* model for wasteload allocation. Specifically, the reservoir phosphorus sedimentation rate and water column total phosphorus concentrations would be defined.

Scope - The existing EWU study would be extended to coincide with the termination date of the WSU study. A recommended modification of the scope of the EWU/DOE Memorandum of Agreement included in Appendix B is measurement of total phosphorus and total soluble phosphorus at reservoir stations.

Another scope addition would be the determination of *in situ* phosphorus sedimentation rates during this monitoring period. This will be accomplished by placement of sediment traps at selected reservoir locations.

I.b. Algal Assay

Objective - The objective is to predict quantitatively the long-term effect of trace metal loading reductions on the indigenous phytoplankton of Long Lake. A hypothesis stated by Soltero and Nichols (1980) suggests that blue-green algal blooms may be due to lower trace metal concentrations in the reservoir. If true, this hypothesis may have significant impact on phosphorus control and compliance with the chlorophyll *a* criterion selected.

TABLE 8-2

PRIORITY AND DEGREE OF EFFORT
FOR RECOMMENDED STUDIES

Study	Type[1]	Priority[2]	Approximate Degree of Effort: Labor Days[4]	Approximate Degree of Effort: Number of Samples	Status[3]
I. Phosphorus Allocation					
a. Routine surveys	F, A	M	140	550	E
b. Algal Assay	F	L	210	200	N
II. Toxicant Allocation					
a. Criteria refinement	F	H	210	100	N
b. Routine surveys	F	M	-[5]	400	E
c. Synoptic surveys	F,A	H	128	100	N,E
III. BOD Allocation					
a. Synoptic survey	F,A	H	15[5]	180	N
b. Routine surveys	F	M	155[5,6]	-	E
IV. Other Studies					
a. Macrophyte control	F	*	120	60	N
b. Fecal contamination	F	*	-(7)	50	E

Footnotes:

(1) F = Field/Lab; A = Analysis (modeling)
(2) H = high; study necessary to provide technically valid basis for wasteload allocation
M = medium; study would increase confidence for appropriate allocation
L = low; study would provide further understanding of system and possibly explain deviations from methodology predictions
* - Allocation may be inappropriate for control
(3) E = can be incorporated into existing studies, represents effort not included in present contracts (see Appendix B.
N = new study
(4) - Days = total number of labor days estimated to conduct work. Provided as an approximate estimate for decision basis only.
(5) - Writing/sampling labor is covered under Ia
(6) - Only pertains to fish sampling
(7) - Labor is covered under IIc

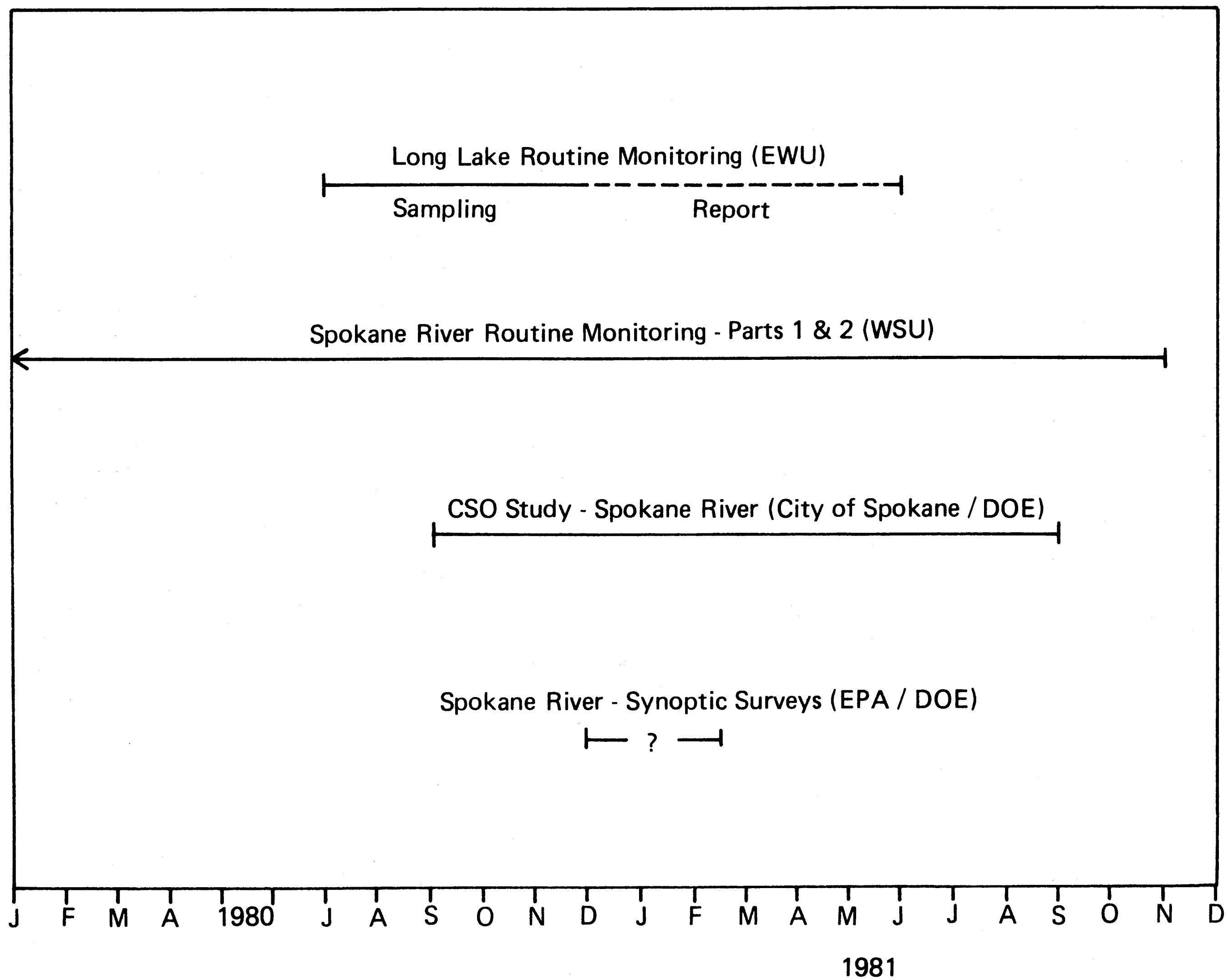


FIGURE 8-1
Current Data Collection Programs for Spokane River/ Long Lake System

Scope - The scope would be to conduct a series of laboratory algal enrichment experiments on reservoir water samples covering a wide range of trace metal concentrations.

Algal assays previously conducted in the Spokane River used receiving water samples and a single species of algae as a test organism. This type of assay, described by Miller, et al. (1978) and APHA (1975), should be used so that the results of the proposed studies can be compared to those of previous studies.

Because of the scientific disagreement over which algal method should be used and because of the economic consequences of decisions resulting from the outcome of this study, it is recommended that the method of Shapiro (1978, personal communication), which uses the indigenous algal community, be used as a refereed assay for comparative purposes (Appendix E).

Specifically, this systematic program of algal assays would evaluate:

1. The quantitative effect of various trace metal loading reductions on the abundance, biomass, and species composition of the indigenous phytoplankton of Long Lake.

2. The roles of nitrogen and phosphorus in controlling algal growth.

II. TOXICANT ALLOCATION

IIa. Criteria refinement

Objective - The objective is to develop basin-specific toxicant criteria for use in the wasteload allocation methodology. Existing trace metal concentrations in the Spokane River are generally in excess of EPA criteria (Chapter 5); however, aquatic organisms in the river do not appear to be affected. In light of the possible need for control of toxicants, basin-specific toxicant criteria will be developed for selected trace metals from EPA's priority pollutant list. With respect to organic chemical toxicants the applicability of current EPA criteria should be evaluated after better baseline data for the Spokane River basin are collected (See IIb. and c.).

Scope - A series of aquatic organism bioassays should be conducted in acordance with EPA acute toxicity methods (Peltier, 1978); however, instead of effluent testing, ambient river water with known additions of select trace metals will be tested. The bioassay will consist of the following:

1. Facilities - an on-site, flow-through bioassay apparatus is recommended.

2. Test Organisms - organisms indigenous to the Spokane River system are recommended. Rainbow trout and the mayfly, Baetis sp., are recommended test organisms.

3. Dilution Water - the flow-through system should use Spokane River water.

4. Trace Metals Evaluated - the trace metals zinc, copper, lead, cadmium and mercury are recommended for evaluation.

5. Test results - the results will establish criteria for acute toxicant effects. Chronic effects for indigenous organisms will be investigated in II.c.

IIb. Routine Surveys

Objective - The objective of the routine surveys is to continue to develop a data base from which water quality trends can be determined. Existing monitoring programs should be continued. The number of monitoring stations in the Spokane River should be increased to evaluate water quality up to the outlet at Coeur d'Alene Lake, and the coverage needs to be expanded to include trace metals.

Scope - The existing monitoring program (Appendix B) has been modified to include the measurement of both total and dissolved zinc, copper, lead, cadmium, and mercury, as well as the major cations and anions.

IIc. Synoptic surveys

Three synoptic surveys are proposed: 1) a trace metal and mutagenicity sediment survey; 2) a CSO evaluation, and 3) a biological survey for an assessment of possible chronic effects of toxicants. Each will be summarized separately.

Trace Metal and Sediment Survey Objective, - The objective is to analyze the river system sediments for evidence of trace metal contamination from various point and non-point sources and for evidence of mutagenic activity. The survey rationale is based on the assumption that sediments will reveal the long-term impacts of source loading better than water column quality measurements (Rickert, et al., 1980).

Scope - The scope for the trace metal component follows Rickert et al. (1980), who conducted a similar study of the Willamette River, Oregon. The bottom sediments associated with major urban runoff, CSO, STP, industrial, and control sites will be sampled under stable, low-flow conditions. Sediments will be fractionated to obtain fine-grained materials prior to trace metal analyses. Parameters measured will include Zn, Cu, Pb, Cd, and Hg. Data analysis will be conducted as described in Velz (1970, p. 522-542) to distinguish between polluted and unpolluted conditions. Sediment samples also will be analyzed for evidence of organic chemical contamination as indicated by mutagenic activity by using the Ames Test (Ames, 1975). This testing will be similar to that conducted in a study on the Buffalo River, New York (Black et al., 1980). Sediment samples are collected and fractionated by chemical extraction. The Ames Test is then employed by exposing special strains of *Salmonella typhimurium* to the sediment extracts and observing the numbers of mutations showing reversion to the wild type. The development and use of the test has shown a strong correlation between the mutations included in the *Salmonella* and the potency of the same chemicals in producing cancer in higher organisms (McCann and Ames, 1976).

CSO evaluation objective - The objective is to determine the toxicant effects of CSO's on the Spokane River through a synoptic survey, incorporating the results into the river steady-state model.

Scope - The scope is similar to that proposed by DOE for the Hollywood and Cochran Street CSO's. The parametric coverage will be modified to include both total and dissolved Zn, Cu, Pb, Cd and Hg. In addition, the river sampling sites will include sites measured in recent EPA synoptic surveys as well as source monitoring of an urban runoff discharge site. This will allow estimates of the actual differences in the water quality effects of urban runoff versus CSO discharges. This additional analysis will aid the determination of cost-effectiveness of sewer separation.

Objective - Biological chronic effect assessment - The objective will be to determine if the indigenous fish of the Spokane River demonstrate chronic effects of toxicant pollution.

Scope - The scope is to obtain fish sampled in the on-going biological surveys for histopathological examination. Primary emphasis will be placed on detecting abnormalities of fish organs due to chronic exposure to trace metals, especially zinc. Target fish should be chosen on the basis of 1) wide distribution in the system, and 2) life history stages directly or indirectly associated with the sediments.

III. BOD ALLOCATION

IIIa. Routine survey

Objective - The objective is to provide an analysis of the effects of low dissolved oxygen on the beneficial uses of the Spokane River, both in the upper reaches and below the Long Lake Dam.

Scope - Data for the upper river will be reviewed to determine the spatial and temporal distribution of fish in relation to documented oxygen deficiency problems. Additional fish sampling will be conducted in the river between the City of Spokane and Long Lake and below Long Lake Dam, and in Long Lake, to determine spatial and temporal changes in abundance, species composition and biomass of the fish community and this will be related to dissolved oxygen conditions. Fish habitat will also be described and characterized. The effects of flow fluctuation on dissolved oxygen concentrations and fish habitat will be determined by routine sampling.

IIIb. Synoptic survey

Objective - The objective is to determine the cause of oxygen deficits in the upper Spokane River and below Long Lake Dam.

Scope - Synoptic surveys will be conducted in each stream reach to obtain data to use in the river steady-state model and the Battelle lake model. Emphasis will be placed on obtaining data for direct calculation of required loading parameters and model coefficients. A similar approach was conducted by USGS on the Willamette River (Rickert, et al., 1976; Hines, et al., 1977). Deoxygenation factors to be monitored include: nitrification, carbonaceous oxygen demand, and benthic demand. The benthic demand is defined by Rickert, et al. (1976) as 1) sediment "in-place" demand, 2) excess algal respiration, and 3) "unknown" sources such as sewer overflows and sediment resuspension.

Each stream reach will be sampled every four hours for a three-day period. Parametric coverage will include flow, D.O. temperature, BOD (ultimate), ammonia, and nitrate-nitrite. Estimates of deoxygenation, reaeration and nitrification coefficients will be determined for each sampling site. Estimates of benthic oxygen demand within Long Lake will be obtained by placement of benthic respirometers.

IV. OTHER STUDIES

IV.a. Macrophyte control

Objective - The objectives are to document the spatial and temporal extent of macrophyte growth in Long Lake, determine where problem conditions exist, and develop a control plan for implementation.

Scope - The scope includes field surveys to monitor the abundance, biomass, and species composition of macrophytes in Long Lake over two consecutive growth seasons. Interviews would be conducted with lake users to define specifically the location of areas needing control.

IVb. Fecal contamination

Objective - The objective is to determine the cause of river fecal contamination and evaluate the specific effects on beneficial uses of the Spokane River.

Scope - The scope of the synoptic CSO, urban runoff survey described in II c. will be adequate to determine the cause of river fecal contamination. Additional fecal coliform data, however, must be collected at swimming beaches and other water contact recreation sites, as part of the river sampling. Figure E-1, Appendix E shows the locations.

CHAPTER 9

WASTELOAD ALLOCATION PROCEDURE

This chapter describes the wasteload allocation procedure developed for the Spokane River Basin. It describes how limits for particular waste constituents are established and a system for assigning load reductions among the various contributing sources. After the general procedure is described briefly, alternative allocation schemes are defined and evaluated. The recommended allocation method is illustrated by the development of an example dealing specifically with phosphorus. How to develop allocations for other parameters is subsequently discussed.

OVERVIEW OF THE PROCEDURE

The major steps comprising the wasteload allocation procedure are summarized in Figure 9-1. It is intended that these steps be followed when a new allocation is developed or an existing one is revised. An explanation of what each of these steps involves follows.

1. Define the water resource system

Define or revise the definition of the water resource system, including surface water system boundaries, groundwater system, groundwater-surface water interchange, waste sources, (type, location) water withdrawals and related system information.

2. Identify beneficial water uses requiring water quality management

Describe the beneficial uses of the water resource system, including type, location, occurrence and frequency; or update existing description.

3. Define water quality criteria to protect beneficial uses

It is necessary to determine the criterion or value of a selected parameter which represents an acceptable water quality condition. Criteria will be either existing water quality standards or some other value which has been shown to be appropriate to the Spokane River system. For seasonal problems (e.g. algal growth) the season during which the specified value is to be maintained must also be defined.

Public input, vital to development of an acceptable allocation plan, is particularly important in selecting criteria and in defining the time period when they should be maintained.

4. Characterize existing conditions

Available data on existing conditions are analyzed to characterize the existing conditions in the Spokane River/Aquifer system. After the initial allocation, periodic updates will be required.

1 Define The Water Resource System

↓

2 Identify Beneficial Uses

↓

3 Define criteria to protect beneficial uses

- State WQ Standards
- Criteria specific to Spokane system

↓

4 Characterize existing conditions

↓

5 Identify problems

↓

6 Evaluate cause/effect data

↓

7 Characterize waste sources

↓

8 Develop or refine a cause/ effect model

↓

9 Set load reductions for system or segments

↓

10 Select allocation scheme

↓

11 Set load reductions for individual sources

↓

12 Simulate effect of load reductions

- If criteria met, issue NPDES permits
- If not met, set new load reductions

FIGURE 9-1
The Wasteload Allocation Process

5. Identify water quality problems

The next step of the allocation procedure is to compare existing and projected conditions to criteria to identify existing or potential problems for each water quality parameter selected. Seasonality of the problem(s) is also identified at this time.

6. Evaluate cause/effect data

The next step is to review and assess available data to determine whether data are sufficient to define adequately a cause/effect relationship or to improve a previously developed relationship.

7. Characterize sources

Current and projected loads from all sources of waste constituents to be allocated should be updated or developed. This will include both loads carried by the river from Idaho and all point and nonpoint discharges within the state.

8. Refine or develop the water quality simulation model(s)

When sufficient data are available, the water quality simulation model(s) should be refined (calibrated and verified) or a new model developed for assessing the effects of specific waste load reduction and allocation schemes.

9. Set waste load reductions for system or segments

The next step is to use the simulation model(s) to establish acceptable waste loads for each segment of the river or for the river system as a whole.

10. Select allocation scheme

Alternative schemes for allocating loads among the contributing sources are refined or defined. These schemes are evaluated with respect to administrative ease, flexibility, equity, cost, effectiveness, and the best scheme is selected.

11. Set waste load reductions for individual waste sources

The next step is to specify the waste load limits for each discharge within each segment of the river, i.e. set allocations. The method for developing these allocations is discussed in the following section.

12. Simulate effect of load reductions

Allocated loads from each discharger are simulated using the system model to determine resultant water quality effects and these are compared to the criteria. If there is compliance, these loads can become the basis for NPDES permit requirements. If not, another set of load reductions is developed and the evaluation is repeated.

PHOSPHORUS ALLOCATION: AN EXAMPLE

The procedure described is illustrated by development of an example for allocating phosphorus loads discharged to the Spokane River system. Much of the information needed for accomplishing the steps identified has been presented in previous chapters.

Preliminary Steps (Steps 1-8)

A definition of the Spokane River system was presented in Chapter 2. Beneficial uses are discussed in Chapter 3. Criteria applicable to the Spokane System are identified in Chapter 5. A standard for mean seasonal chlorophyll a concentration for Long Lake does not exist. The choice of a criterion is subject to judgement as to what is a reasonable value with respect to maintaining an acceptable level of water quality, as are the associated requirements and costs for controlling phosphorus discharges to the Spokane River. For this example, a value of 10 ug/l was used; other values including 8, 12, and 15 are also examined. The rationale for use of 10 ug/l is discussed in Chapter 6 and it is basically related to turbidity and hence water clarity and recognition by others (Ciecka, et al., 1980) that 10 ug/l or greater is an indication that a lake is eutrophic.

Existing conditions in the Spokane River System are discussed in Chapter 4. Comparison of these conditions to the criteria, as described in Chapter 5, provides the basis for identification of problems. A number of current and potential problems, including excessive levels of heavy metals, BOD and coliforms as well as phosphorus, were identified. Available cause/effect information for these problems was evaluated. (See Chapter 6, especially Table 6-1.)

This evaluation revealed that cause/effect data are insufficient to carry out an allocation of heavy metals or BOD. Because adequate cause/effect data for the phosphorus/chlorophyll a relationship in the Spokane River-Long Lake system are available, reduction of phosphorus discharges was selected as the example for illustrating the allocation procedure. Information about sources is provided in Chapters 4 and 7. Chapter 7 also discusses the system model developed for use in the allocation.

Set Load Reductions for the System (Step 9)

The phosphorus/chlorophyll a relationship that provides a basis for setting phosphorus limitations relates the mean chlorophyll a concentration in Long Lake from June through November to the areal phosphorus loading rate during the same season.

The areal loading rate is defined as the actual phosphorus load in the inflow to the reservoir during the defined season divided by the surface area of the reservoir times (1-R) divided by the flushing rate during the season. The phosphorus retention coefficient, R, is the portion of influent phosphorus that is retained within the reservoir. The flushing rate is determined by seasonal stream flow.

Because the areal loading rate varies with streamflow and the retention coefficient, appropriate values of each must be selected to determine the acceptable loading rate. Figure 9-2 shows the relationship between the

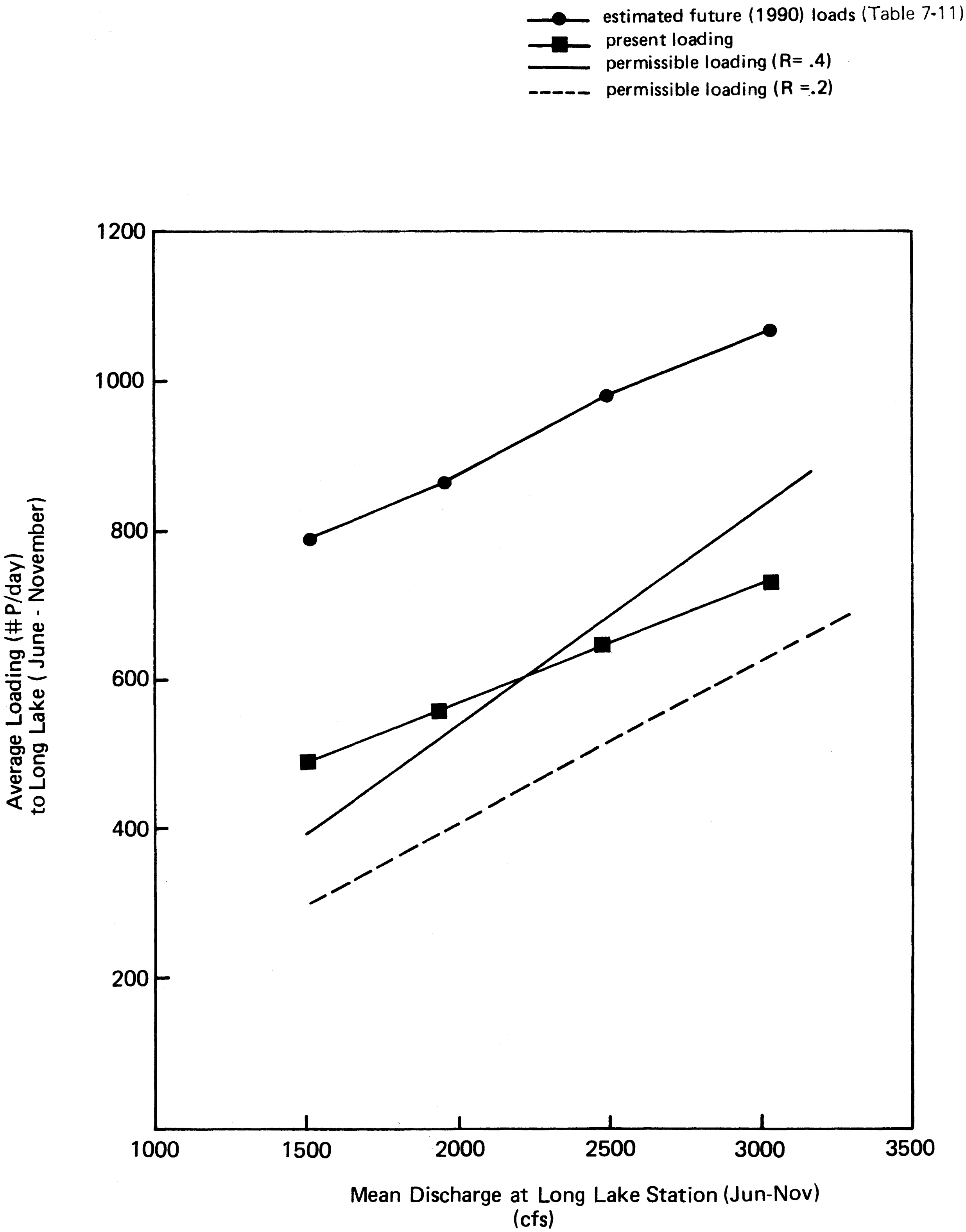


FIGURE 9-2
Variation of Phosphorus Loading
with Flow Rate

permissible loading rates corresponding to two values of R and streamflow. [Records, provided by Washington Water Power (Clegg, 1980), indicate that stream flow into the reservoir differs little from outflow; therefore, USGS records for Long Lake station downstream from the dam were used.]. The actual loading rate and the loading rate projected to occur in 1990 (assuming AWT at the Spokane STP) are also shown in Figure 9-2.

Comparison of the projected loading rate to the permissible loading rate shows that the latter increases faster. The difference between projected and permissible loading at any specific streamflow is the load reduction that would be needed to meet the criterion. This required load reduction is plotted in Figure 9-3 as a function of recurrence interval. The recurrence intervals correspond to the streamflows shown in Figure 9-2 and were calculated by averaging the June to November streamflows (see Appendix G for design flow calculations and flow statistics at the system boundaries.)

To minimize the risk of exceeding the selected criterion, a low flow should be selected as the design flow. The additional cost of greater safety is quite small, as shown in Figure 9-3. For example, for R = .2, selection of a streamflow with a recurrence interval of 20 years results in a load reduction requirement only seven pounds/day greater than selecting one with a recurrence interval of 10 years. For development of the example, a 20-year recurrence interval design flow was selected. This flow corresponds to flows of 1600 cfs at Post Falls and 2535 cfs at Long Lake. Tables 9-1 to 9-4 show the variation of permissible phosphorus loads as a function of design flow and selected chl a criteria.

Phosphorus retention also has a significant influence on the permissible load. Data for Long Lake (Soltero, 1980) indicate that the fraction retained varies from about 0.23 to 0.44. (See Appendix B.) R can also be calculated from the sedimentation rate and the number of exchanges (Uttormark and Hutchins, 1980); for the selected design flow, a value of 0.2 is obtained. This value is in the low end of the observed range for Long Lake, and was observed with flow rates similar to the design flow. This low R value also reflects reduced settling effect due to advanced treatment of the City of Spokane discharges.

To provide an equitable basis for phosphorus load allocation, the required reduction is based on the difference between the permissible load and the load that would occur if all STPs were operating at a secondary treatment level, as required by current regulations. Expected loads under these conditions are shown in Table 9-5, which also shows present conditions (including AWT at Spokane) for comparison. To determine the required load reduction, the loss to the aquifer and the permissible load (which is shown in Table 9-6) should be subtracted from the total system load. Loss to the aquifer varies with phosphorus concentration in the river and is estimated to be 37 lb/day currently and 50 lb/day by 1990 based on phosphorus removal in the system. To provide a margin of safety as required by law and simplify calculations, the loss of phosphorus to the aquifer is dropped. Thus, since the system load is estimated to be 2816 pounds/day for the year 1990 and the permissible load is 466 lb/day, a reduction of the load by 2350 pounds/day, 83 percent is necessary.

TABLE 9-1

MEAN PERMISSIBLE PHOSPHORUS LOADING
(lb-P/day) for chl a Criterion = 8 ug/l

Design Flow	Permissible Loading* lb-P/day for	
Q_s	R = 0.2	R = 0.4
2500	227	303
3000	273	364
4000	364	486
6000	546	728
10000	910	1213

* According to Soltero's (Dillon's) Model

TABLE 9-2

MEAN PERMISSIBLE PHOSPHORUS LOADING
(lb-P/day) for Chl a Criterion = 10 ug/l

Design Flow	Permissible Loading* lb-P/day for	
Q_s	R = 0.2	R = 0.4
2500	459	612
3000	552	736
4000	736	981
6000	1103	1470
10000	1839	2451

* According to Soltero's (Dillon's) Model

TABLE 9-3

MEAN PERMISSIBLE PHOSPHORUS LOADING
(lb-P/day) for chl a Criterion = 12 ug/l

Design Flow	Permissible Loading* lb-P/day for	
Q_s	R = 0.2	R = 0.4
2500	691	922
3000	831	1108
4000	1108	1477
6000	1660	2213
10000	2767	3690

* According to Soltero's (Dillon's) Model

TABLE 9-4

MEAN PERMISSIBLE PHOSPHORUS LOADING
(lb-P/day) for chl a Criterion = 15 ug/l

Design Flow	Permissible Loading* lb-P/day for	
Q_s	R = 0.2	R = 0.4
2500	1039	1386
3000	1249	1665
4000	1665	2220
6000	2495	3327
10000	4161	5547

* According to Soltero's (Dillon's) Model

TABLE 9-5

ESTIMATED PHOSPHORUS LOADS DISCHARGED TO THE SPOKANE RIVER

Source	1980[1]	%	1990[2]	%
Idaho Inflow	121	6.6	121	4.3
Idaho STPs	126	6.9	312	11.1
Liberty Lake STP	0	0	106	3.8
Spokane Ind. Park	17	0.9	17	0.6
Kaiser (net)	0	0	0	0
Spokane Valley Runoff	13	0.7	16	0.6
Inland Empire	14	0.8	14	0.5
Millwood STP	9	0.5	9	0.3
City CSO	26	1.5	0	0.0
Hangman Cr	33	1.8	33	1.2
Spokane STP	1375 (182)	75.4	2068	73.4
Spokane Urban Runoff	24	1.3	48	1.7
NW Terrace STP	8	0.4	8	0.3
N. Spokane Runoff	4	0.2	9	0.3
Little Spokane River	49	2.7	49	1.7
Groundwater Inflow	6	0.3	6	0.2
Total System Load	1825		2816	

Note: Mean values for June-November period for a 20 year low flow.

(1) Existing loads (lbs-P/day) with secondary treatment at Spokane STP, value in parentheses denotes the results of phosphorus removal at AWT.

(2) Projected loads (lbs-P/day), with secondary treatment at all STPs

TABLE 9-6

PERMISSIBLE PHOSPHORUS LOADS TO LONG LAKE FOR
10 UG/L CHLOROPHYLL A CRITERION

Recurrence Interval (Years)	$Q_{Long\ Lake}$ (cfs)	$Q_{Post\ Fall}$ (1) (cfs)	$Q_{Hangman\ Creek}$ (2) (cfs)	Q_{LSR} (3) (cfs)	Permissible Load (lb-P/day)
5	3226	2100	30	418	593
10	2644	1700	17	382	487
20	2535	1600	14	380	466

(1) With the total-P concentration = 0.014 mg/l.

(2) With the total-P concentration = 0.440 mg/l.

(3) With the total-P concentration = 0.024 mg/l.

Table 9-7 provides a basis for obtaining different permissible phosphorus loads as a function of the chlorophyll a criteria selected and the model (Soltero, Dillon or Vollenweider) used to compute the relationship. Figure 9-4 is a plot of permissible P load vs chlorophyll a using the Soltero/Dillon model.

Select Allocation Scheme (Step 10)

Several alternative schemes for making the allocations required in steps 5 and 6 were evaluated. These alternatives included the following:

A. Uniform Reduction - all point and non-point dischargers are required to reduce the wasteloads in proportion to their contribution to the system. For example, if an 83 percent reduction in loading to Long Lake is required, a discharger currently discharging Y must reduce his discharge to (1-.83)Y.

B. Selected Sources - an analysis of the sensitivity of the system (or segment) water quality to loads from all sources is used to select those sources that have the greatest effect on the system. The criterion (percent contribution greater than a designated value) must be set at a reasonable level. The level must include enough sources so that the required system load reduction can be feasibly made, but should exclude sources that have only a minor effect or cannot be controlled reliably (e.g., groundwater inflow).

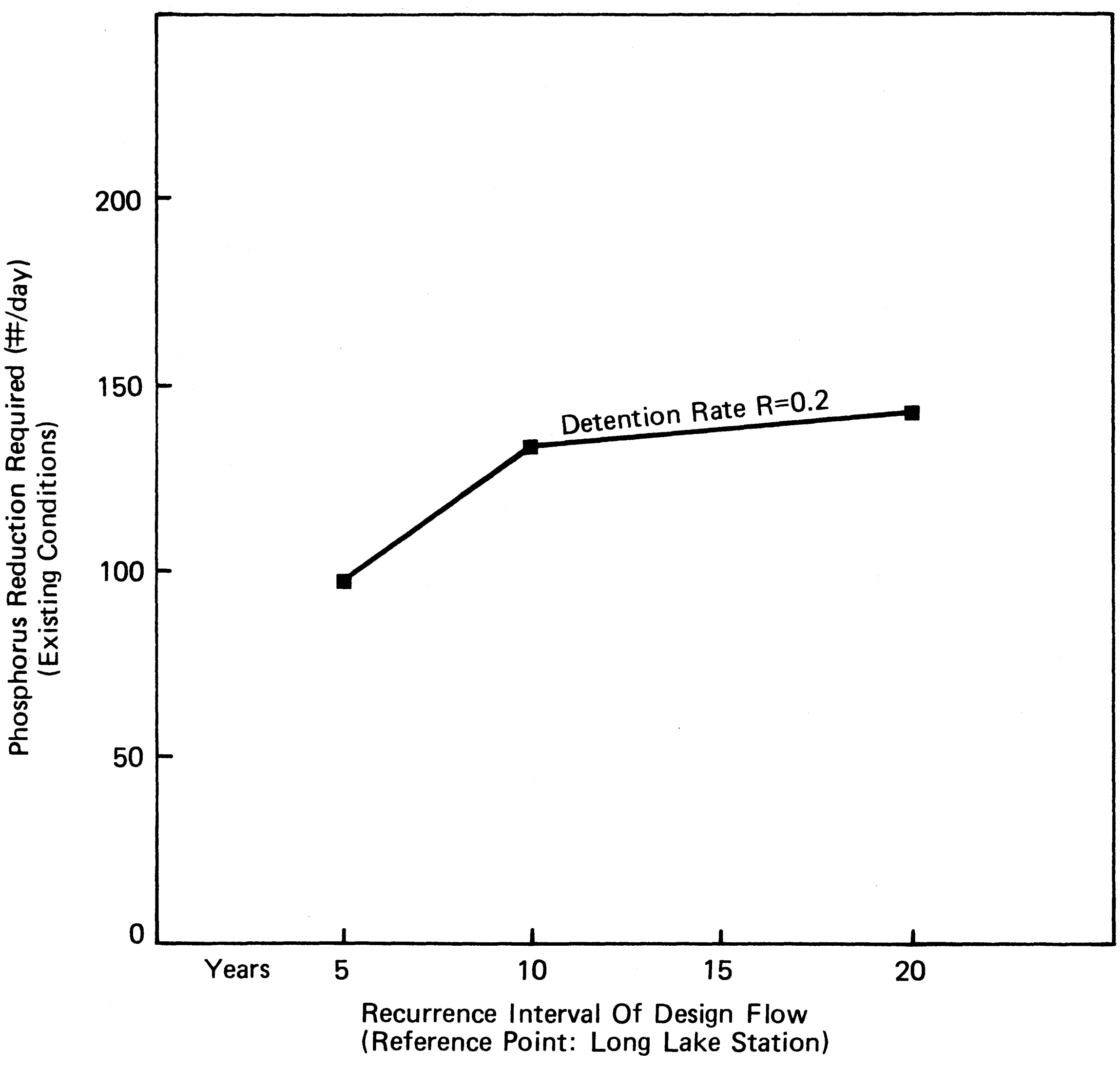


FIGURE 9-3
Required phosphorus reduction in Spokane River/Long Lake System vs. recurrence interval of design flow

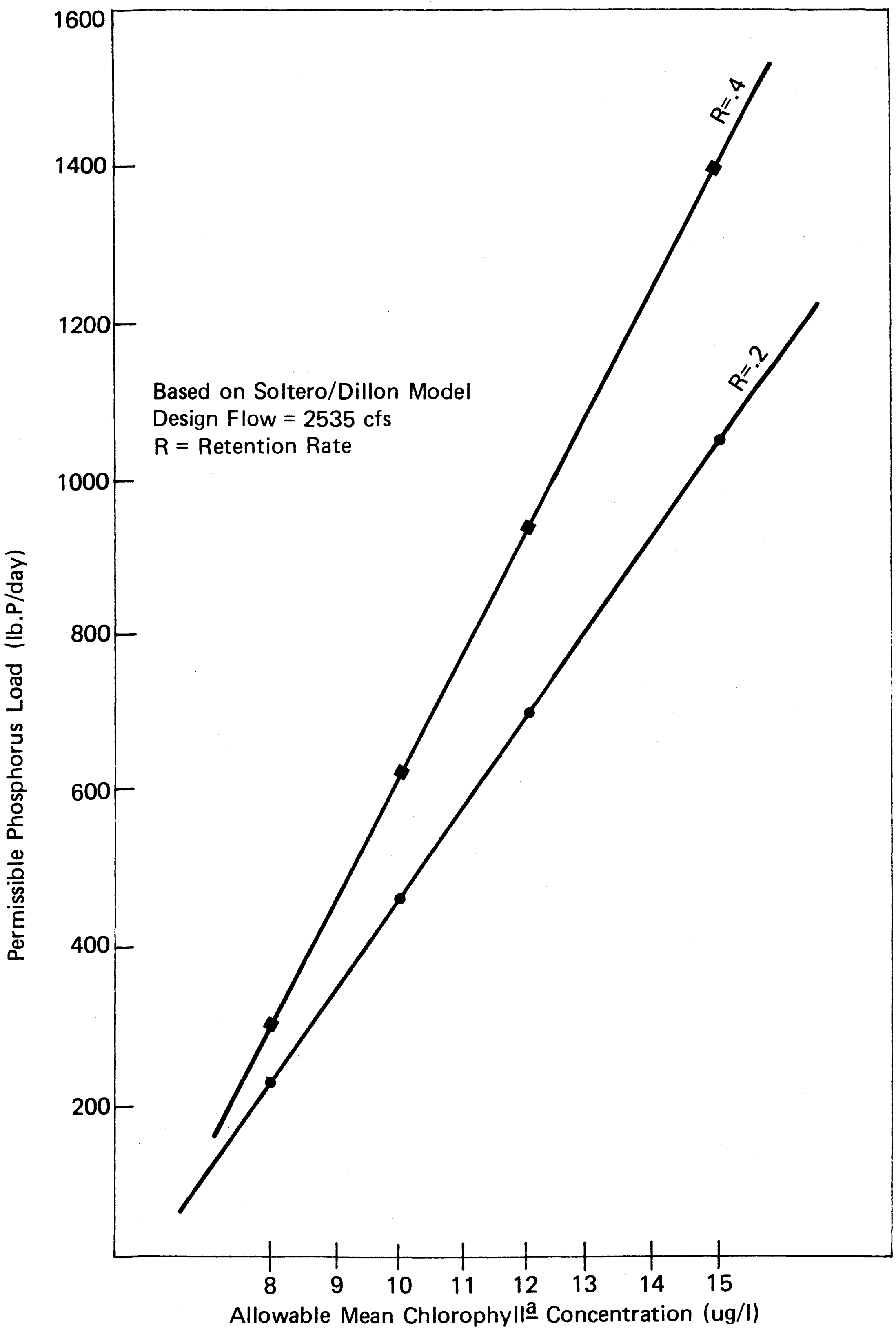


FIGURE 9-4
Permissible phosphorus load versus mean chlorophyll[a] concentration

TABLE 9-7

RANGE OF PERMISSIBLE LOADS BASED ON SOLTERO'S/DILLON'S AND VOLLENWEIDER'S MODELS FOR ALTERNATIVE CHLOROPHYLL A CRITERIA

Chlorophyll a criteria	Permissible Load							
	Soltero's/Dillon's Model					Vollenweider's Model		
		R = 0.2		R = 0.4				
	Lp_d	L		L		Lp_v	L	
ug/l	g-P/m^2	g-P/m^2	#-P/day	g-P/m^2	#-P/day	g-P/m^3	g-P/m^2	#-P/day
8	.1974	.918	230	1.164	292	.0137	1.133	284
10	.3989	1.855	466	2.478	622	.0245	2.025	508
12	.6004	2.793	701	3.729	936	.0395	3.265	820
15	.9027	4.199	1054	5.607	1407	.0707	5.845	1467

* Based on design flow:

Q_s = 2535 cfs, 95 percent exceedance level

Conversion factor: g-P/m^2 x 251 = lb-P/day (183 days in a growth season, June to November)

In general, each of the selected sources would be required to reduce its load in proportion to its contribution to the total load. Thus, if four percent were used as the criterion for 1990 (see Table 9-5), the Idaho STPs share of the reduction would be 11.1 percent ÷ (11.1 + 73.4 + 4.3) = 12.5 percent, which corresponds to 293 lb-P/day for a permissible load of 466 lb-p/day. (Note: Because the Idaho sources are treated as a single source at the Washington border, the total load exceeds the cut-off criterion.) Feasibility of making reductions is also considered. For instance, requiring more than 30 percent removal for urban runoff appears to be impractical (i.e., measures such as two vacuum sweeps would probably be needed and might not be successful).

Some equitable cost-sharing arrangement could be devised so that the sources selected do not bear a disproportionate share of the cost burden.

C. Least Cost - Cost functions (including annualized capital costs plus operation and maintenance (O & M costs) for reduction of wasteloads from each source are used to determine how the required reduction can be accomplished at least cost.

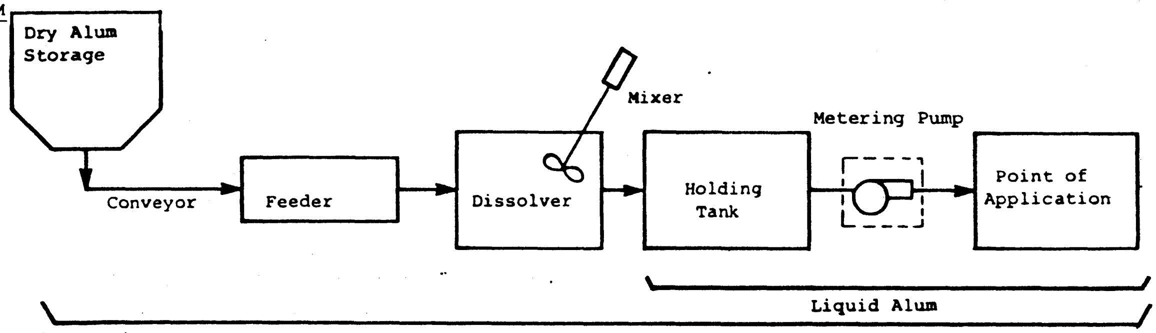
A typical STP cost function for phosphorus removal by alum addition is shown in Figure 9-5. Detailed characteristics, proposed modifications, and required removal level would be needed to generate enough cost separation to make an allocation. Thus this approach would require detailed knowledge of all treatment alternatives and all sources.

D. Free Market Version of Selected Sources - major sources are selected as in method B. Point source discharges and jurisdictions having responsibility for non-point discharges negotiate to determine how the required reduction will be achieved. For instance, small dischargers might arrange to pay the City of Spokane to reduce its load enough to include their share of the required reduction.

Evaluation of Alternatives - Allocation alternatives were evaluated with respect to effectiveness in meeting water quality goals, cost, equity, flexibility, ability to accommodate growth, reliability and administrative ease. This evaluation is summarized in Table 9-8.

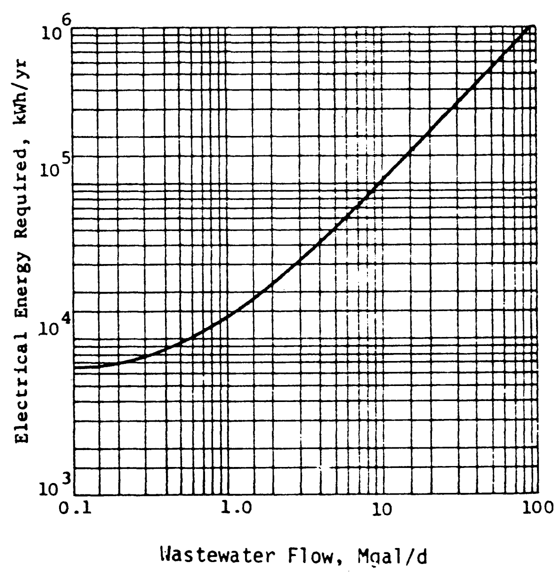
Water Quality Goals - The alternatives vary somewhat in effectiveness in meeting water quality goals. A scheme is considered effective if practical techniques to achieve the required reduction are available. Uniform reduction is the worst method since infeasible load reductions may be specified. For instance, requiring 83 percent phosphorus load reduction for groundwater input would not make sense, and 83 percent reduction of urban runoff phosphorus loads would be extremely costly to achieve. If one of the other methods is used, it appears that criteria can be met more easily.

FLOW DIAGRAM



ENERGY NOTES - Assumptions:

1. Power consumption based on the operation of pumps, mixers and feeders.
2. Alum dosage = 200 mg/l as $Al_2(SO_4)_3 \cdot 14\ H_2O$.
3. Type of energy: Electrical

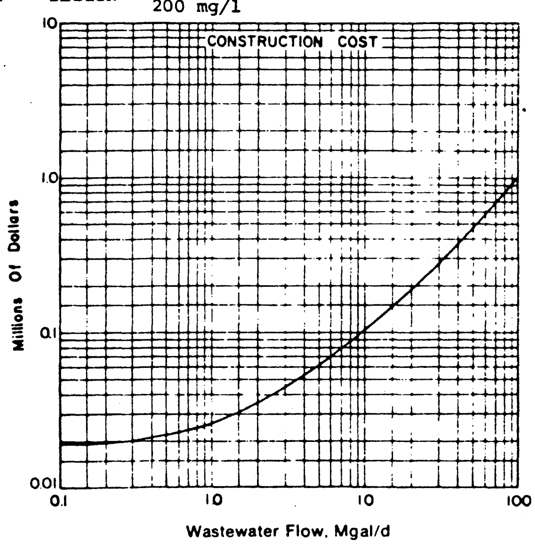


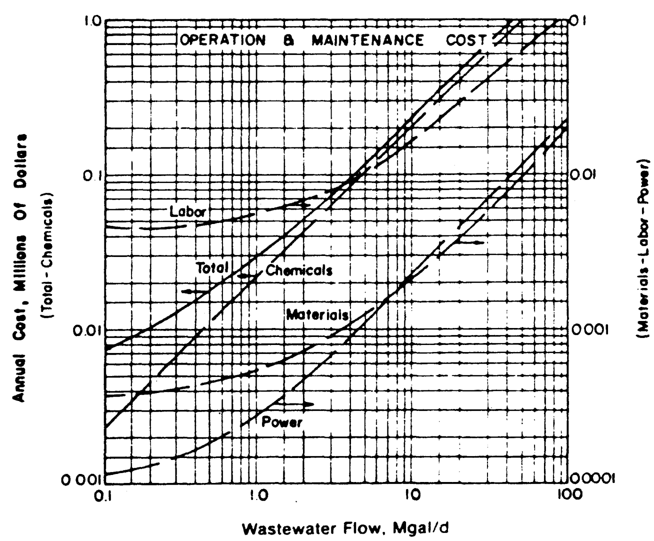
COSTS*- Assumptions:

1. Alum dosage = 200 mg/l as $Al_2(SO_4)_3 \cdot 14\ H_2O$. Phosphorus removal for other dosages, see adjustments below.
2. The rapid mix tank is constructed of concrete, and multiple basins are used for volumes greater than 1,500 ft^3.
3. Costs include liquid alum (8.3% Al_2O_3), chemical feed equipment sized for twice the average feed rate and storage of at least 15 days. Price of building is included except for plants with a capacity of less than 1 Mgal/d. Rapid mix tank includes stainless steel mixer.
4. Service life = 20 years.
5. ENR Index = 2475.

Adjustment factor: To adjust cost curves for other alum dosages, enter cost curve at effective flow (Q_E):

$$Q_E = Q_{DESIGN} \times \frac{\text{Alum Dose}}{200\ \text{mg/l}}$$





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*To convert construction cost to capital cost see Table A-2.

FIGURE 9-5
Typical STP Cost Function for Phosphorus Removal

Source: USEPA, Innovative and Alternative Technology Assessment Manual, 430/9-78-009, Feb 1980

TABLE 9-8

EVALUATION OF ALLOCATION ALTERNATIVES

	SCHEME	WQ GOALS	COST	EQUITY	RELIABILITY	FLEXIBILITY	GROWTH	EASE OF ADMINISTRATION
A	Uniform reduction	may not meet goals if reduction of some sources not feasible	highest--all sources must reduce load, regardless of cost	higher costs for low concentration or hard-to-control sources	reliable methods unavailable for some sources	changes in treatment must be made by many discharges	reallocation required	few calculations required; DOE defines loads; enforcement difficult
B	Selected Sources	will meet WQ goals if technically feasible	intermediate-more sensitive sources may be more expensive	costs borne by major sources, unless cost-sharing used	reliable methods more likely available	Change in chemical dose may be enough	reallocation required for sources to which system will be sensitive	sensitivity analysis required; DOE defines loads;enforcement: few sources
C	Least Cost	will meet goals if technically feasible	lowest	costs borne by cheapest-control sources, unless cost-sharing used	cheapest methods may not consistently achieve required reduction	Change in chemical dose may be enough	reallocation required	detailed cost analysis required; DOE define loads; enforcement: few sources
D	Free Market/ Selected Sources	will meet goals if technically feasible	may be lower than B but higher than C	costs borne by major sources, unless cost-sharing used	reliable methods more likely available	Change in chemical dose may be enough	sensitivity evaluation required; reallocation may be needed	DOE does less work than for B, but must wait to issue permits; enforcement: few sources

Cost - Total costs (including both capital and O & M costs) to the dischargers would be lowest for the least cost method (C), followed by methods B and D. Costs of the selected sources solution might be higher; however, it seems relatively unlikely since the major sources are all municipal treatment plants. The highest costs would result from uniform reduction, since reductions would be required for discharges for which only high cost techniques were available. For instance, reduction of the phosphorus loads from the small package plants like Millwood would require extensive plant modifications and considerably higher O & M costs.

Equity - Equity of the alternatives is evaluated on the basis of fairness of cost distribution. Thus, under a perfectly equitable scheme, the costs borne by an industry discharging a given amount of pollutant would be the same whether the industry was connected to Spokane sewers or directly to the river.

The uniform reduction method is probably least equitable since reducing phosphorus loads from minor sources such as the package plants (e.g. Millwood) and dilute sources (e.g. Inland Empire Paper Co.) is much more costly per pound phosphorus removed than removal at a large STP. The other methods all require some of the discharges to bear all costs unless some cost-sharing method is devised. Development of such a method would probably be easier for a DOE-implemented solution (B or C) than for a free-market solution.

Flexibility - Flexibility is defined as the ability of a scheme to handle changing knowledge of the system, improvements in treatment technology, or other unanticipated changes. All of the schemes would require reallocation if a major change occurs. Because the uniform reduction method requires reduction by all sources, facilities required to meet wasteload limits specified by an initial allocation may be inappropriate after reallocation Minor changes affecting sources with waste loads lower than the selection criterion would not affect allocation for methods B to D. Furthermore, since these methods would require most of the load reduction to be accomplished by STPs that can vary P removal efficiency by changing the chemical dosage, the facilities provided would be suitable to respond to the load changes required.

Growth - The ability of each allocation scheme to accomodate anticipated and unanticipated growth was evaluated. Unanticipated growth cannot be handled by any of the methods without reallocation using new projections. If the free market method were used, new dischargers might be required to pay higher costs than reallocation under methods A, B, or C.

Reliability - The reliability of the various schemes was evaluated on the basis of whether available methods for implementing required removals higher than they normally achieve. The uniform reduction method requires reductions for some sources which may not reliably be achieved; for example, common methods to control urban runoff phosphorus loads (street cleaning and sedimentation basins) will not consistently achieve removals of 83 percent under realistic assumptions about operation and maintenance. Similarly, the least costly methods (C or D) may not be the most reliable. For instance, a street sweeping program to reduce urban runoff phosphorus loads may be cheaper than adding a phosphorus removal process to the Liberty Lake STP; however, the latter is more likely to be reliable. The selected sources method (B) is selected here as most reliable.

Administrative Ease - Three factors were considered in rating administrative ease: amount of staff work required to develop an allocation, extent of negotiations required and, ease of enforcement. Although DOE staff need not take part in the negotiations, they have to ascertain that the required water quality will be achieved before issuing permits.

Of the alternatives that maintain DOE control, least staff work would be required for the uniform reduction method. Somewhat more effort would be required to make allocations using the selected sources scheme, since a sensitivity analysis is required. The least cost method would require substantially more computation and knowledge of details of existing and possible treatment techniques and management practices for each source.

The free market scheme requires less staff work by DOE, but requires that negotiations among dischargers be completed before loads are known and NPDES permit conditions can be established.

Enforcement of a wasteload allocation based on uniform reduction would be much more difficult than for the other schemes, because reduction would be required for numerous small sources (such as all farms in the Little Spokane River Drainage Basin).

Recommended Alternative - The two selected sources methods (B and D) appear to have the most advantages and fewest disadvantages. Either would ensure that water quality goals are met consistently if feasible. Although they require more staff effort than uniform reduction, the difference is not great enough to outweigh the more difficult enforcement, lower equity, and effectiveness, and higher cost of that method. The additional staff work required for the least cost method (C) is probably not justified by the somewhat lower costs borne by dischargers. The free market variation does not have enough advantages to offset the loss of DOE control. Furthermore, development and implementation of a cost-sharing method would probably be easier for a DOE-imposed allocation. Therefore, the discussion of detailed methodology and the allocation example will use the selected sources method (B).

Set Load Reductions For Individual Sources (Step 11)

The procedure for allocating loads among individual sources using the selected sources method is shown in Figure 9-6, which is discussed in the following paragraphs.

First, a sensitivity analysis is made to determine the relative importance of each source (Step A). The loads shown in Table 9-5 were obtained using the system model described in Chapter 7. Loads from STPs providing secondary treatment, including Spokane, are assumed to be 80 percent of discharged influent phosphorus loads (Elliot, et al., 1978).

The selection criterion is defined by examining the implications of various possible criteria (Step b). As shown in Table 9-5, two sources account for most (84.5 percent) of the load. Because such a large fraction (83 percent) of the phosphorus load must be removed from the system; the

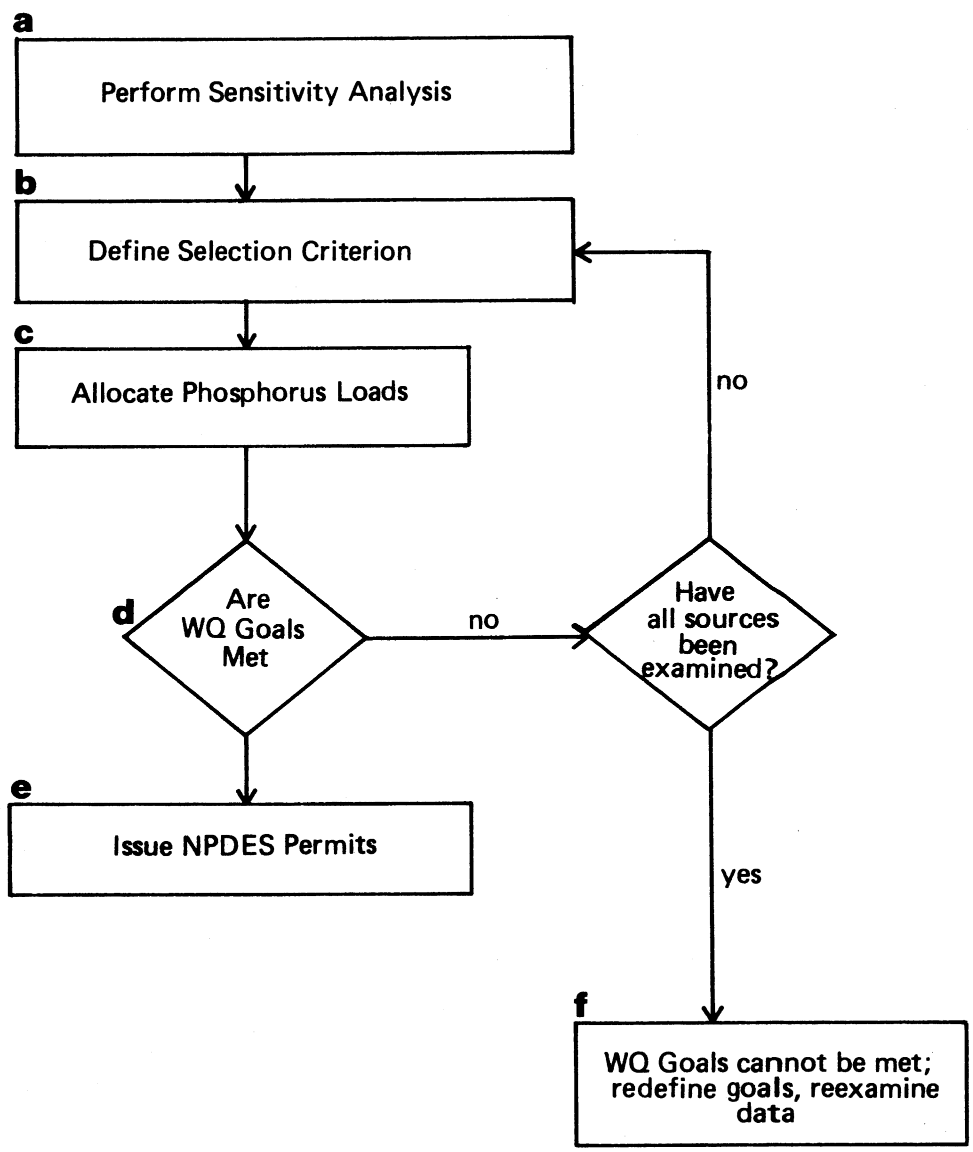


FIGURE 9-6
Procedure For Load Allocation
By Selected Sources Method

criterion must be at least as low as 4.0 percent (see Table 9-9). Sources contributing more than four percent of the total load (Spokane STP, the Idaho STPs and the Idaho's non-point loads account for 88.8 percent of the load). If phosphorus loads from only these sources are to be controlled, they must reduce their loads by 94.0 percent. The required phosphorus reduction drops from 94.0 to 90.2 percent if reduction is also required for the new Liberty Lake STP (ie the criterion is changed to 3 percent). Since the load estimates used to derive Table 9-5 are assumed to be 80 percent of the plant influent, the actual removal requirement for STPs would be 92.2 percent.

A 86 percent P removal is required for all sources (88.9 percent for STPs) that contribute more than one percent of the total system load. Use of such a low cutoff criterion can be justified only with modifications to the allocation method since sources now include Hangman Creek (1.2 percent), the Little Spokane River (1.7 percent) and stormwater runoff from the Spokane urban area (1.7 percent). It is highly unlikely that an 86 percent removal efficiency could be achieved for these three sources, which can be classified as non-point (see Table 9-10 for a summary of removal methods). If the criterion selected is 1.0 percent, non-point source phosphorus reductions would have to realistically be set at a lower percentage than 86. Under ideal circumstances, 60 percent might be attained; realistically 30 percent or half that value seems more likely to be achievable on a consistent basis.

Accordingly, the point sources (STPs) would have to make up the difference between the 86 percent and 30 percent removal efficiency of the non-point sources.

The next step shown in Figure 9-6 (Step c) is carried out as shown in Table 11 for the one percent criterion. It should be noted that STP removal requirements in compensating for the increased P load from non-point sources increased from 88.9 percent to 93 percent for the 1 percent criterion.

It is questionable whether these removals can be achieved at an acceptable cost. For example the existing City of Spokane plant, which was designed to achieve 85 percent removal, might be able to achieve 93 percent removal consistently if high alum dosages were used; however, costs per pound of phosphorus removed increase very rapidly after a certain level of phosphorus removal is achieved. Tests to determine this level for Spokane AWT have not been performed; however, it is quite possible that an additional process, such as rapid sand filtration to remove colloidal particles, or seasonal land disposal might be required to achieve removals this high economically.

By referring to the flow diagram shown in Figure 9-6, it is possible that the step (f) indicating that the initially selected water quality criterion cannot be feasibly met has been reached (i.e., 93 percent phosphorus removal at all treatment plants might be regarded as too costly to keep Long Lake's mean seasonal chlorophyll a below 10 ug/l).

At this point, a repeat of the overall process using a different criterion would be in order. Selection of a higher chlorophyll a criterion or more frequent exceedance of the criterion (i.e. higher design flow) will yield a higher permissible phosphorus loading rate.

TABLE 9-9

IMPLICATIONS OF SELECTION CRITERION FOR SELECTED SOURCE METHOD

Selection Criterion (% of total load) (A)	Percent of Total P Load from Sources ≥ Criterion[1] (B)	Percent P Reduction Required For Sources ≥ Criterion (see Tables 9-5 and 9-6)[2] (C)	Percent P Reduction Required For STPs meeting Criterion[3] (D)
10.0	84.5	**	**
4.0	88.8	94.0%	95.2%
3.0	92.6	90.2%	92.2%
1.0*	97.0	86.1%	88.9%
0.0*	100.0	83.5%	86.8%

* Groundwater inputs are not included

** Not feasible -- calculated value exceeds 100%

(1) Add percent contributions of all sources whose contributions exceeds the criterion (A).

e.g. 3% criterion: Percent of Total load = 73.4 + 11.1 + 4.3 + 3.8 = 92.6%

(2) To calculate % P reduction required for sources equal to or greater than the selection criterion

Consider the following example for the 3 percent criterion.

system load reduction required = 2816 - 466 = 2350 lb
R = 2350/2816 = .835 or 83.5% = overall reduction required
Required reduction = 0.835/0.926 = 0.902

(3) Calculate as: 0.80 x (C) + .2

Explanation follows:

STP phosphorus loads in Table 9-5 are 80 percent of plant influent phosphorus P_i; therefore, Tot P to be removed = amount removed by secondary (0.2 P_i) + amount to be removed after secondary [0.8 P_i x (C)].

$= P_i\ (0.2 + 0.8\ (C))$

For 3 percent criterion, % P removal required = (.80 x .902) + .20 = 92.2

TABLE 9-10

Source Type	Potential Phosphorus Reduction Techniques
Point	Alum Addition Alum treatment is flexible and can be applied to wastewater treatment alternatives; it may be added directly to primary clarifiers, secondary clarifiers or aeration tanks. Alum should not be dosed directly to trickling filters. Dosages are not stoichiometric and must be reconfirmed frequently. Alum sludge tends to be voluminous and difficult to dewater. Phosphate concentrations are reduced to low levels although effluent quality may vary somewhat. Two-Stage Tertiary Lime Treatment Produce typical effluent concentrations of 0.01 to 1 mg/l. Is a reliable process with good operator attention. Low alkalinity wastewaters tend to form a poorly settleable floc, reducing the treatment efficiency. pH adjustment necessary prior to discharge. Large amounts of lime sludge are produced. Ferric Chloride Addition Is flexible to various wastewater treatment alternatives. Dosages are not stoichiometric and must be reconfirmed frequently. pH adjustment may be necessary in low alkalinity wastewaters. Iron concentrations in plant effluents may be excessively high.

TABLE 9-10 (CONT)

Source Type	Potential Phosphorus Reduction Techniques
Point	Phostrip Requires the use of the activated sludge process. Requires greater automation, capital investment and more equipment than conventional methods. However, operating costs are reduced. This process is capable of reducing phosphorus concentrations to less than 1 mg/l. However, biological upsets in the activated sludge process will affect phosphorus removal and effluent concentrations. Chemical dosage requirements and production of chemical sludges are reduced as compared to conventional phosphorus.
Urban Runoff	Mechanical Sweeping Phosphorus removal varies from 25% for single sweep to over 40% for two sweeps. Vacuum Sweeping Phosphorus removal varies from 60 percent to almost 80% Vacuum sweeping is approximately twice as efficient as mechanical sweeping for removing particles in the small size range (with which most of the phosphorus is associated). Sedimentation Sedimentation prior to discharge of runoff waters to the river could reduce suspended solids by 70%. Phosphorus removal efficiencies may be as low as 10% approximately 90% of the phosphorus in urban wastewaters is associated with fine particulate matter. Grassed Percolation Areas Nutrient removal is achieved by plant uptake. Removal efficiencies are not accurately known. This system may not be feasible in areas in which soils have low filtration rates.

TABLE 9-11

PHOSPHORUS LOAD (LB-P/DAY) ALLOCATION FOR SELECTED SOURCES BASED ON ONE PERCENT SELECTION CRITERION

	Sources	Load Existing	Load 1990	% Reduction Required Existing	% Reduction Required 1990	Allocated Load (Allowable Discharge) Existing	Allocated Load (Allowable Discharge) 1990
1.	Idaho non-point sources	121	121	30	30	85	85
2.	Idaho STPs	126(b)	312(b)	85(88)(a)	91(93)(a)	19	28
3.	Liberty Lake STP	---	106(b)	--	91(93)(a)	--	10
4.	Spokane Industrial Park	17	17	0	0	17	17
5.	Kaiser (net)	0	0	0	0	0	0
6.	Spokane Valley URO	13	16	0	0	13	16
7.	Inland Empire	14	14	0	0	14	14
8.	Millwood STP	9	9	0	0	9	9
9.	City CSO	26	0	30	0	18	0
10.	Hangman Creek	33	33	30	30	23	23
11.	Spokane STP	1375(b)	2068(b)	85(88)(a)	91(93)(a)	206	186(c)
12.	Spokane URO	24	48	30	30	17	34
13.	NW Terrace STP	8	8	0	0	8	8
14.	No. City URO	4	9	0	0	4	9
15.	Little Spokane River	49	49	30	30	34	34
16.	Groundwater Inflow	6	6	0	0	6	6
	TOTAL	1825	2816			473(d)	479(d)

Note: For achieving mean seasonl chlorophyll a concentration of 10 ug/l

(a) Based on Table 9-5 and compensation for lesser treatment of non-point sources for STPs, percentage based on P reduction required after secondary treatment. Values in parentheses denote the required P reduction based on raw influent P loads.

(b) Phosphorus load with secondary treatment only.

(c) Using the same selected sources method, the increased system load in 1990 has resulted in a lower allocated load for the Spokane STP.

(d) The difference between the total allocated and the mean permissible load (466 lb-P/day) is a result of rounding off reduction percentages.

The effect of various design flows has been discussed above. As shown in Figure 9-3, the required load reduction does not increase substantially as the recurrence interval for selected design flow increases from 10 to 20 years.

The effect of selecting a less stringent chlorophyll a criterion is shown in Tables 9-12 and 9-13 and Figure 9-7. Even if the acceptable level for mean seasonal chlorophyll a is set as high as 15 ug/l (a level exceeded only in 1973), future loads would have to be reduced substantially. The phosphorus removal efficiency required for STPs would range from 73 percent (30 percent for other sources) if all sources were selected, to 79 percent if only the two largest sources were required to remove phosphorus. With a chl a criterion of 12 ug/l and a 10 percent selection criterion, 91 percent removal of influent phosphorus would be required. The required removal efficiency for 15 ug/l chl a drops to 87 percent if Liberty Lake STP and the Idaho non-point sources are also included. If Idaho non-point sources is excluded, 91 percent removal would be required. Table 9-14 summarizes STP phosphorus removal requirements for chlorophyll a criteria for 10, 12 and 15 ug/l, respectively.

Another option is to redefine the system. Estimation of future loadings requires numerous assumptions. For example, the assumptions used in the estimates reported in Table 9-5 (and discussed in Chapter 7) include implementation of the alternative that appeared most likely to be recommended by the on-going wastewater treatment facilities planning program -- construct a sanitary sewer system to serve the Spokane Valley and other areas adjoining Spokane, and treat these wastes at the Spokane STP. Since the Spokane STP would account for 73 percent of the total loading to the system, development of an alternative resulting in much lower loads to the river from the new urbanizing areas would reduce the overall system load and thus decrease the wasteload reductions required to maintain a 10 ug/l chl a criterion.

After the examination and inclusion of all the point and non-point phosphorus loads in Spokane River at both Idaho and Washington States, the phosphorus load restriction at the state border will be the sum of the total allocated Idaho loads in Table 9-11, which are 104 lb-P/day for the present and 113 lb-P/day for year 1990.

Additional data collection, as discussed in Chapter 8, would enable DOE to make allocations with more confidence. If DOE makes an interim allocation based on available data, the new data would provide a basis for a more definitive subsequent allocation.

ALLOCATION OF OTHER POLLUTANTS

The process outlined in Figure 9-1 is general and applicable to all water quality constituents for which wasteload allocation would be appropriate. Additional data needed to allocate constituents that may be present or future problems in the Spokane River System (such as toxicants and BOD) have been discussed in Chapters 6, 7, and 8).

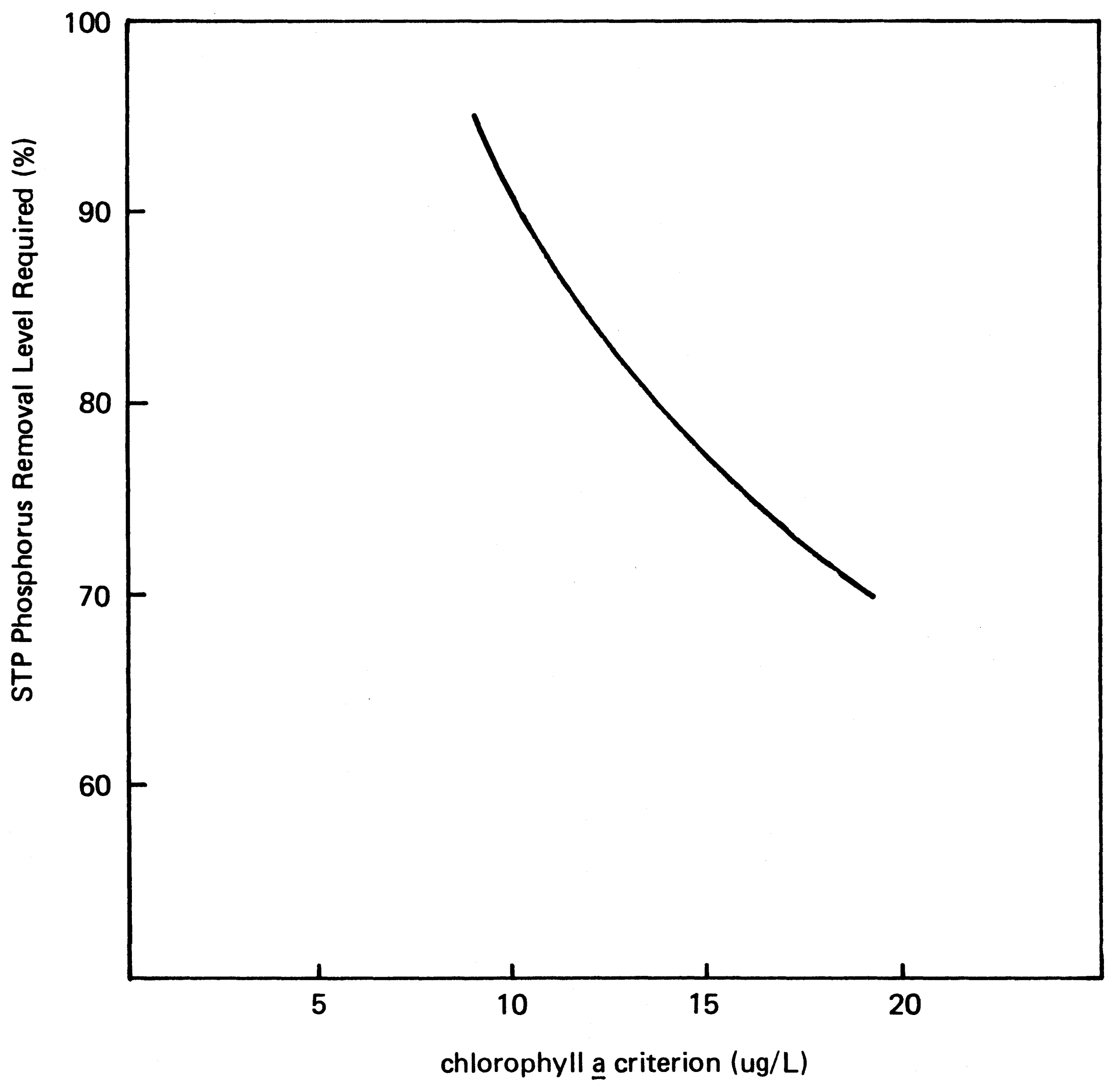


FIGURE 9-7
Effect of algal criterion on level of phosphorus removal required at STPs discharging to the Spokane River System (using 1% criterion and adjustment made to compensate for limited phosphorus removal from the non-point sources)

TABLE 9-12

IMPLICATIONS OF SELECTION CRITERION FOR SELECTED SOURCE METHOD (FOR ACHIEVING A MEAN SEASONAL CHL A CONCENTRATION OF 12 UG/L)

Permissible load = 701 lb-P/day (Table 9-7)
System load reduction = 2816 - 701 = 2115 lb-P/day
Percent reduction = 2115 ÷ 2816 = 0.751 or 75.1 percent

Selection Criterion (% Contribution)	Percent of Total Load	Required Reduction	Required STP Removal	Adjusted Required* STP Removal
10.0	84.5	88.9%	91.1%	91.1%
3.0	92.6	81.1%	84.8%	86.7%
1.0	97.0	77.4%	81.9%	85.4%
0.0	100.0	75.1%	80.1%	83.6%

TABLE 9-13

IMPLICATIONS OF SELECTION CRITERION FOR SELECTED SOURCE METHOD (FOR ACHIEVING A MEAN SEASONAL CHLA CONCENTRATION OF 15 UG/L)

Permissible load = 1054 lb-P/day (Table 9-7)
System load reduction = 2816 - 1504 = 1762 lb-P/day
Percent reduction = 1762 ÷ 2816 = 0.626 or 62.6 percent

Selection Criterion (% Contribution)	Percent of Total Load	Required Reduction	Required STP Removal	Adjusted Required* STP Removal
10.0	84.5	74.1%	79.3%	79.3%
3.0	92.6	67.6%	74.1%	75.5%
1.0	97.0	64.5%	71.6%	74.1%
0.0	100.0	62.6%	70.1%	72.6%

* Based on the following:

1. Load that would have been removed by non-point sources under uniform reduction is computed.

2. Load that will be removed at 30 percent efficiency is computed for non-point sources.

3. Difference between 1 and 3 above is computed.

4. Sum of all differences for non-point sources is calculated and added to the loads to be removed by STPs.

5. Adjusted STP removal percent is calculated by dividing total loads to be removed by influent STP load.

TABLE 9-14

EFFECT OF CHLOROPHYLL A CRITERION ON
REQUIRED PHOSPHORUS LOAD REDUCTION

Chl a Criterion	Permissible Loading (#/ day)	Required Reduction at STPs 10% Criterion*	3%*** Criterion*	0%*** Criterion*
10 ug/L	466	**	94%	91%
12 ug/L	701	91%	87%	84%
15 ug/L	1054	79%	76%	73%

* Selected sources criterion level - all sources that contribute at least this amount of the total load are selected to make reductions.

** Not Feasible

*** Add appropriate percentage to compensate the added load from the limited treatment of the Idaho non-point sources and other non-point sources.

To gain some knowledge on the sensitivity of the future pollutant (other than phosphorus) loads on the receiving water quality, an assessment is made on the possible receiving water effects as a result of the projected 1982, 1992, 2002 pollutant discharges. The future loading conditions are based on Plan A of the Comprehensive Wastewater Management Plan, the Regional Treatment at the Spokane wastewater treatment facility.

Plan A would provide secondary treatment plus phosphorus removal of wastewater flows from the City of Spokane and from areas outside of the City; namely, North Spokane, Spokane Valley, Moran Prairie, Liberty and Newman Lakes, Indian Trails and West Plains, at the existing Central Treatment Plant and the effluent would be discharged to the Spokane River at the current discharge site (Rm 67.3).

The impact assessment reported here is focused on the following constituents: oxygen demanding substances (BOD and NOD), chlorine residuals, heavy metals (Zn, Pb, Cu, Cd) and unionized ammonia, that are critical to the quality of the receiving water.

A steady-state mass balance model, URS/SRM, is used to simulate the resultant in-stream concentrations from the projected 1982, 1992, and 2002 discharges for the 30 day-10 year low flow condition. The 30 day-10 year low flow at Post Falls (USGS station) is 220 cfs and it is used as the boundary condition for the model. The corresponding flow at the Riverside State Park is 627 cfs.

Table 9-15 gives the projected flows, the expected effluent concentration of the concerned constituents and the loads. The listed concentration values are obtained either from recent plant surveys jointly conducted by DOE and EPA (Bernhardt, 1981), or the STP operation records. It is assumed here that these concentration values will not vary significantly in the future.

Table 9-16 compares the simulated parameter levels at upstream of the Spokane STP and downstream at Riverside State Park (immediately downstream of the STP) to water quality standards or criteria.

The effects of the Spokane STP discharge on DO are much greater on the reaches downstream of Riverside State Park, e.g., at the pools behind the Seven Mile Bridge and Nine Mile Dam, where the reaeration rate is much lower and the time of passage is much longer as a result of lower velocity and greater water depth. The simulated downstream DO concentrations at Nine Mile Dam are 7.23, 6.23 and 5.93 mg/l for the 1982, 1992, and 2002 conditions, respectively.

Almost all of the simulated concentrations (with the exception of zinc) are not in compliance with pertinent Washington water quality standards (DO) or EPA criteria. This suggests that discharges of these constituents may require reductions and hence allocation. However, it should be noted that the significance of the criteria cited to beneficial uses in the Spokane River/Aquifer/Long Lake system needs to be examined along with the significance of departures from the values shown in Table 9-16.

TABLE 9-15

CHARACTERISTICS OF THE PROJECTED EFFLUENT DISCHARGES OF THE SPOKANE CENTRAL PLANT UNDER PLAN A OF COMPREHENSIVE WASTEWATER MANAGEMENT PLAN

Concentrations (total)

BOD[2] (mg/l)	NH_3-N[3] (mg/l)	Res-Cl_2[3] (mg/l)	Zn[3] (ug/l)	Pb[3] (ug/l)	Cu[3] (ug/l)	Cd[3] (ug/l)
8.5	9.3	0.8	150.	$<50.$	300.	$<10.$[4]

Loads

Year	Flow[1] (cfs)	BOD (lb/day)	NH_3-N (lb/day)	Res-Cl_2 (lb/day)	Zn (lb/day)	Pb (lb/day)	Cu (lb/day)	Cd (lb/day)
1982	49	2249	2461	212	40	13	80	3
1992	85	3902	4269	367	69	23	138	5
2002	96	4406	4821	415	78	26	156	5

(1) Dry weather flow

(2) From 1979 Spokane STP operation records

(3) Average data of DOE/EPA intensive monitoring program, March 31, June 10-11, 1980, and February 11, 1981 (Bernhardt, 1981)

(4) One sample only

TABLE 9-16

COMPARISON OF SIMULATED PARAMETER LEVELS UPSTREAM OF THE SPOKANE STP AND DOWNSTREAM AT RIVERSIDE STATE PARK TO WATER QUALITY STANDARDS OR CRITERIA FOR CRITICAL FLOW CONDITIONS[1]

	Simulated Concentration						
	1982		1992		2002		
Parameter	Upstream	Down-stream	Upstream	Down-stream	Upstream	Down-stream	W.Q. Criterion
zinc (ug/l)	19.22	29.44	19.63	36.23	19.87	38.21	47[2,3]
lead (ug/l)	3.46	7.10	3.50	9.42	3.52	10.07	0.75[2,3]
copper (ug/l)	4.34	27.46	4.37	42.02	4.38	46.05	5.6[2]
cadmium (ug/l)	0.08	0.86	0.08	1.35	0.08	1.48	0.012[2,3]
un-ionized ammonia -N (mg/l)	0.000	0.023	0.000	0.038	0.001	0.042	0.017[4]
chlorine residual (mg/l)	0.00	0.06	0.00	0.10	0.00	0.11	0.002
DO (mg/l)	8.97	9.03	8.92	9.02	8.88	9.00	>8.0

(1) Critical flow conditions assumed to be 220 cfs at Post Falls.

(2) "Water Quality Criteria Document; Availability" Part 5, Federal Register, November 8, 1980.

(3) Average in-stream hardness assumed to be 50 mg/l.

Only one step in the allocation procedure varies substantially according to the type of pollutant to be allocated. The total load reduction can be set for the system (as done above) only when the pollutant is conservative (i.e. does not undergo biochemical transformation as it moves downstream). Conservative parameters of possible concern include trace metals as well as phosphorus. For non-conservative parameters, like BOD, acceptable loads and required load reductions must be specified for individual river segments. The acceptable load to each segment must be determined iteratively for BOD because the relationship between cause and effect is not linear (like that between chl a and phosphorus).

Alternative allocation schemes evaluated for phosphorus would also be appropriate for other parameters. Thus, the wasteload allocation procedure developed in this chapter can be be applied to any parameter in the Spokane River/Aquifer system when a problem becomes evident or is anticipated. By following the steps outlined, additional data needs are also defined precisely.

CHAPTER 10

SEASONAL PHOSPHORUS REMOVAL

INTRODUCTION

This chapter examines the feasibility of allowing wastewater treatment facilities along the Spokane River to discharge effluents with higher phosphorus levels during the late fall, winter and early spring period ("winter" season) than allowed during the algal growth or "summer" season. The reason that phosphorus removal is presently required is to control algal growth in Long Lake.

Two questions are addressed: would higher levels of phosphorus during the "winter" season cause water quality conditions in Long Lake during the "summer" season to differ from conditions observed with year-round phosphorus removal? How can the period during which removal should be required be defined?

If 1) algal growth is limited by phosphorus concentration only during a certain season and 2) phosphorus discharged into the river during the remainder of the year is unavailable to algae during this sensitive season, then a seasonal phosphorus control strategy that results in low phosphorus levels in the lake during this season will be as effective as year-round phosphorus removal.

The period during which phosphorus removal is required may differ from the algal growing season for two reasons: 1) The season during which minimal algal growth is desired may be shorter than the growing season; and 2) a finite period of time, dependent on the hydraulics of the system, is required between initiation of phosphorus removal and reduction of phosphorus concentrations in the lake to a specified level.

DEFINITION OF THE PHOSPHORUS SENSITIVE PERIOD

Growing Season

The dominant species within an algal population and the amount of algal biomass produced depend upon numerous environmental factors, including light, water temperature, nutrient levels, and residence time, as discussed in detail by numerous limnologists (e.g., Hutchinson, 1957, 1967). The period when most of these factors are favorable is called the growing season. If one of the factors is unfavorable to growth, low algal production will occur even if all of the others are present at optimal levels; the unfavorable factor is said to be "limiting."

As discussed in Chapter 4, algal assays (Soltero, et al., 1979) have indicated that phosphorus is a limiting nutrient in Long Lake water. Comparison of algal levels in Long Lake before and after initiation of phosphorus removal by the Spokane treatment plant demonstrates that maintaining low loadings of phosphorus to the reservoir will keep algal productivity low.

The seasonal variation in chlorophyll a levels in Long Lake prior to phosphorus removal (shown in Figure 10-1) indicates that algal growth in Long Lake during winter and early spring is controlled by factors other than nutrient availability, since the nutrient concentrations were high throughout the year. Factors known to limit algal growth and be present in Long Lake in the winter and spring include low temperatures, high flushing rates (which may wash out algal cells before a large population can become established), and high suspended sediment loads (which reduce the amount of light reaching the algae.)

To define the growing season for Long Lake, available data on chlorophyll a levels in the lake prior to initiation of phosphorus removal at Spokane's STP were reviewed. Because collection has typically begun in May or June, few data are available for March or April; May data are unavailable for two of the five years studied. Because the variability is large (see Figure 10-1) mean values were used to define a seasonal pattern. Monthly means for all study years with data were used to obtain the average monthly means shown in Figure 10-2. As shown in this Figure, algae are most abundant from April through October. All monthly means for this period exceeded 10 ug/l chlorophyll a.

Thus, available data support the first necessary condition for seasonal phosphorus removal: algal production is limited by phosphorus levels only during a portion of the year (April to October).

Phosphorus Retention and Availability

As discussed in Chapter 6, a portion of the phosphorus entering Long Lake is retained in the sediments of the lake and is therefore potentially available to promote algal growth during the summer when the lake's hypolimnion becomes anoxic. Studies of sediment cores performed by Thomas and Soltero (1977) showed, however, that clay particles carried into the lake by high spring runoff (April to June) settle out to form a layer of clay over sediments deposited earlier.

The drop in mean chlorophyll a levels observed after initiation of phosphorus removal by the City of Spokane supports Thomas and Soltero's hypothesis that the clay layer seals off the sediments, preventing recycling of phosphorus trapped in the sediments. Furthermore, analysis of the phosphorus budget for Long Lake (see Chapter 6, especially Table 6-3) indicates that the quantities of phosphorus typically released from sediments (up to 3 kg P/day) are small relative to the average phosphorus loads in the inflow to the reservoir (at least 200 kg P/day). Thus, it is reasonable to assume that only phosphorus entering the lake during or shortly before the growing season is available to stimulate algal growth.

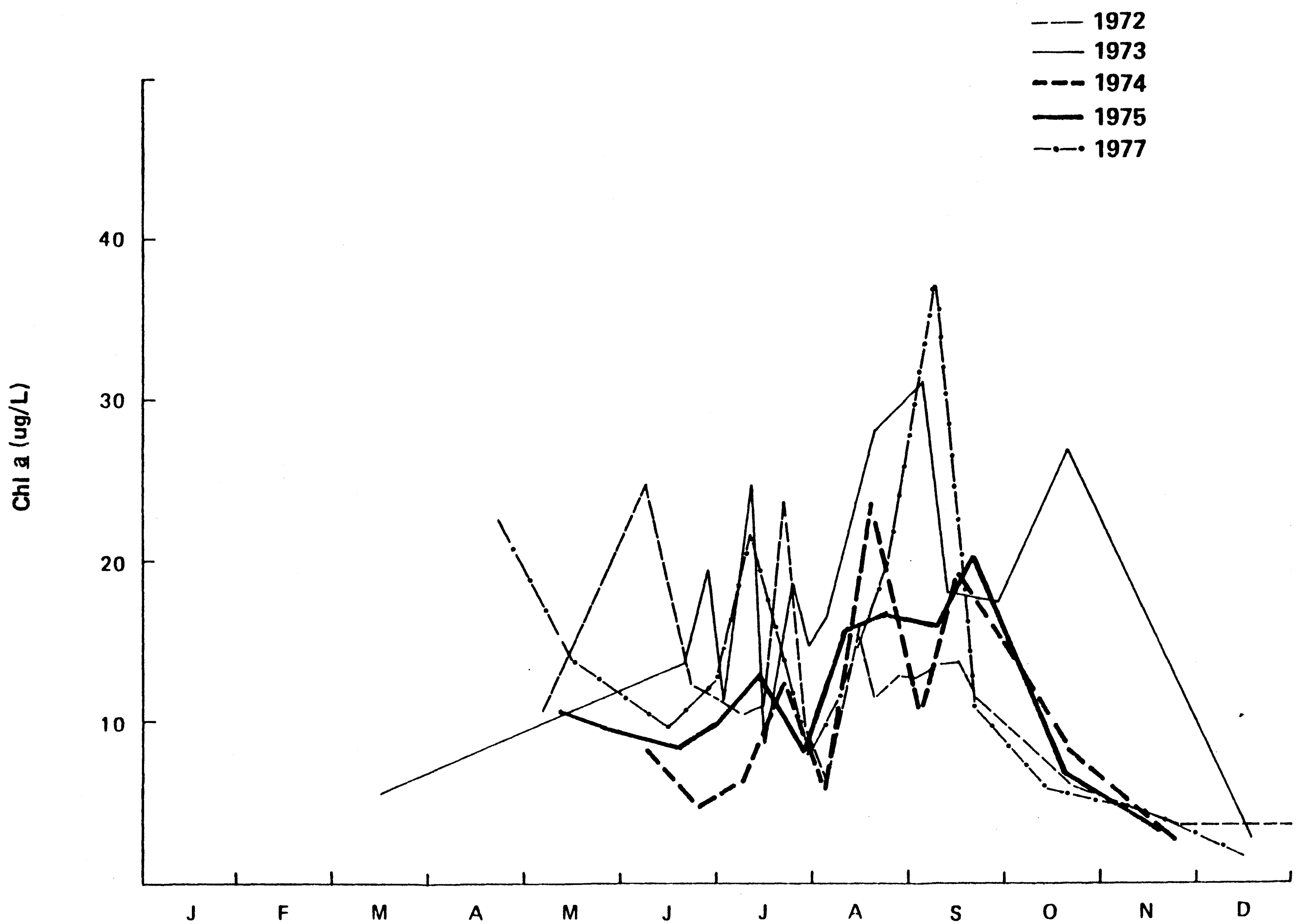


FIGURE 10-1
Seasonal variation in lakewide mean chlorophyll a concentrations

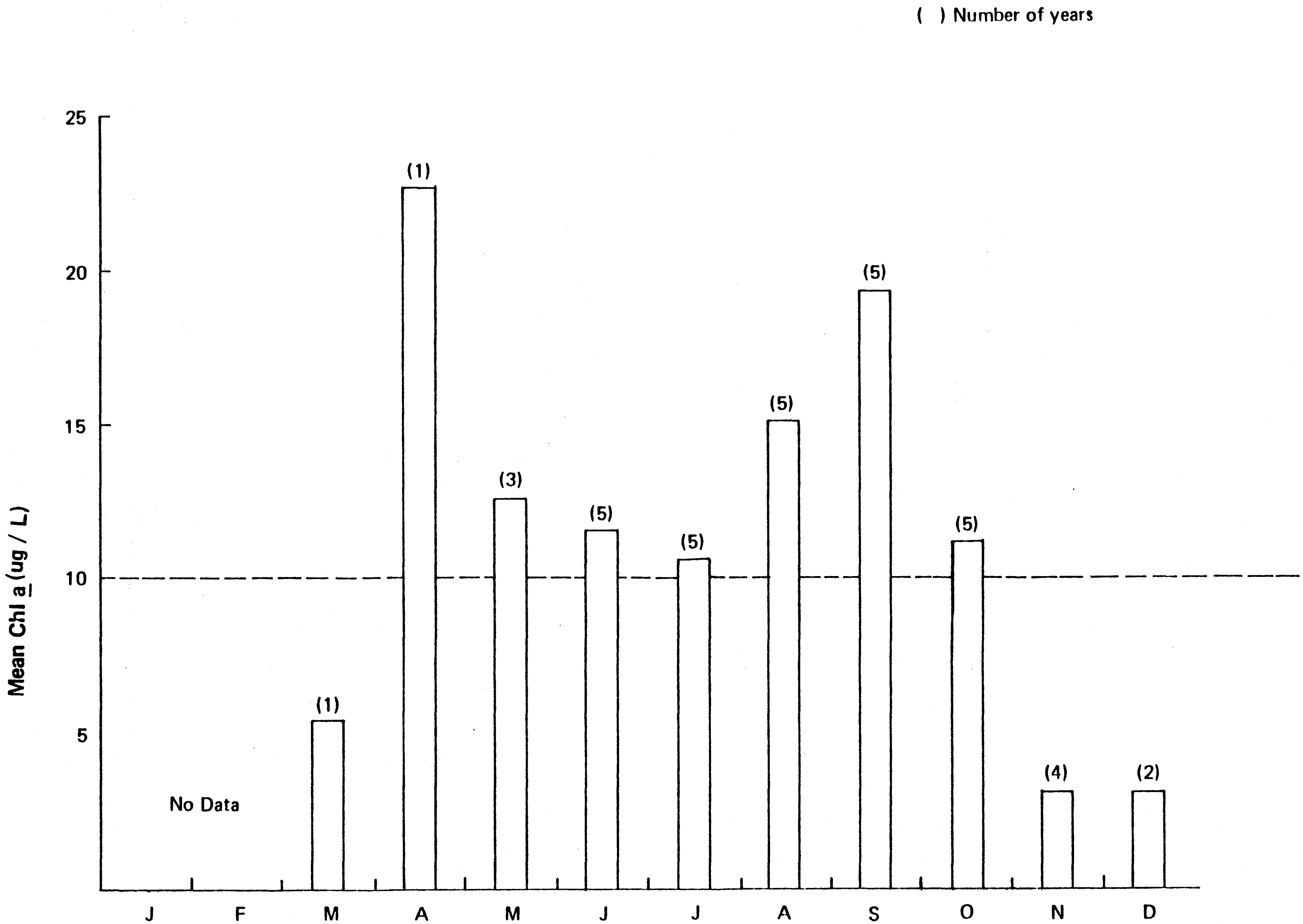


FIGURE 10-2
Mean monthly chlorophyll a concentrations in Long Lake (1972-1977)

CRITERIA USED IN THE DEVELOPMENT OF THIS METHOD

To perform calculations discussed in subsequent portions of this chapter, quantitative criteria are needed for acceptable phosphorus levels and the period during which those levels must be maintained. The criteria selected and the rationale for the selection are discussed below.

Please note that the method developed in this chapter is independent of the specific values chosen as criteria.

Algal biomass

For this example, a mean seasonal chlorophyll a level of more than 10 ug/l will be used as a criterion indicating unacceptable levels of algae in Long Lake. Examination of the relationship between chlorophyll a and secchi disk transparency suggests that maintaining a criterion level of 10 ug/l would typically result in a secchi depth of 3.2 meters (Figure 10-3). In addition chlorophyll levels at or above 10 ug/l are often taken as an indication that a lake is eutrophic (Ciecka, et al., 1980)

Critical Season

The season of concern to DOE and other concerned groups may not include the entire growing season. As discussed in Chapter 4, diatoms form the largest portion of the standing crop in the spring. Diatom blooms are not generally considered nuisances. Although detritus from the diatom bloom does contain organic material that increases the sediment oxygen demand, most of the material will probably either be removed by the May to June high flows or covered by the layer of clay particles that seal off the sediments after the high flow period. Based on this hypothesis, thus reducing the size of the early diatom bloom does not appear to be necessary.

As discussed above, the major concerns about algal growth in the lake appear to be maintaining a clean lake for recreation during the summer (June through September), minimizing algal production when it is likely to contribute to development of anoxia in the hypolimnion of the lake, and reducing the size of blue-green algal blooms, which occur late in the summer (August through October). These concerns can be addressed by considering a critical season from June 1 to October 30. Therefore, this period will be taken as the critical season for this examination of seasonal phosphorus removal.

Critical Loading Rate

Mean seasonal chlorophyll a levels in Long Lake are closely correlated to total phosphorus loading. Figure 10-4 shows that a seasonal (June to November) areal phosphorus loading (phosphorus load adjusted for retention and flushing) of 0.40 g P m^2 or less should result in mean chlorophyll a levels no greater than 10 ug/l. As discussed in Chapter 6, phosphorus loads from sources other than inflow (including recycling) are much smaller than inflow sources. If a loading rate of 0.40 g P m^2 were maintained and no net changes in phosphorus content to occur, an in-lake steady-state phosphorus concentration (areal phosphorus load divided by mean depth) of 27 ug/l would eventually result. Because the data do not fit the regression equation shown in Figure 10-4 exactly it is more realistic to state the range of

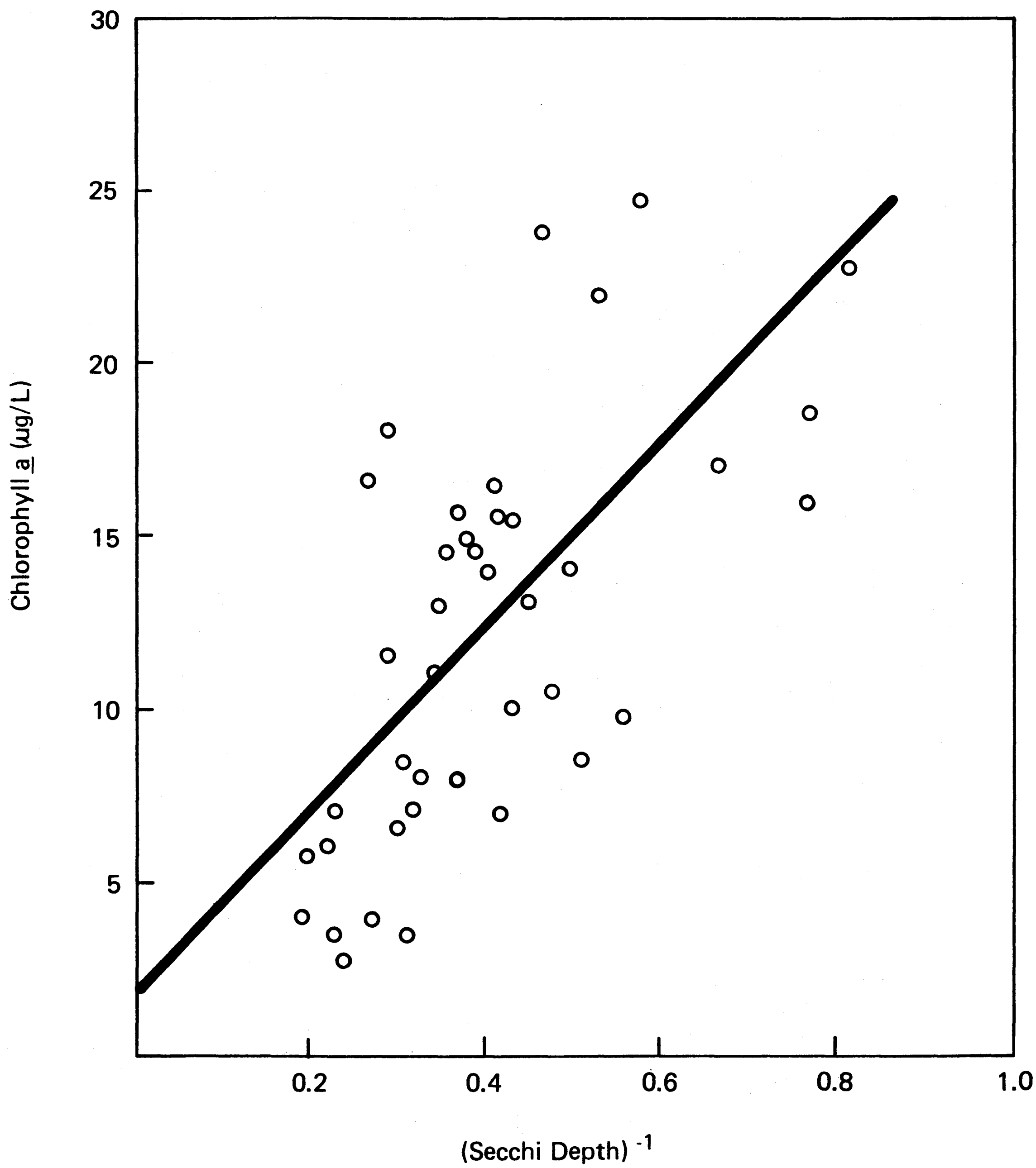


FIGURE 10-3
Relationship Between Transparency and Algal Abundance in Long Lake

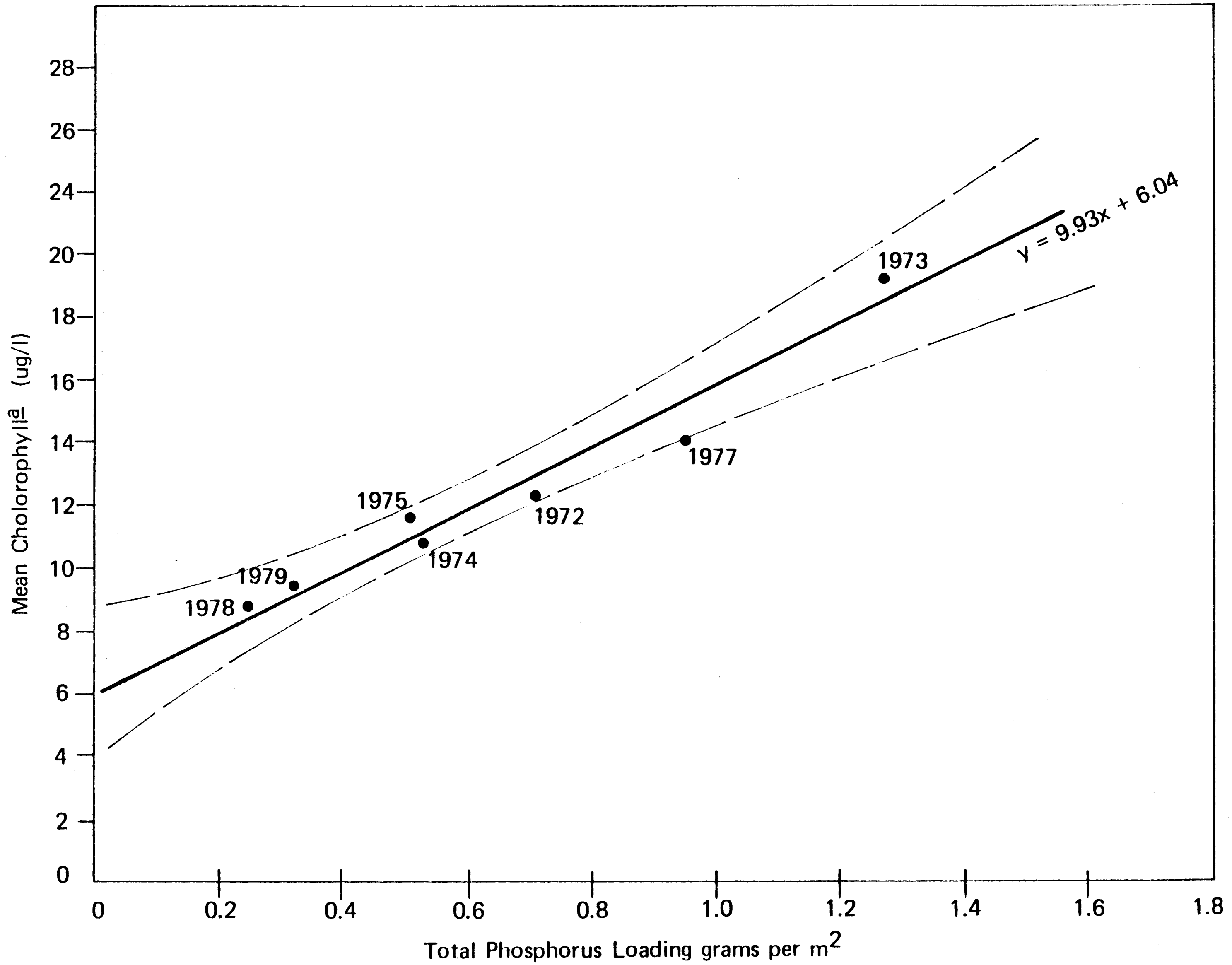


FIGURE 10-4
Total areal phosphorus loading (g p m^2) and mean chlorophyll[a] concentration (ug/l) in Long Lake, for all years of study during the period June through November (1973 chlorophyll[a], June- October).
Dashed lines are 95% confidence interval.
Source: Dillon (1975) , Soltero, et.al.(1979,1980) modified by URS

TABLE 10-1

RANGE OF PERMISSIBLE IN-LAKE PHOSPHORUS CONCENTRATIONS
CORRESPONDING TO THE 95 PERCENT CONFIDENCE LIMITS

Selected chla (ug/l) Criterion	Permissible Load g-P/m2			Permissible In-lake Phosphorus concentration ug/l		
	Mean	Lower Limit	Upper Limit	Mean	Lower Limit	Upper Limit
8	.1974	*	.29	13.5	*	19.9
10	.3989	.28	.48	27.3	19.2	32.9
12	.6004	.52	.70	41.1	35.6	47.9
15	.9027	.80	1.05	61.8	54.8	71.9

* Cannot be defined

phosphorus concentrations corresponding to the 95 percent confidence limits (Table 10-1). This range (.28 to .48 g P m^{3}) corresponds to inlake phosphorus concentrations of 19 to 33 ug/l for a chlorophyll level of 10 ug/l.

DEFINITION OF THE PHOSPHORUS REMOVAL PERIOD

The information presented in the section on definition of the phosphorus-sensitive period indicates that water quality during the growing season would not be adversely affected by allowing dischargers to release larger amounts of phosphorus during the remainder of the year. It must be noted, however, that the algae in the reservoir actually respond to phosphorus concentrations rather than loading rates.

If a phosphorus loading rate greater than that determined to be critical is maintained during the non-sensitive season, the loading rate must be reduced soon enough for the lake concentration to reach a steady state concentration corresponding to the critical loading rate by the beginning of the critical season. A finite time period, called the reduction period, is required. The length of this period determines how long before the growing season phosphorus removal must be initiated.

To test how quickly in-lake phosphorus concentrations change when the influent concentration changes, seasonal variation in phosphorus concentration was calculated as described in Appendix A. A number of factors influence the calculated in-lake phosphorus concentrations:

- sedimentation rate
- reservoir hydraulics
- date of initiation of P removal
- flow regime

For use in the modeling described here, three flow regimes (Figure 10-5) were identified as described in Appendix A.

Sedimentation Rate

Patterns for a single flow regime (low) and differing sedimentation rates (assumed constant for the period of analysis) are compared in Figure 10-6. This figure highlights the importance of an accurate estimate of the sedimentation rate. As discussed in Appendix A, such an estimate can be made for Long Lake, and the limited data available in the literature (e.g. Dillon, 1975) indicates that for a lake with as rapid a flushing rate as Long Lake, a range of values from 0 to 0.5 is reasonable. (It should be noted that the specific sedimentation rate is not the same as the phosphorus retention coefficient, R, discussed in Chapter 9. The relationship is R = $/(\sigma + \rho)$. where σ = sedimentation rate and ρ = hydraulic dentention time.

Prior to the operation of the Spokane Advanced Wastewater Treatment Plant, the average phosphorus retention rate (R) during the growing season for Long Lake is found to be linearly related to the average discharge from the Long Lake Dam for the same period (Figure 10-7). After the application of the AWT (after 1978), the retention rate is found to be lower than it would be prior to the AWT. For example, the calculated R for 1978 and 1979 are both 0.23 and for the same flow in these two years, the regression line (drawn for the data prior to 1978) suggests that the R is 0.35 and 0.37, respectively. The regression line indicates also that R is zero when flow exceeds 420 cms (14800 cfs). The validity of this condition is demonstrated in the following simple calculations:

For the given lake dimension: mean width = 572 m
mean depth = 14.6 m
mean length = 35400 m

The mean cross-section area is:

$$A = 572 \times 14.6 = 8351.2 \text{ m}^2$$

The average flow velocity through the lake for flow of Q = 420 cms is:

$$V = Q/A = \frac{420 \text{ m}^3/\text{sec}}{8351.2 \text{ m}^2} = 0.05 \text{ m/sec}$$

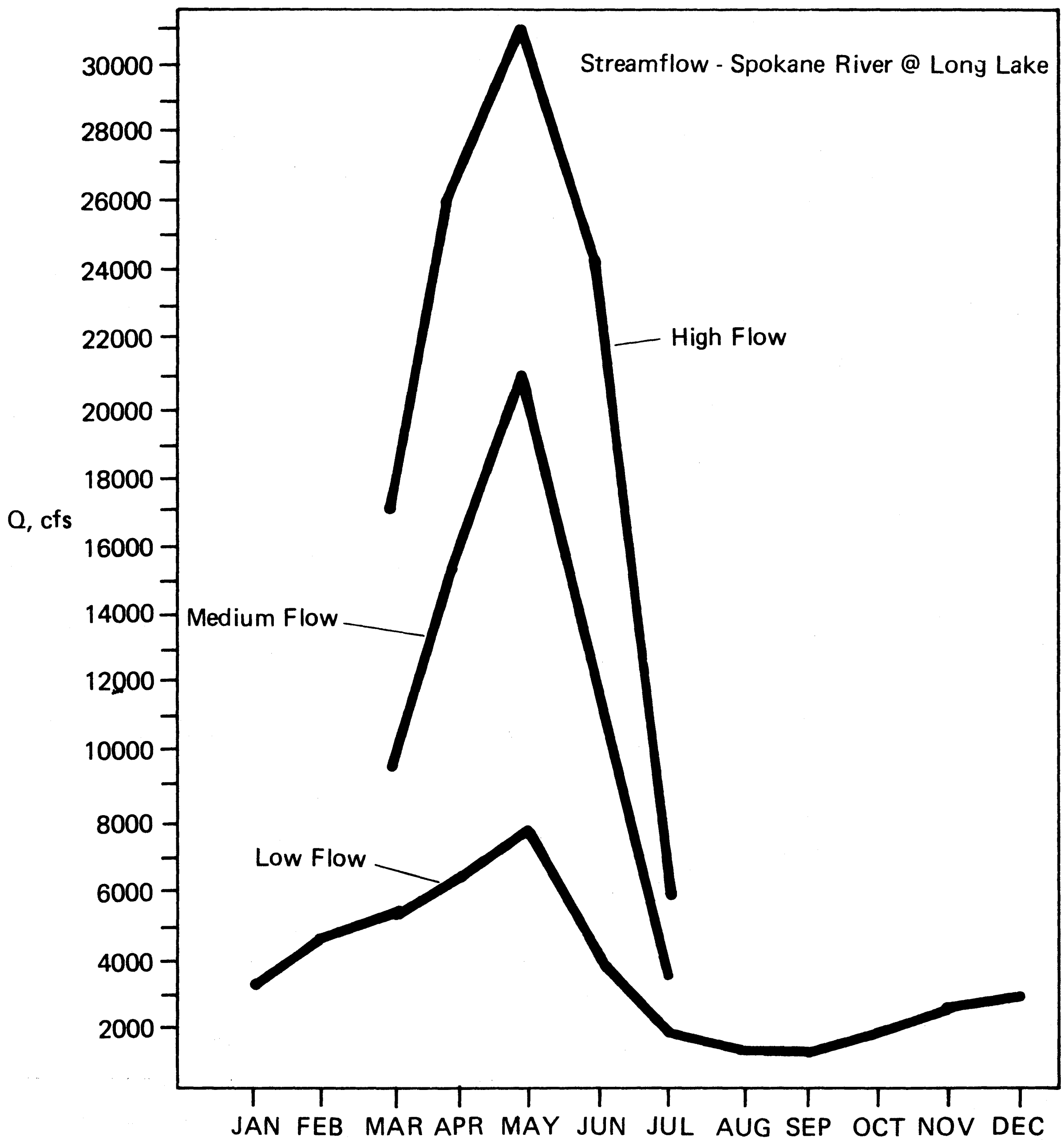


FIGURE 10-5
Inflow to Long Lake under high, medium, and low streamflow regimes used to calculate patterns of in-lake P concentration

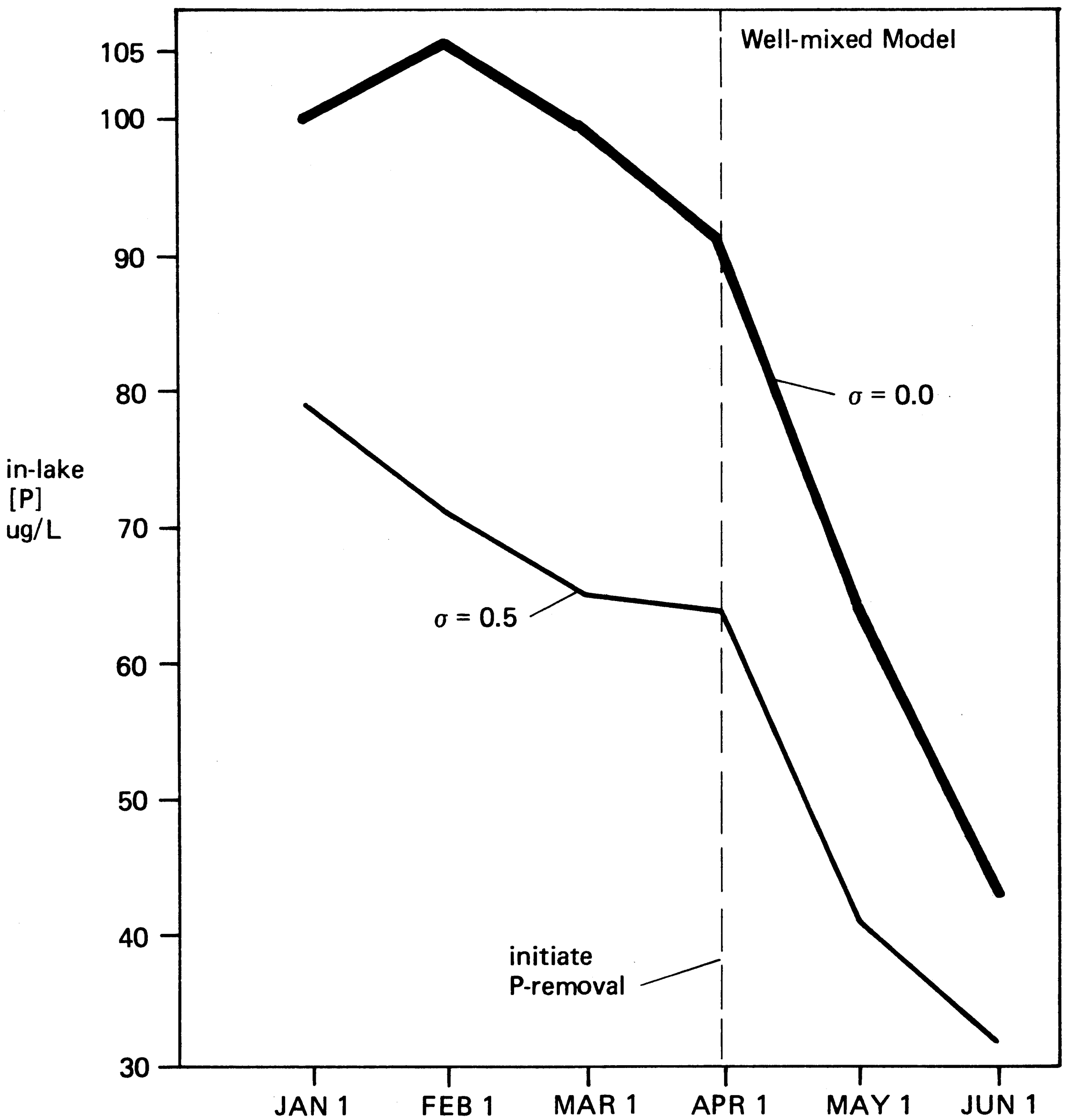


FIGURE 10-6
Sensitivity of total phosphorus levels to sedimentation rate.

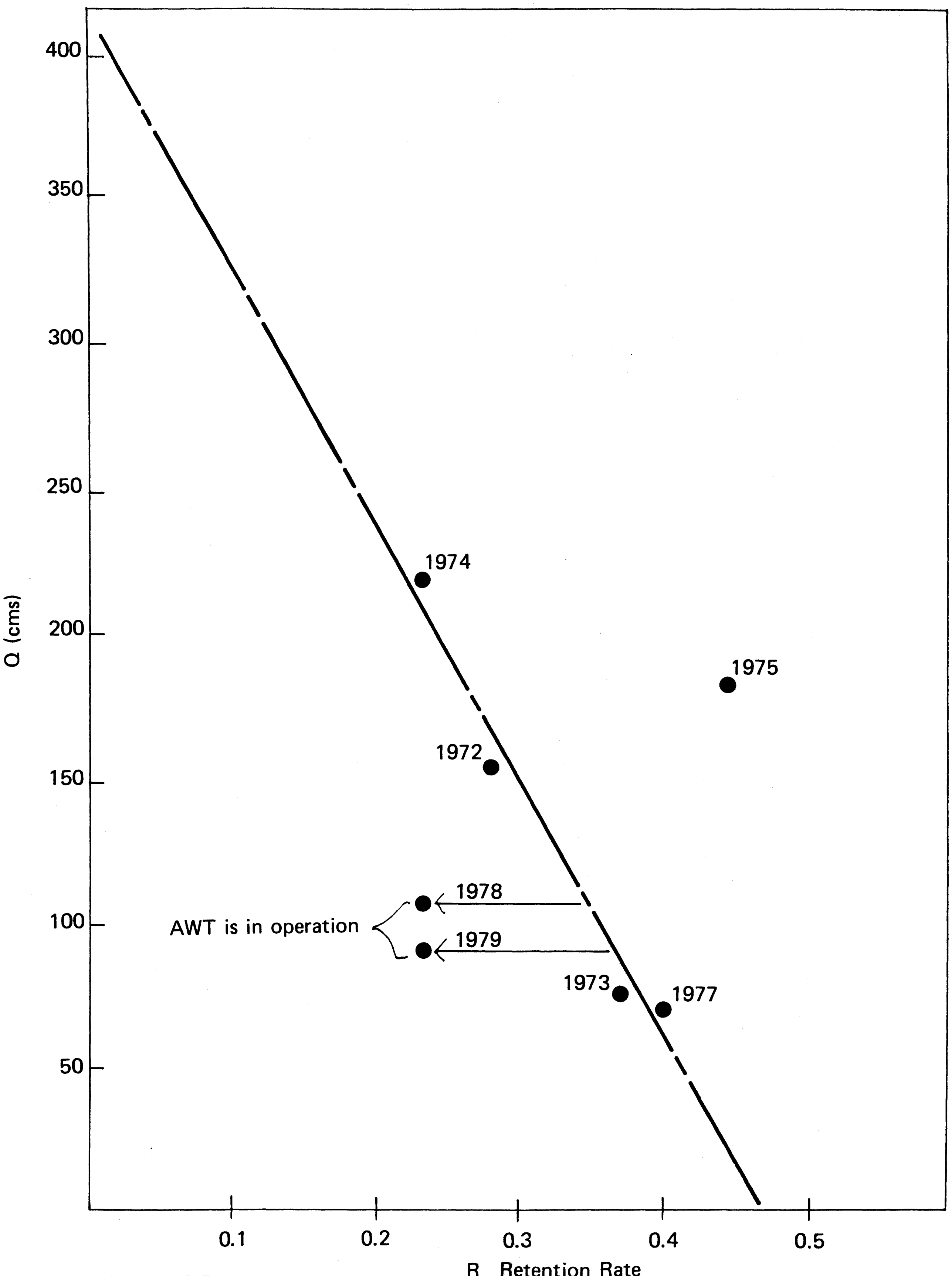


FIGURE 10-7
Seasonal (June - November) phosphorus retention rate in Long Lake vs. Mean seasonal discharges at Long Lake Dam

The time of travel across the lake, t, is:

$$t = \frac{\text{lake length}}{v} = \frac{35400 \text{ m}}{0.05 \text{ m/sec} \times 86400 \text{ sec/day}} = 8.2 \text{ days}$$

There is no data available on the settling velocity of the particulate-P in the lake. The values given in the literature ranges from 0.01 to 4.0 m/day (Battelle, 1976). Using the given range of the settling velocity, the time that it takes for the particle to sink to the lake bottom (assuming very little resuspension) is:

$$t_{sink} = \frac{\text{mean depth}}{Vs} = \frac{14.6}{4} \text{ or } \frac{14.6}{0.01} = 3.7 \text{ to } 1460 \text{ days}$$

Adding the factor of resuspension and lake mixing, the aforementioned theoretical settling time could easily be doubled and to exceed 8.2 days, the flow through time. It is therefore reasonable to assume that R=0 when Q is greater than 420 cms. The approach for determining the sedimentation rate, , is then as follows:

(a) Before application of AWT, R is determined by the regression line:

For $Q < 420$ cms (cubic meter per second)

$$R = 0.00115 \times Q + 0.470$$

For $Q > 420$ cms

$$R = 0$$

(b) After AWT:

Same equation in a) applies with the exception when $R > 0.2$ then set as the upper limit.

$R = 0.2$ (to match the post-AWT value in 1978 and 1979)

Then $\sigma = \frac{R * \rho}{(1-R)}$

Where $\rho = \frac{Q}{V}$ = no. of exchange in a unit of time

Reservoir Hydraulics

Two models of the hydraulics of the reservoir were compared: 1) well-mixed, in which the lake is assumed to maintain uniform phosphorus concentration as flow is added and discharged; and 2) a plug-flow model, which assumes that the lake behaves like a river with essentially no longitudinal mixing. Loss of phosphorus by sedimentation is assumed to occur in both models.

As shown in Figure 10-8, even under low flow conditions, the hydraulic behavior of the reservoir (i.e., well-mixed vs plug flow) seems to have relatively little effect on the predicted reduction time. This is partially due to the higher March 1 concentration under the plug-flow assumption. As explained in Appendix A, an in-lake total P concentration of 0.02 ug/l on December 1 was assumed for all calculations. (This value corresponds to the mean total phosphorus concentration observed in late October or early November at Long Lake Dam.) Because the plug-flow model responds much faster to changes in the inflow, the higher loading rates in early spring lead to a higher in-lake concentration in the spring.

Because it yields slightly more conservative predictions, the completely mixed-model is used for all subsequent calculations described here.

Initiation Date

The reduction time can be determined by examining the variation in total phosphorus concentration in Long Lake as a function of when phosphorus removal at the major STPs (e.g., Spokane STP, Idaho STPs) is initiated. Figure 10-9 indicates that under the worst flow conditions (low flow), even all year around removals of phosphorus at the 85 percent level at the Spokane STP could not reduce lake phosphorus concentrations to levels within the 95 percent confidence band for a chlorophyll a criterion of 10 ug/l by June 1. Figure 10-9 also shows the effect of differing start-up dates for phosphorus removal at the Spokane STP on in-lake P concentrations. Figure 10-10 shows that removal at 90 percent at the Spokane STP needs to be initiated by April 1 to reduce phosphorus concentrations to the permissible in-lake phosphorus concentration range. Figure 10-11 shows that removal at 85 percent level at both the Spokane STP and Idaho STPs will get the same effect as that shown by removal 90 percent of P-load at the Spokane STP only. Under the existing loading condition, initiation of removal any earlier than April 1 will not result in a lower concentration on June 1, although levels on April 1 and May 1 are lower.

Streamflow

Concentrations of total-P in Long Lake are quite sensitive to streamflow, as shown in Figure 10-12, which shows the phosphorus concentration patterns at low, normal and high flow conditions for 85 percent phosphorus removal at the Spokane STP. As can be seen from Figure 10-12, initiation of phosphorus removal on April 1 results in acceptable levels of phosphorus by June 1 if inflow into Long Lake is in high flow condition. For low flow conditions, 90 percent removal at the Spokane STP must be initiated April 1, as shown in Figure 10-10.

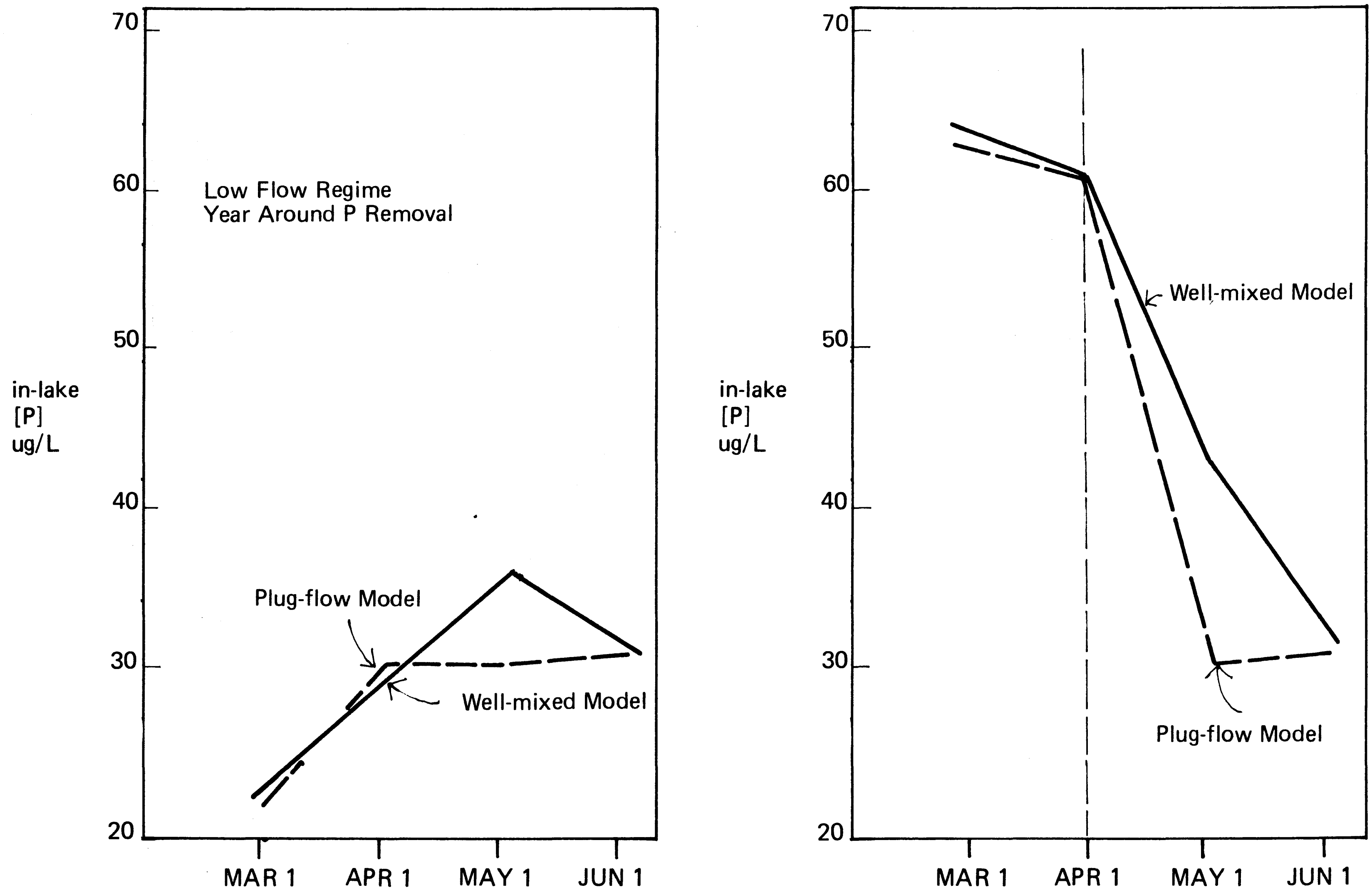
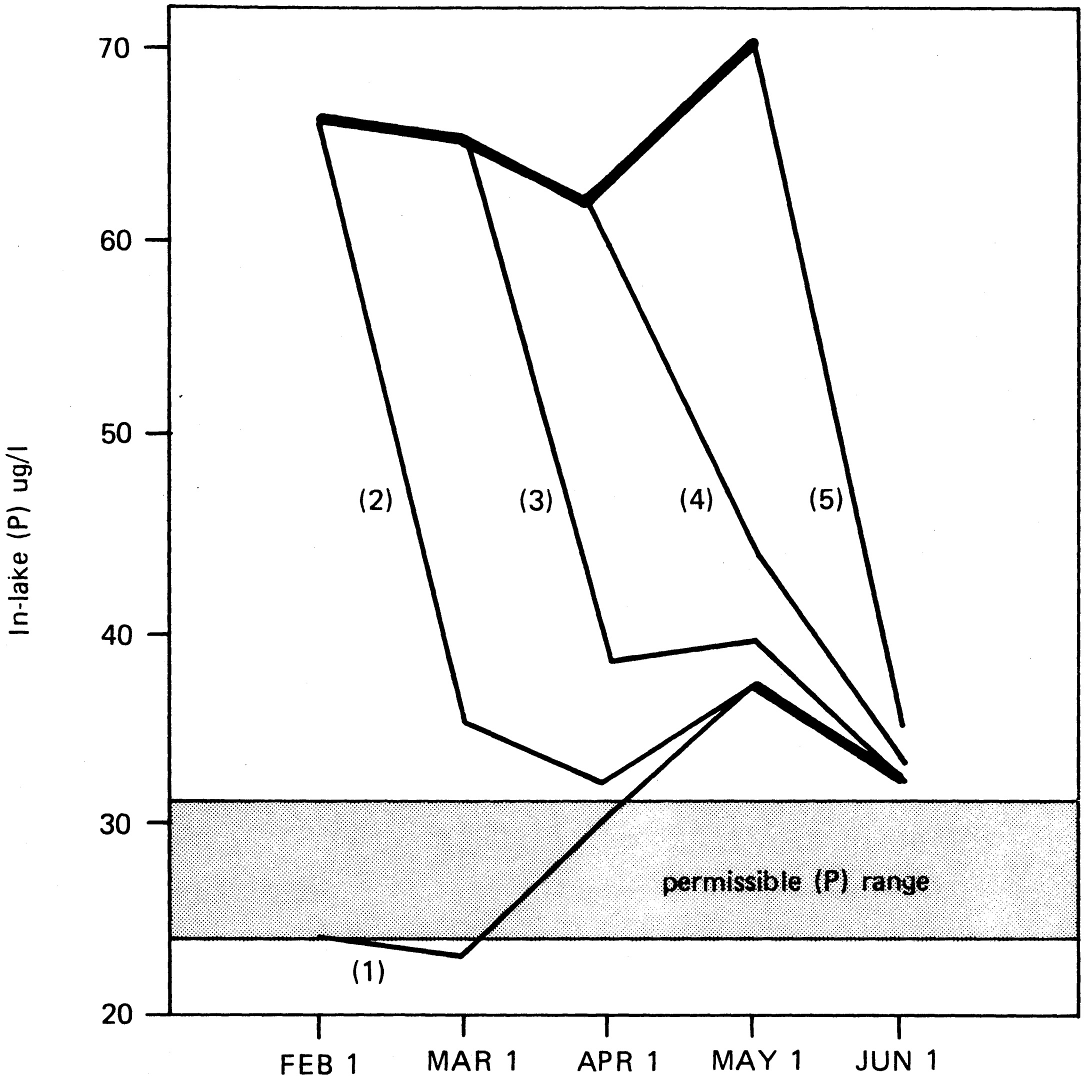
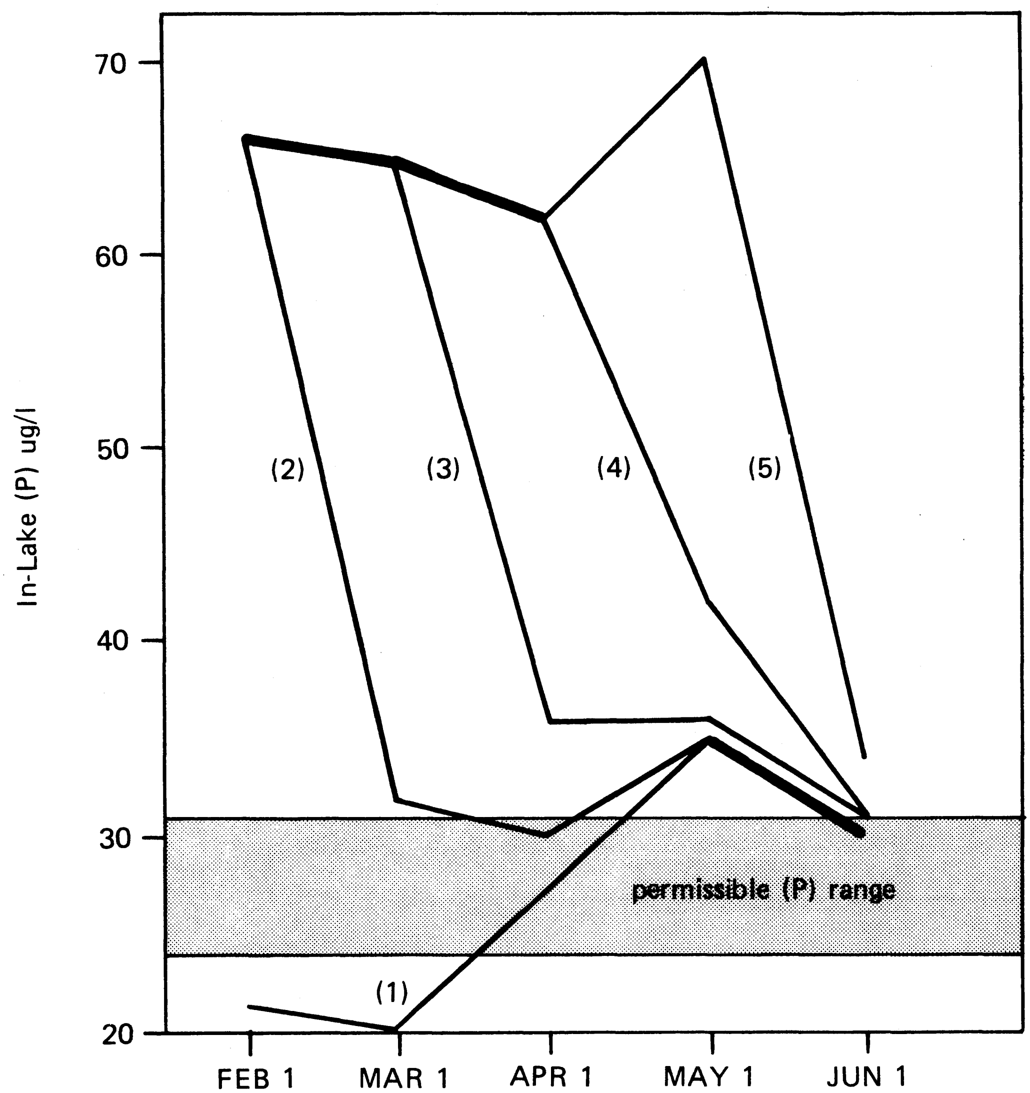


FIGURE 10-8
Comparison of predicted total phosphorus concentrations in Long Lake using well-mixed and plug flow hydraulic models.



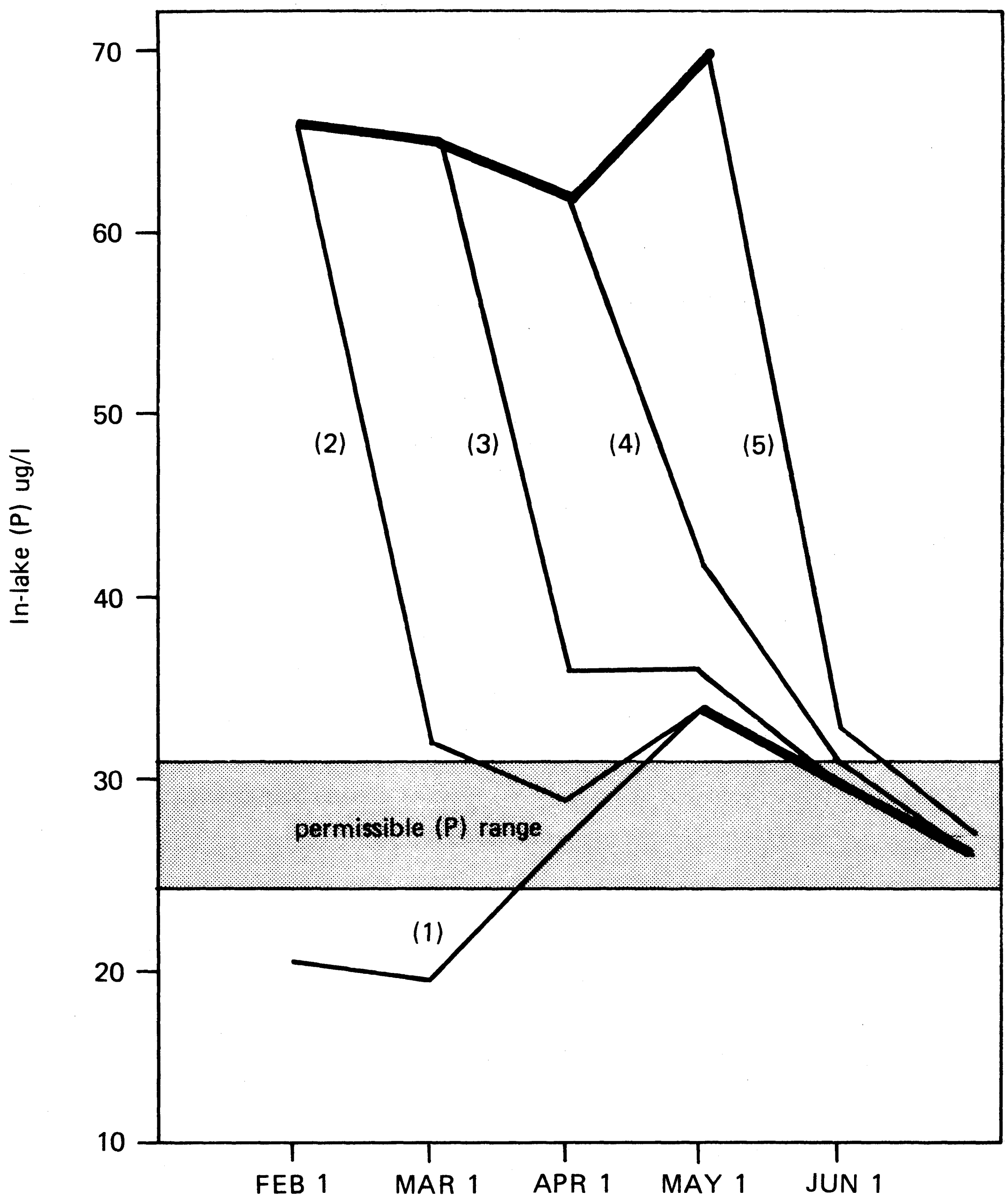
(1) all year around removal
(2) removal begins @ Feb. 1
(3) removal begins @ Mar. 1
(4) removal begins @ Apr. 1
(5) removal begins @ May 1

FIGURE 10-9
Simulated patterns of total phosphorus concentration in Long Lake for seasonal phosphorus removal initiation dates (85% P removal at the Spokane STP only) — 1980 condition



(1) all year around removal
(2) removal begins @ Feb. 1
(3) removal begins @ Mar. 1
(4) removal begins @ Apr. 1
(5) removal begins @ May 1

FIGURE 10-10
Simulated patterns of total phosphorus concentration in Long Lake for several phosphorus removal initiation dates (90% P removal at Spokane STP only) — 1980 condition



(1) all year around removal
(2) removal begins @ Feb. 1
(3) removal begins @ Mar. 1
(4) removal begins @ Apr. 1
(5) removal begins @ May 1

FIGURE 10-11
Simulated patterns of total phosphorus concentration in Long Lake for several phosphorus removal initiation dates (90% P removal at the Spokane and Idaho STPs) — 1980 condition

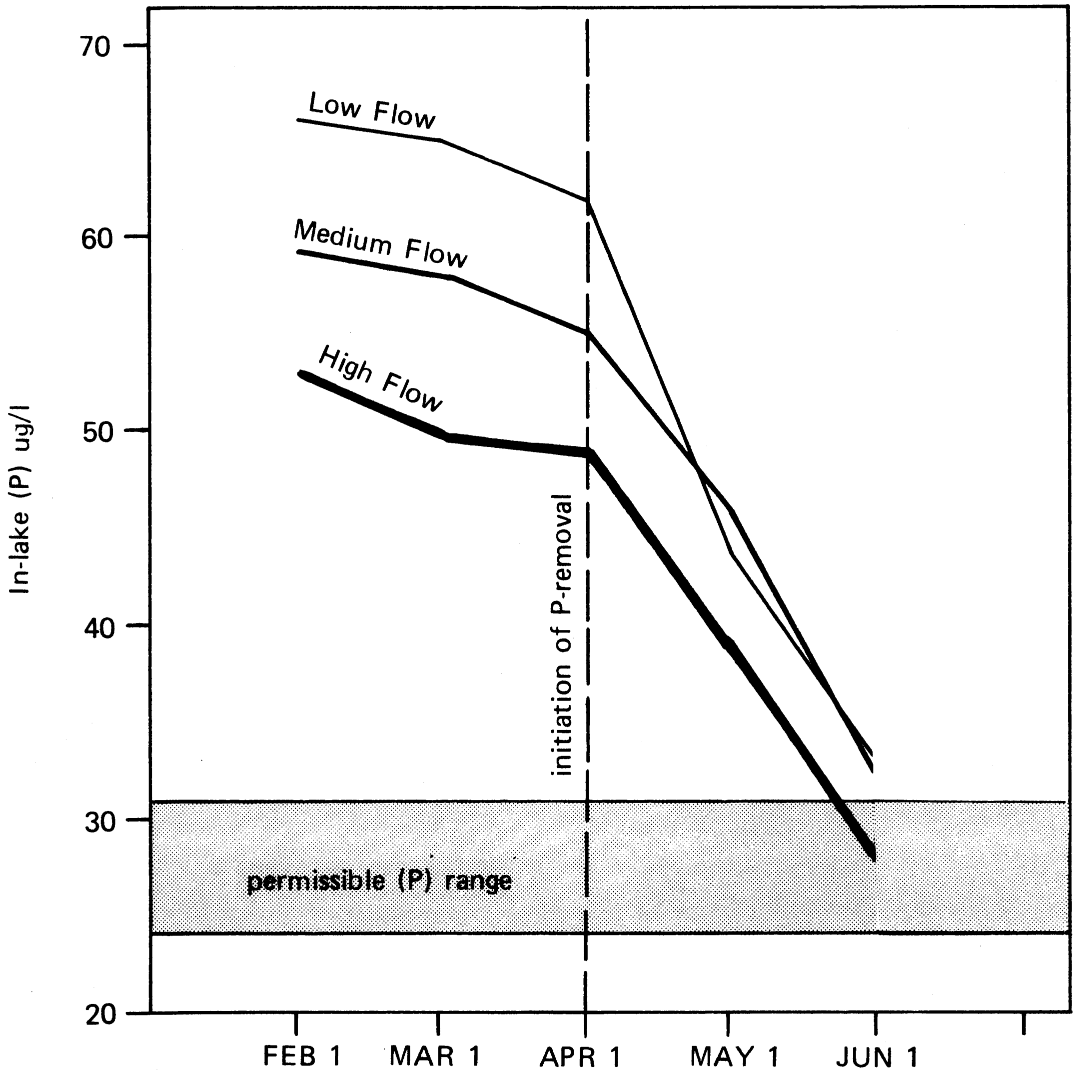


FIGURE 10-12
Influence of river discharge patterns on patterns of total phosphorus concentration in Long Lake, with initiation of phosphorus removal on April 1

Figure 10-13 shows the existing lake phosphorus loading rates as a function of the streamflow measured at Long Lake under three conditions: 1) without any STP removals, 2) with 85 percent removal at the Spokane STP only (model 1), and 3) with 85 percent phosphorus removal at the Idaho STP and Spokane STP (model 2). These curves are constructed using the in-stream phosphorus concentration and flow relationship developed by Yake (1979) and adjustments of effluent data from the Spokane and Idaho STPs. As shown in Figure 10-5, between the month of March to May, the low flow regime is between 5000 to 8000 cfs, the medium flow regime is from 9000 to 21000 cfs and the high flow regime is from 17000 to 31000 cfs. The relative ratio of flushing rate for the three flow regimes is roughly 3.7:2.2:1. The relative ratio of phosphorus loading for the three flow regimes is roughly 3:2:1 in order of high to low flow. The relative ratio will increase when the sedimentation factor is included. Because the lower the flow, the greater the sedimentation rate and the actual (or effective) P load to the lake will be less. Therefore, it is important to recognize that while high flow represents a greater flushing rate, at the same time it brings a greater load to be flushed. The net effect on in-lake phosphorus concentration is still in favor of higher flow, i.e., it decreases. Interestingly, the in lake P concentration under a low flow regime may be lower than that under the medium flow regime as shown in Figure 10-12.

This analysis clearly indicates that it would be possible to attain the desired level of in-lake phosphorus at the beginning of the critical season by varying the initiation date as a function of flow regime. According to conversations with Joe Clegg of Washington Water Power (November 6, 1980) and Robert T. Davis, Survey Snow Supervisor for the U.S. Soil Conservation Service (SCS) (November 7, 1980), estimates of inflow to Long Lake from February to June are not available. It would probably be possible to develop an estimate using forecasted runoff into Lake Coeur d'Alene (prepared by the SCS) or other data. Development of such a forecasting technique, would permit the City of Spokane and future municipal dischargers required to remove P seasonally to initiate P removal a month later when it is known that inflow in May will be adequate to achieve desirable lake water quality conditions. Savings associated with a later start-up date for the Spokane AWT would be substantial and would probably exceed costs of developing a forecasting technique within a year.

Future Considerations

Figure 10-14 shows the predicted in-lake phosphorus concentration under the 1990 condition. It will become necessary to initiate 90 percent phosphorus removal as early as March 1 in order to reach the upper permissible phosphorus concentration limit on June 1. If the removal is initiated a month later on April 1, the concentration on June 1 is just 1 ug/l above the upper limit of the permissible phosphorus concentration. The initiation date for phosphorus removal is thus very sensitive to the upper limit of the permissible phosphorus concentration. In order to allow the in-lake phosphorus concentration on June 1 be lowered to the middle of the permissible range, treatment of other sources along with the STPs will become necessary in 1990 with the percent reduction will being as indicated in Chapter 9.

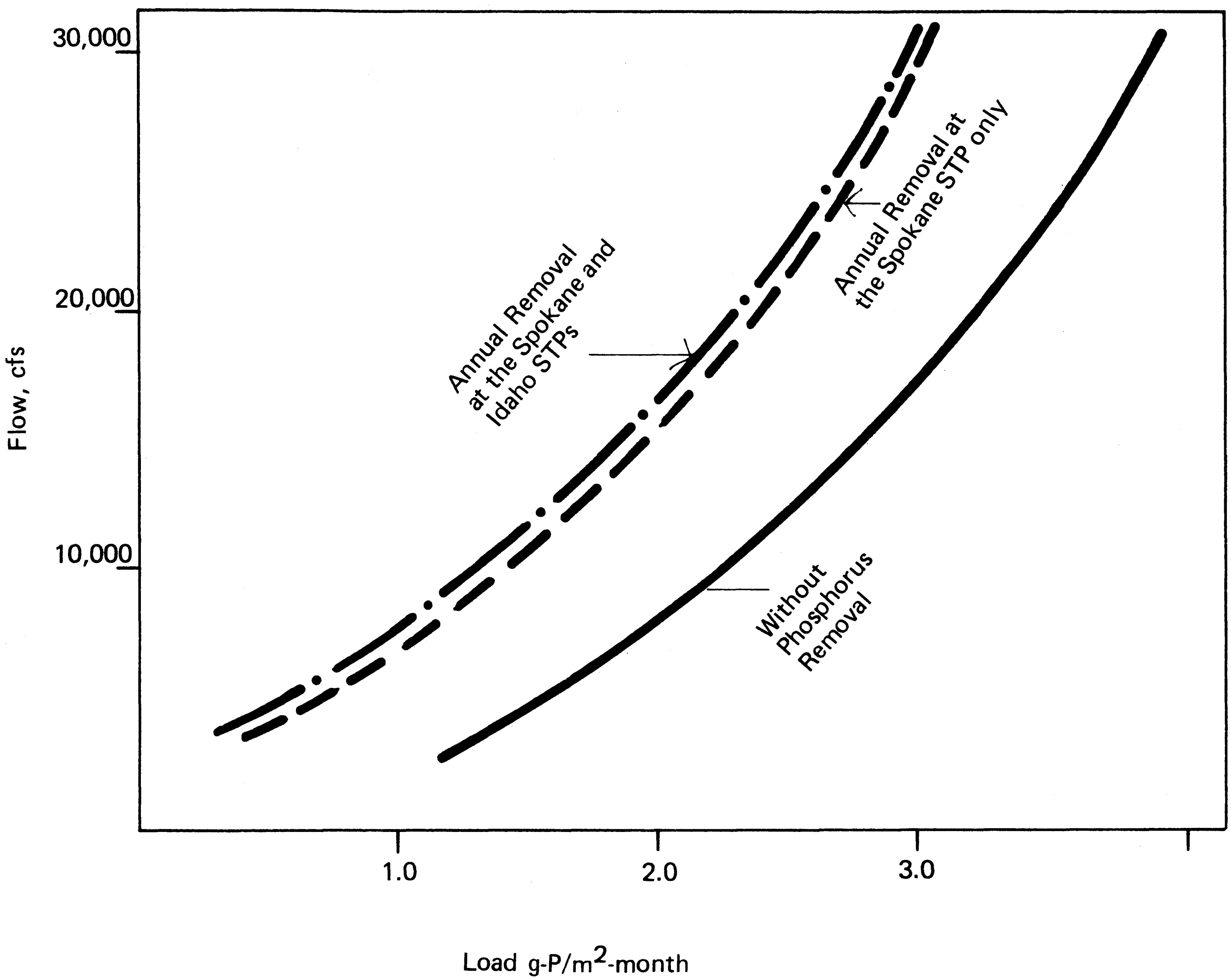
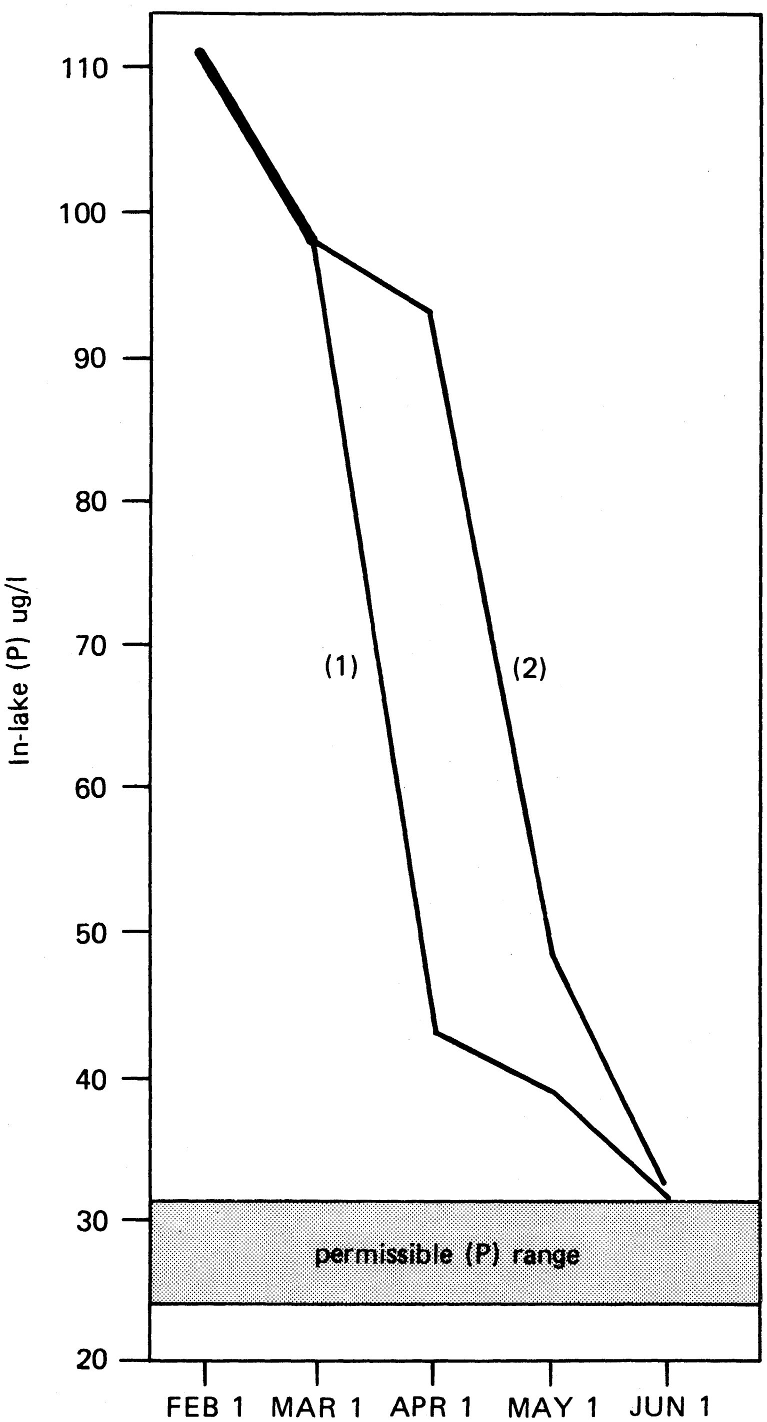


FIGURE 10-13
Phosphorus loading rate to Long Lake as a function of Long Lake discharges



(1) removal begins @ Mar. 1
(2) removal begins @ Apr. 1

FIGURE 10-14
Simulated in-lake phosphorus concentrations in Long Lake for 1990 condition (90% P removal at all major STPs)

Conclusions

The analysis described here shows that at present phosphorus loading rates to Long Lake, discontinuation of phosphorus removal at the Spokane AWT from November 1 through March 31 would be expected (with 95 percent confidence) to result in a mean seasonal chlorophyll a concentration of 10 ug/l. If an accurate method of forecasting inflow to Long Lake is developed, initiation of phosphorus removal could be delayed until May 1 during high flow years.

This conclusion is based on the assumptions described above; therefore, the removal season would change if other assumptions are made. These assumptions include: critical season extends from June through October, mean seasonal chlorophyll a level of 10 ug/l in Long Lake is the criterion for acceptable water quality conditions, the reservoir can be approximated by a completely mixed-model and 90 percent phosphorus removal at the Spokane STP or 85 percent removal at both the Spokane and Idaho STPs.

The concentrations predicted by the model with year-round removal are in the upper portion of the acceptable range; this corresponds to the results observed by Soltero, et al. (1979, 1980) suggesting that the model is a reasonable approximation to the system.

Although it would be desirable to use a smaller time step (e.g., days or weeks) to set a start date for phosphorus removal, the available data are monthly. Extrapolation to a smaller time step is not justified since flow may vary considerably during a month. For example, a major portion of the total runoff for a month might occur during the first week of the month. Thus, a monthly time step should be used for definition of the removal period.

Since a number of assumptions must be made in an analysis of this type, if a seasonal removal policy is implemented, a monitoring program like that outlined in Appendix E should be continued through the following growing season to verify that the lake has not been harmed.

It should also be noted that the foregoing analysis deals with the present situation. As the area population increases, the feasibility of continuation of seasonal phosphorus removal should be reevaluated for the higher loading rates that will occur with the larger population.

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APPENDIX A

COMPUTATION OF SEASONAL CONCENTRATION PATTERNS

Computation Scheme

To predict the in-lake total phosphorus concentration prior to the "growing season" that will result from the various seasonal phosphorus removal strategies, two types of phosphorus models, which bracket the behavior of Long Lake, are used. One model assumes that the lake is well mixed and expresses the mass balance for phosphorus in the lake as shown in equation 1 with respect to the Spokane River - Long Lake system.

$$V\frac{dp}{dt} = M - \sigma PV - QP \qquad (1)$$

where P = lake phosphorus concentration (ug/L)

V = lake volume (10^6 m^3)

M = mass rate of phosphorus inflow to lake (10^3 kg/unit of time)

Q = volume rate of water outflow from lake (10^6 m3/unit of time)

σ = sedimentation coefficient (per unit of time)

t = the chosen time unit

This equation states that the change in phosphorus mass in the lake per unit of time is equal to the phosphorus loading minus the sum of phosphorus lost to the sediment and phosphorus leaving the lake through the outflow. The time-dependent solution (of equation 1) is:

$$P(t) = \frac{L}{\sigma z + z/\varphi}[1-e^{-(\frac{1}{\varphi}+\sigma)t}] + P(t-1)e^{-(\frac{1}{\varphi}+\sigma)t} \qquad (2)$$

where

P(t) = in-lake phosphorus concentration at time t (mg/l)

L = M/A = areal phosphorus loading (g/m^2 - unit of time)

z = lake mean depth (m)

φ = hydraulic detention time (unit of time), V/Q

t = length of time

V = volume of the lake

Q = reservoir discharge

P(t-1) = in-lake phosphorus concentration (mg/L), at previous time step

The in-lake phosphorus concentration, P(t), is influenced by the two terms on the right side of equation (1). The first term represents the in-lake concentration change due to the external loading in that time period, while the second term represents the influence of residual in-lake concentration at the beginning of the time period. The exponential term represents the rate at which the concentration decreases as a result of flushing and sedimentation. If the external phosphorus loading rate, the mean depth of the lake, and the flushing and sedimentation rates are known, this model can be used to compute the temporal profile of the in-lake phosphorus concentration.

The second model is simpler. It assumes that prior to the growing season, the reservoir behaves as a plug flow system, like a river, so that the in-lake concentration is equal to the concentration of the inflow.

The actual behavior of Long Lake probably falls somewhere between the conditions assumed by these two models. Thus, the concentrations calculated using these two models would represent the boundaries that bracket the true concentration at any given time period.

Input Data

Table A-1 gives the results of a statistical analysis by month of the inflow data of Long Lake. The values in each column are those exceeded a specified percentage of time. For subsequent computations, the flows exceeded 90, 50, 10 percent of the time are used to represent low, medium, and high flow regimes.

Yake (1979) stated that the phosphorus concentration at the lower Spokane River stations appears to be primarily flow-related. This relationship is shown in the following equation, which relates the total PO_4-P concentration to the flow measured at Riverside State Park.

$$[P] = 6.288/Q^{(.504)}$$

The product, Q x [P], for each month gives the input phosphorus load for that month to Long Lake from the Spokane River without advanced waste treatment (phosphorus removal). The input from the Little Spokane River is relatively constant due to the influence of the Spokane aquifer, (which amounts to about 4.5 percent of the input from the Spokane River). The sum of the Spokane and Little Spokane River load gives the total phosphorus load to Long Lake.

The measured 1979 mean flow and phosphorus concentration of the Spokane Treatment Plant (STP) influents on a monthly basis are listed in Table A-2. It is assumed that these loads represent a typical loading profile for any year and that the STP removes 85 percent of the phosphorus load from the influent to the plant. For those months when the phosphorus removal is applied at the Spokane STP, the total phosphorus load to Long Lake is reduced by 85 percent of the influent to the Spokane AWT in that month.

TABLE A-1

SPOKANE RIVER FLOW STATISTICS AT LONG LAKE STATION
(USGS DATA 1939-79)

Period of Record	Month	Value exceed P percent of the time (cfs)						
		P_{95}	P_{90}	P_{75}	P_{70}	P_{50}	P_{25}	P_{10}
1940-79	January	2900	3400	4600	4900	5800	7500	13000
1940-79	February	3800	4500	5700	5900	7100	11000	16000
1940-79	March	4400	5200	6500	7000	9500	12000	17000
1939-79	April	5300	6300	11000	12000	15000	20000	26000
1939-79	May	6000	7500	15000	17000	21000	26000	31000
1939-79	June	3100	3800	5100	5500	11000	18000	24000
1939-79	July	1300	1700	2300	2500	3200	4200	5200
1939-79	August	540	1100	1600	1700	2200	2600	3000
1939-79	September	600	1100	1800	2000	2400	2800	3300
1939-79	October	1200	1700	2400	2500	2900	3500	4200
1939-79	November	2000	2500	2900	3100	3600	4700	6000
1939-79	December	2300	2800	3600	4000	5000	7100	13000

TABLE A-3

Month	Flow	Concentration from Curve-fitted eqn.	Untreated Load to Long Lake	Spokane STP Influent Flow	Spokane STP Influent Concentration	Reduced Load	Reduced Load to Long Lake, LD
DEC	2800	0.1718 mg/l	1.8275 g/m^2	1.30 (m^3/s)	5.99 mg/l	.8495 g/m^2	.978 g/m^2
JAN	3400	0.1044 mg/l	1.3486 g/m^2	1.38 (m^3/s)	6.59 mg/l	.9920 g/m^2	.356 g/m^2

Month	Flow	$\frac{1}{\varphi} = \frac{Q}{V}$	σ	$\frac{1}{\varphi} + \sigma$	$Z\left(\frac{1}{\varphi} + \sigma\right)$	$e^{-\left(\frac{1}{\varphi} + \sigma\right)}$	$\frac{LD}{Z\left(\frac{1}{\varphi} + \sigma\right)}$	$1 - e^{-\left(\frac{1}{\varphi} + \sigma\right)}$
DEC	2800	0.674	0.5	1.174	17.14	0.3091	0.05706	0.6909
JAN	3400	0.846	0.5	1.346	19.65	0.2603	0.01812	0.7397

Month	Flow	$\frac{LD}{Z\left(\frac{1}{\varphi} + \sigma\right)} \; 1 - e^{-\left(\frac{1}{\varphi} + \sigma\right)}$	$P(t-1)\, e^{-\left(\frac{1}{\varphi} + \sigma\right)}$	P(t)	PP(t) = phos. conc. from plug flow model
DEC	2800	0.039	0.006	0.045	0.096
JAN	3400	0.013	0.012	0.025	0.029

APPENDIX B-1 PROGRAM LISTING - DATA ANALYSIS PROGRAM

PROGRAM PLOADS1

```
      PROGRAM PLOAD1(INPUT,TAPE2,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMMON /DATE/ IYEAR(10),KMTH(12),KDAY(12),N(12)
      COMMON /LOADSM/ P1SM(6,12),P2SM(6,12),P3SM(12),P4(10)
      COMMON /LDLSR/ P1LSR(6,12),P2LSR(6,12),P3LSR(12)
      COMMON /LDLLD/ P1LLD(6,12),P3LLD(6,12),QLLD(6,12),
     1               CLLD(6,12),AQLLD(12),ACLLD(12)
      COMMON /LAKE/ PLAKE(6,12),P3LAKE(12),DP(12)
      COMMON /RESULT/ RHO(12),DELP(12),SIGMA(12)
      DIMENSION QSM(6,12),CSM(6,12),QLSR(6,12),CLSR(6,12)
      REAL LP1,LP2
      DATA C1/35.3/,C2/.00414/,C3/.000001/,V/305000000./
      DATA A/20840000./,ZBAR/14.6/,C4/0.326/
      DATA KMTH/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,3HJUN,3HJUL,3HAUG
     *          ,3HSEP,3HOCT,3HNOV,3HDEC/
      DATA KDAY/31,28,31,30,31,30,31,31,30,31,30,31/
C
C     THIS PROGRAM COMPUTES PHOSPHORUS BUDGET AT LONG LAKE
C
C
C     P1= INSTANTANEOUS AREAL P-LOAD, G/SQ.M./DAY
C     P2= INSTANTANEOUS P-LOADS, IN METRIC TONS
C     P3= MEAN MONTHLY AREAL P-LOAD, G/SQ.M.
C     P4= SEASONSL P-LOAD, G/SQ.M.
C
C     READ INPUTS AND BEGIN THE COMPUTATION LOOPS
      READ(5,10) NSET
      DO 100 NN=1,NSET
      READ(5,10) IYEAR(NN)
      WRITE(6,50) IYEAR(NN)
      WRITE(6,51)
15    READ(5,30) MTH,J,IUNIT,QSM(J,MTH),CSM(J,MTH),QLSR
     1          (J,MTH),CLSR(J,MTH)
      READ(2,30) MTH,J,IUNIT,QLLD(J,MTH),CLLD(J,MTH)
      N(MTH)=J
      IF(MTH.EQ.13) 80,35
35    P1SM(J,MTH)=C2*QSM(J,MTH)*CSM(J,MTH)
      P1LSR(J,MTH)=C2*QLSR(J,MTH)*CLSR(J,MTH)
      P1LLD(J,MTH)=C2*QLLD(J,MTH)*CLLD(J,MTH)
      PLAKE(J,MTH)=CLLD(J,MTH)*V/A
      IF (IUNIT.EQ.0) 40,36
36    QSM(J,MTH)=QSM(J,MTH)/C1
      QLSR(J,MTH)=QLSR(J,MTH)/C1
      QLLD(J,MTH)=QLLD(J,MTH)/C1
      P1SM(J,MTH)=P1SM(J,MTH)/C1
      P1LSR(J,MTH)=P1LSR(J,MTH)/C1
      P1LLD(J,MTH)=P1LLD(J,MTH)/C1
40    GO TO 15
80    SUMPIN=0.
      SUMPOUT=0.
      SUMDELP=0.
      SUMSIG=0.
      SUMRHO=0.
      WRITE(6,54)
      WRITE(6,55)
      DO 95 MTH=6,11
      JJ=N(MTH)
      SUMPSM=0.
      SUMPLSR=0.
      SUMPLLD=0.
      SUMQLLD=0.
      SUMPLK=0.
      DO 90 J=1,JJ
      WRITE(6,56) KMTH(MTH),QSM(J,MTH),CSM(J,MTH),P1SM(J,MTH),
     1          QLSR(J,MTH),CLSR(J,MTH),P1LSR(J,MTH),QLLD(J,MTH)
     2         ,CLLD(J,MTH),P1LLD(J,MTH)
      SUMPSM=SUMPSM+P1SM(J,MTH)
      SUMPLSR=SUMPLSR+P1LSR(J,MTH)
      SUMPLLD=SUMPLLD+P1LLD(J,MTH)
      SUMQLLD=SUMQLLD+QLLD(J,MTH)
      SUMPLK=SUMPLK+PLAKE(J,MTH)
90    CONTINUE
      P3SM(MTH)=SUMPSM*KDAY(MTH)/JJ
      P3LSR(MTH)=SUMPLSR*KDAY(MTH)/JJ
      P3LLD(MTH)=SUMPLLD*KDAY(MTH)/JJ
      P3LAKE(MTH)=SUMPLK/JJ
      AQLLD(MTH)=SUMQLLD/JJ
      RHO(MTH)=AQLLD(MTH)*KDAY(MTH)*86400./V
      ACLLD(MTH)=SUMPLLD/(C2*AQLLD(MTH))/JJ
      DELP(MTH)=P3SM(MTH)+P3LSR(MTH)-P3LLD(MTH)
      IF(MTH.GT.6) 92,94
92    MTHM1=MTH-1
      DP(MTH)=P3LAKE(MTH)-P3LAKE(MTHM1)-DELP(MTH)
      SIGMA(MTH)=-DP(MTH)*A/(ACLLD(MTH)*V)
94    WRITE(6,60) P3SM(MTH),P3LSR(MTH),AQLLD(MTH),ACLLD(MTH),
     1          P3LLD(MTH),SIGMA(MTH),RHO(MTH),DELP(MTH),DP(MTH)
      SUMPIN=SUMPIN+P3SM(MTH)+P3LSR(MTH)
      SUMPOUT=SUMPOUT+P3LLD(MTH)
      SUMDELP=SUMDELP+DELP(MTH)
      SUMSIG=SUMSIG+SIGMA(MTH)
      SUMRHO=SUMRHO+RHO(MTH)
95    CONTINUE
C
```

APPENDIX B-1 (con)

```
      SIGBAR=SUMSIG/6.
      P4(NN)=SUMPIN
      P4P=SUMPIN*C4
      POUTP=SUMPOUT*C4
      R=SUMDELP/SUMPIN
      LP1=SUMPIN*(1-R)/SUMRHO*C4
      LP2=SUMPIN/(SIGBAR+SUMRHO)*C4
      PSS1=LP1/ZBAR
      PSS2=LP2/ZBAR
      CHLA1=10.12*LP1+5.58
      CHLA2=10.12*LP2+5.58
C
      WRITE(6,65) P4(NN),P4P
      WRITE(6,66) SUMPOUT,POUTP
      WRITE(6,67) R,SIGBAR,SUMRHO
      WRITE(6,68) LP1,LP2
      WRITE(6,69) CHLA1,CHLA2
      WRITE(6,70) PSS1,PSS2
100   CONTINUE
C
10    FORMAT (I5)
30    FORMAT(2I2,I1,4F10.0)
50    FORMAT(//,*YEAR*,I5,11X,*SPOKANE RIVER*,23X,*LITTLE SPOKANE*,
     1        *RIVER*,22X,*LONG LAKE DAM*)
51    FORMAT(10X,33H---------------------------------,1X,8H--------,
     1        25H-------------------------,1X,20H--------------------,
     2        13H-------------)
54    FORMAT(/,*MONTH*,4X,*CMS*,1X,*MG-PO4/L*,1X,*G/SQ.M-DAY*,1X,
     1        *G/SQ.M-MO*,1X,*CMS*,1X,*MG-PO4/L*,1X,*G/SQ.M-DAY*,1X,
     2        *G/SQ.M-MO*,1X,*CMS*,1X,*MG-PO4/L*,1X,*G/SQ.M-DAY*,1X,
     3        *G/SQ.M-MO*,1X,*SIGMA*,1X,*RHO*,3X,*DELP*,3X,*DP*)
55    FORMAT(5H=====,4X,3H===,1X,8H========,1X,10H==========,1X,
     1        9H=========,1X,3H===,1X,8H========,1X,10H==========,1X,
     2        9H=========,1X,3H===,1X,8H========,1X,10H==========,1X,
     3        9H=========,1X,5H=====,1X,3H===,3X,4H====,3X,2H==)
56    FORMAT(1X,A3,5X,F4.0,1X,F5.2,5X,F5.2,14X,F4.0,2X,F5.2,5X,F5.2,14X,
     1        F4.0,1X,F5.2,5X,F5.2)
60    FORMAT(/,3X,*MEAN*,27X,F5.2,29X,F5.2,3X,F4.0,1X,F5.2,16X,F5.2,3X,
     1        F5.2,1X,F5.2,F5.2,1X,F5.2)
65    FORMAT(/,5X,26H*****TOTAL SEASONAL LOAD =,F8.2,16H G PO4/SQ.M. OR
     1        ,F8.2,*G-P/SQ.M.*,5H*****)
66    FORMAT(/,5X,45H*****TOTAL SEASONAL LOAD EXIT FROM THE LAKE =,
     1        F8.2,16H G-PO4/SQ.M. OR ,F8.2,*G-P/SQ.M.*,5H*****)
67    FORMAT(/,5X,3H*R=,F5.2,2X,8H*SIGBAR=,F6.4,2X,8H*RHOBAR=,F5.2,2X,
     1        *DURING THE GROWING SEASON*)
68    FORMAT(/,5X,33H*****SPECIFIC AREAL LOADING RATE=,F7.2,F7.2,
     1        2X,*G-P/SQ.M.*,5H*****)
69    FORMAT(/,5X,29H*****REGRESSED CHLOROPHYLL A=,F6.2,F6.2,
     1        2X,*MG/CU.M.*,5H*****)
70    FORMAT(/,5X,41H*****GROWING SEASON STEADY STATE P CONC.=,F6.2,
     1        F6.2,2X,*G-P/CU.M.*,5H*****)
C
      STOP
      END
```

APPENDIX B-2a
INPUT DATA TO DATA ANALYSIS PROGRAM
FLOW AND TOTAL PHOSPHORUS (PO_4-P) CONCENTRATIONS MEASURED AT SPOKANE RIVER (Nine Mile Dam) AND LITTLE SPOKANE RIVER

Month — CFS — mg/l — Nine Mile Dam — Little Spokane River

```
1972
189.4   12.90
06 1128113.    0.12    222.   0.05
06 2114475.    0.12    210.   0.15
07 113828.     0.23    176.   0.19
07 214688.     0.12    156.   0.20
07 314526.     0.17    154.   0.10
07 414035.     0.27    151.   0.14
07 512725.     0.44    140.   0.14
08 112158.     0.54    136.   0.14
08 211592.     0.53    128.   0.11
08 312068.     0.58    140.   0.11
08 412604.     0.41    141.   0.15
09 112096.     0.46    133.   0.13
09 211314.     0.73    134.   0.12
09 311604.     0.82    132.   0.11
09 411996.     0.52    152.   0.11
10 112103.     0.73    141.   0.12
11 111891.     0.73    170.   0.16
13
```

CMS (for rest of years)

```
1973
67.8   19.86
6 1 119.40    .41    3.56   .14
6 2 80.74     .42    3.56   .09
7 1 81.02     .33    3.14   .09
7 2 57.05     .47    2.86   .08
7 3 40.55     .78    2.74   .07
7 4 30.22     .70    2.41   .08
7 5 25.98     .92    2.38   .10
8 1 27.62     1.13   2.32   .15
8 2 36.51     .74    2.60   .08
8 3 35.57     .68    2.91   .08
9 1 42.39     .75    3.14   .06
9 2 70.52     .53    3.00   .08
9 3 66.19     .45    3.71   .10
10 1 62.94    .40    3.73   .09
11 1 122.68   .49    7.67   .14
13
1974
244.8   11.72
6 1 796.71    .13    12.39  .16
6 2 744.71    .10    7.22   .10
7 1 547.38    .10    6.73   .10
7 2 133.77    .18    7.16   .06
7 3 128.09    .13    6.62   .06
7 4 114.36    .24    6.48   .08
7 5 90.73     .22    5.49   .08
8 1 92.26     .27    5.21   .08
8 2 76.13     .26    4.98   .06
8 3 65.09     .43    4.92   .06
8 4 44.43     .37    4.78   .07
9 1 53.77     .47    4.61   .09
9 2 53.49     .55    4.78   .07
9 3 39.34     .32    4.90   .07
9 4 47.26     .35    4.87   .07
9 5 48.39     .30    4.81   .06
10 1 61.13    .32    5.12   .08
11 1 89.43    .31    5.0    .12
13
1975
194.2   12.84
6 1 556.60    .08    9.17   .12
7 1 138.92    .22    7.76   .14
7 2 179.05    .21    7.84   .51
7 3 98.62     .41    5.30   .12
8 1 43.05     .46    4.81   .14
8 2 99.82     .36    5.52   .13
9 1 74.87     .30    4.98   .11
9 2 92.40     .34    4.73   .05
10 1 99.17    .39    5.32   .14
11 1 126.60   .37    5.92   .15
13

1977
69.1   15.23
6 1 125.06    .28    3.99   .08
6 2 63.05     .41    3.17   .20
7 1 55.95     .40    2.91   .06
7 2 48.31     .54    2.91   .06
8 1 43.64     .55    2.77   .11
8 2 38.88     .49    2.72   .09
9 1 61.81     .33    3.28   .06
9 2 60.28     .30    3.40   .08
10 1 68.29    .28    3.59   .08
11 1 80.57    .33    4.61   .07
13
1978
113.6   9.54
6 1 174.7     .05    5.32   .10
7 1 151.8     .12    5.01   .14
7 2 82.7      .06    4.50   .10
8 1 54.7      .07    3.59   .09
8 2 47.8      .07    3.45   .08
8 3 78.2      .06    4.16   .10
9 1 76.5      .08    4.75   .10
10 1 74.1     .08    4.33   .06
11 1 79.3     .05    4.50   .02
13
1979
93.2   10.17
6 1 341.4     .06    4.44   .07
6 2 129.2     .07    3.51   .11
7 1 81.3      .09    3.28   .10
7 2 58.5      .06    2.89   .10
8 1 44.0      .12    2.69   .10
8 2 36.9      .08    2.97   .04
9 1 63.4      .11    3.68   .08
9 2 71.7      .09    3.28   .04
10 1 69.5     .10    3.23   .05
11 1 76.2     .09    4.19   .06
13
```

APPENDIX B-2b
INPUT DATA TO DATA ANALYSIS PROGRAM
FLOW AND TOTAL PHOSPHORUS (PO_4–P) CONCENTRATIONS
MEASURED AT LONG LAKE DAM

Month **CFS** **mg/l**

```
81/04/16. 22.08.22.
PROGRAM  INLLD

 6 1127540.   .12
 6 2115620.   .14
 7 113760.    .17
 7 215360.    .13
 7 315510.    .13
 7 414730.    .18
 7 511920.    .15
 8 111360.    .17
 8 212150.    .16
 8 313080.    .24
 8 413530.    .25
 9 113130.    .19
 9 212980.    .29
 9 311910.    .35
 9 412830.    .28
10 112280.    .18
11 112850.    .39
13
```

CMS(for rest of years)

```
 6 1 139.24   .20
 6 2 79.81    .16
 7 1 85.47    .18
 7 2 92.26    .24
 7 3 71.32    .16
 7 4 35.66    .32
 7 5 39.90    .39
 8 1 44.71    .36
 8 2 51.51    .44
 8 3 42.45    .46
 9 1 58.02    .42
 9 2 76.98    .53
 9 3 51.22    .38
10 1 52.36    .30
11 1 144.90   .20
13

 6 1 812.78   .13
 6 2 713.16   .07
 7 1 557.79   .10
 7 2 163.86   .05
 7 3 146.03   .06
 7 4 129.05   .09
 7 5 105.28   .09
 8 1 103.58   .13
 8 2 63.96    .16
 8 3 56.88    .17
 8 4 93.11    .20
 9 1 84.33    .19
 9 2 94.52    .17
 9 3 97.63    .21
 9 4 90.28    .28
 9 5 82.92    .20
10 1 103.58   .18
11 1 119.14   .18
13

 6 1 565.77   .11
 7 1 146.68   .14
 7 2 186.89   .08
 7 3 103.92   .11
 8 1 47.86    .11
 8 2 105.34   .14
 9 1 79.85    .18
 9 2 97.13    .15
10 1 104.49   .17
11 1 132.52   .18
13
 6 1 128.86   .09
 6 2 76.41    .14
 7 1 63.39    .11
 7 2 59.15    .13
 8 1 45.56    .24
 8 2 45.00    .27
 9 1 63.39    .44
 9 2 63.11    .25
10 1 78.39    .31
11 1 100.47   .16
13
 6 1 180.8    .06
 7 1 144.1    .05
 7 2 79.2     .07
 8 1 53.2     .06
 8 2 54.1     .03
 8 3 83.2     .08
 9 1 86.3     .04
10 1 98.5     .06
11 1 81.5     .05
13
 6 1 353.5    .07
 6 2 136.7    .06
 7 1 89.1     .05
 7 2 64.8     .06
 8 1 65.9     .05
 8 2 30.8     .01
 9 1 70.5     .04
 9 2 82.1     .04
10 1 71.3     .05
11 1 77.0     .07
13
```

APPENDIX B-3 Phosphorus Loading Data 1972

YEAR 1972	SPOKANE RIVER				LITTLE SPOKANERIVER				LONG LAKE DAM							
MONTH	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	SIGMA	RHO	DELP	DP
JUN	796.	.12	.40		6.	.05	.00		780.	.12	.39					
JUN	410.	.12	.20		6.	.15	.00		442.	.14	.26					
JUL	108.	.23	.10		5.	.19	.00		107.	.17	.07					
JUL	133.	.12	.07		4.	.20	.00		152.	.13	.08					
JUL	128.	.17	.09		4.	.10	.00		156.	.13	.08					
JUL	114.	.27	.13		4.	.14	.00		134.	.18	.10					
JUL	77.	.44	.14		4.	.14	.00		54.	.15	.03					
AUG	61.	.54	.14		4.	.14	.00		39.	.17	.03					
AUG	45.	.53	.10		4.	.11	.00		61.	.16	.04					
AUG	59.	.58	.14		4.	.11	.00		87.	.24	.09					
AUG	74.	.41	.13		4.	.15	.00		100.	.25	.10					
SEP	59.	.46	.11		4.	.13	.00		89.	.19	.07					
SEP	37.	.73	.11		4.	.12	.00		84.	.29	.10					
SEP	45.	.82	.15		4.	.11	.00		54.	.35	.08					
SEP	57.	.52	.12		4.	.11	.00		80.	.28	.09					
OCT	60.	.73	.18		4.	.12	.00		65.	.18	.05					
NOV	54.	.73	.16		5.	.16	.00		81.	.39	.13					

*****TOTAL SEASONAL LOAD = 27.04 G PO4/SQ.M. OR 8.82G-P/SQ.M.*****

*****TOTAL SEASONAL LOAD EXIT FROM THE LAKE = 19.34 G-PO4/SQ.M. OR 6.31G-P/SQ.M.*****

*R= .28 *SIGBAR=0.0000 *RHOBAR= 0.00 DURING THE GROWING SEASON

*****SPECIFIC AREAL LOADING= 2.19

*****SPECIFIC RETENTION RATE= .05

APPENDIX B-4 Phosphorus Loading Data 1973

YEAR 1973	SPOKANE RIVER				LITTLE SPOKANERIVER				LONG LAKE DAM							
MONTH	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	SIGMA	RHO	DELP	DP
JUN	119.	.41	.20		4.	.14	.00		139.	.20	.12					
JUN	81.	.42	.14		4.	.09	.00		80.	.16	.05					
JUL	81.	.33	.11		3.	.09	.00		85.	.18	.06					
JUL	57.	.47	.11		3.	.08	.00		92.	.24	.09					
JUL	41.	.78	.13		3.	.07	.00		71.	.16	.05					
JUL	30.	.70	.09		2.	.08	.00		36.	.32	.05					
JUL	26.	.92	.10		2.	.10	.00		40.	.39	.06					
AUG	28.	1.13	.13		2.	.15	.00		45.	.36	.07					
AUG	37.	.74	.11		3.	.08	.00		52.	.44	.09					
AUG	36.	.68	.10		3.	.08	.00		42.	.46	.08					
SEP	42.	.75	.13		3.	.06	.00		58.	.42	.10					
SEP	71.	.53	.15		3.	.08	.00		77.	.53	.17					
SEP	66.	.45	.12		4.	.10	.00		51.	.38	.08					
OCT	63.	.40	.10		4.	.09	.00		52.	.30	.07					
NOV	123.	.49	.25		8.	.14	.00		145.	.20	.12					

*****TOTAL SEASONAL LOAD = 24.48 G PO4/SQ.M. OR 7.98G-P/SQ.M.*****

*****TOTAL SEASONAL LOAD EXIT FROM THE LAKE = 15.36 G-PO4/SQ.M. OR 5.01G-P/SQ.M.*****

*R= .37 *SIGBAR=0.0000 *RHOBAR= 0.00 DURING THE GROWING SEASON

*****SPECIFIC RETENTION RATE= .08

APPENDIX B-5 Phosphorus Loading Data 1974

YEAR 1974	SPOKANE RIVER				LITTLE SPOKANERIVER				LONG LAKE DAM							
MONTH	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	SIGMA	RHO	DELP	DP
JUN	797.	.13	.43		12.	.16	.01		813.	.13	.44					
JUN	745.	.10	.31		7.	.10	.00		713.	.07	.21					
JUL	547.	.10	.23		7.	.10	.00		558.	.10	.23					
JUL	134.	.18	.10		7.	.06	.00		164.	.05	.03					
JUL	128.	.13	.07		7.	.06	.00		146.	.06	.04					
JUL	114.	.24	.11		6.	.08	.00		129.	.09	.05					
JUL	91.	.22	.08		5.	.08	.00		105.	.09	.04					
AUG	92.	.27	.10		5.	.08	.00		104.	.13	.06					
AUG	76.	.26	.08		5.	.06	.00		64.	.16	.04					
AUG	65.	.43	.12		5.	.06	.00		57.	.17	.04					
AUG	44.	.37	.07		5.	.07	.00		93.	.20	.08					
SEP	54.	.47	.10		5.	.09	.00		84.	.19	.07					
SEP	53.	.55	.12		5.	.07	.00		95.	.17	.07					
SEP	39.	.32	.05		5.	.07	.00		98.	.21	.08					
SEP	47.	.35	.07		5.	.07	.00		90.	.28	.10					
SEP	48.	.30	.06		5.	.06	.00		83.	.20	.07					
OCT	61.	.32	.08		5.	.08	.00		104.	.18	.08					
NOV	89.	.31	.11		5.	.12	.00		119.	.18	.09					

*****TOTAL SEASONAL LOAD = 23.78 G PO4/SQ.M. OR 7.75G-P/SQ.M.*****

*****TOTAL SEASONAL LOAD EXIT FROM THE LAKE = 18.35 G-PO4/SQ.M. OR 5.98G-P/SQ.M.*****

*R= .23 *SIGBAR=0.0000 *RHOBAR= 0.00 DURING THE GROWING SEASON

*****SPECIFIC AREAL LOADING= 1.61

*****SPECIFIC RETENTION RATE= .05

APPENDIX B-6 Phosphorus Loading Data 1975

YEAR 1975	SPOKANE RIVER				LITTLE SPOKANERIVER				LONG LAKE DAM							
MONTH	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	SIGMA	RHO	DELP	DP
JUN	557.	.08	.18		9.	.12	.00		566.	.11	.26					
JUL	139.	.22	.13		8.	.14	.00		147.	.14	.09					
JUL	179.	.21	.16		8.	.51	.02		187.	.08	.06					
JUL	99.	.41	.17		5.	.12	.00		104.	.11	.05					
AUG	43.	.46	.08		5.	.14	.00		48.	.11	.02					
AUG	100.	.36	.15		6.	.13	.00		105.	.14	.06					
SEP	75.	.30	.09		5.	.11	.00		80.	.18	.06					
SEP	92.	.34	.13		5.	.05	.00		97.	.15	.06					
OCT	99.	.39	.16		5.	.14	.00		104.	.17	.07					
NOV	127.	.37	.19		6.	.15	.00		133.	.18	.10					

*****TOTAL SEASONAL LOAD = 27.19 G PO4/SQ.M. OR 8.86G-P/SQ.M.*****

*****TOTAL SEASONAL LOAD EXIT FROM THE LAKE = 15.13 G-PO4/SQ.M. OR 4.93G-P/SQ.M.*****

*R= .44 *SIGBAR=0.0000 *RHOBAR= 0.00 DURING THE GROWING SEASON

*****SPECIFIC AREAL LOADING= 1.59

*****SPECIFIC RETENTION RATE= .09

APPENDIX B-7 Phosphorus Loading Data 1977

YEAR 1977 — SPOKANE RIVER — LITTLE SPOKANERIVER — LONG LAKE DAM

MONTH	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	SIGMA	RHO	DELP	DP
=====	===	========	==========	=========	===	========	==========	=========	===	========	==========	=========	=====	===	====	==
JUN	125.	.28	.14		4.	.08	.00		129.	.09	.05					
JUN	63.	.41	.11		3.	.20	.00		76.	.14	.04					
JUL	56.	.40	.09		3.	.06	.00		63.	.11	.03					
JUL	48.	.54	.11		3.	.06	.00		59.	.13	.03					
AUG	44.	.55	.10		3.	.11	.00		46.	.24	.05					
AUG	39.	.49	.08		3.	.09	.00		45.	.27	.05					
SEP	62.	.33	.08		3.	.06	.00		63.	.44	.12					
SEP	60.	.30	.07		3.	.08	.00		63.	.25	.07					
OCT	68.	.28	.08		4.	.08	.00		78.	.31	.10					
NOV	81.	.33	.11		5.	.07	.00		100.	.16	.07					

*****TOTAL SEASONAL LOAD = 18.15 G PO4/SQ.M. OR 5.92G-P/SQ.M.*****

*****TOTAL SEASONAL LOAD EXIT FROM THE LAKE = 10.92 G-PO4/SQ.M. OR 3.56G-P/SQ.M.*****

*R= .40 *SIGBAR=0.0000 *RHOBAR= 0.00 DURING THE GROWING SEASON

*****SPECIFIC AREAL LOADING= 2.92

*****SPECIFIC RETENTION RATE= .09

APPENDIX B-8 Phosphorus Loading Data 1978

YEAR 1978	SPOKANE RIVER				LITTLE SPOKANERIVER				LONG LAKE DAM							
MONTH	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	SIGMA	RHO	DELP	DP
JUN	175.	.05	.04		5.	.10	.00		181.	.06	.04					
JUL	152.	.12	.08		5.	.14	.00		144.	.05	.03					
JUL	83.	.06	.02		5.	.10	.00		79.	.07	.02					
AUG	55.	.07	.02		4.	.09	.00		53.	.06	.01					
AUG	48.	.07	.01		3.	.08	.00		54.	.03	.01					
AUG	78.	.06	.02		4.	.10	.00		83.	.08	.03					
SEP	77.	.08	.03		5.	.10	.00		86.	.04	.01					
OCT	74.	.08	.02		4.	.06	.00		99.	.06	.02					
NOV	79.	.05	.02		5.	.02	.00		82.	.05	.02					

*****TOTAL SEASONAL LOAD = 5.33 G PO4/SQ.M. OR 1.74G-P/SQ.M.*****

*****TOTAL SEASONAL LOAD EXIT FROM THE LAKE = 4.08 G-PO4/SQ.M. OR 1.33G-P/SQ.M.*****

*R= .23 *SIGBAR=0.0000 *RHOBAR= 0.00 DURING THE GROWING SEASON

*****SPECIFIC AREAL LOADING= .73

*****SPECIFIC RETENTION RATE= .10

APPENDIX B-9 Phosphorus Loading Data 1979

YEAR 1979	SPOKANE RIVER				LITTLE SPOKANERIVER				LONG LAKE DAM							
MONTH	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	CMS	MG-PO4/L	G/SQ.M-DAY	G/SQ.M-MO	SIGMA	RHO	DELP	DP
JUN	341.	.06	.08		4.	.07	.00		354.	.07	.10					
JUN	129.	.07	.04		4.	.11	.00		137.	.06	.03					
JUL	81.	.09	.03		3.	.10	.00		89.	.05	.02					
JUL	59.	.06	.01		3.	.10	.00		65.	.06	.02					
AUG	44.	.12	.02		3.	.10	.00		66.	.05	.01					
AUG	37.	.08	.01		3.	.04	.00		31.	.01	.00					
SEP	63.	.11	.03		4.	.08	.00		71.	.04	.01					
OCT	70.	.10	.03		3.	.05	.00		71.	.05	.01					
NOV	76.	.09	.03		4.	.06	.00		77.	.07	.02					

*****TOTAL SEASONAL LOAD = 5.94 G PO4/SQ.M. OR 1.94G-P/SQ.M.*****

*****TOTAL SEASONAL LOAD EXIT FROM THE LAKE = 4.54 G-PO4/SQ.M. OR 1.48G-P/SQ.M.*****

*R= .23 *SIGBAR=0.0000 *RHOBAR= 0.00 DURING THE GROWING SEASON

*****SPECIFIC AREAL LOADING= .97

*****SPECIFIC RETENTION RATE= .10

*****CHLA-PHOSPHORUS LOAD REGRESSION EQUATION= CHLA= 13.18 + 3.07(ALOAD - 1.98)

*****RETENTION FACTOR-FLOW REGRESSION EQUATION= SPR= .08 + -.00(QOUT -131.76)

*****R SQUARE FOR CHLA= .96 FOR RETENTION= .51

APPENDIX C

DESCRIPTION OF CAUSE-EFFECT MODELS SELECTED FOR THE WASTE LOAD ALLOCATION USE

URS/Spokane River Model

The URS/Spokane River Model (SRM) is a simple steady-state mass balance model. The underlying rationale for the mass-balance approach is as follows. During periods of relatively stable low flow, streamflow and other hydraulic properties at any fixed cross-section can be considered as essentially time invarient on an average daily basis. Similarly, biological processes, wastewater loads, and tributary inflows can be considered constant on an average daily basis. In short, the biochemical, transport, and loading regimes of the river approach a steady state under which incremental volumes of water can be envisioned as moving downstream in distinct units or "plugs". Waste inputs, mixing, dilution and biochemical reactions (for non-conservative variables) occur within the units as they move down river, but because the river is at steay state, the water quality of each unit passing a given cross-section is the same as that preceding it.

Using these concepts, only one incremental volume of water needs to be modeled (for the time of travel through the reach of interest) to generate an average daily river-quality profile.

The model is programmed to analyze nine variables: BOD, total-phosphorus, zinc, chlorine-residual, lead, copper, cadmium, ammonia-nitrogen, and dissolved oxygen.

Total-phosphorus, zinc, chlorine-residual, lead, cadmium, and copper are modeled as strictly conservative variables (i.e., mixing and dilution but no decay or sedimentation). BOD and ammonia-N is modeled using classical first-order decay kinetics of the form:

$$L_t = L_o 10^{-K_1 t}$$

where L_t = mass of variable at time t

L_o = mass of variable at time zero

K_1 = decay coefficient ($\log_{10}$)

t = time of increment sinze time zero (or time of travel between points of interest)

In the literature, K_1 values for BOD ranging between 0.1 to 2.0 per day and for ammonia ranging between 0.2-1.0 per day are reported. Dissolved oxygen is modeled by a differential equation of the form:

$$\frac{dO}{dt} = K_2 (O^* - O) - K_{BOD} L_{BOD} - \alpha \cdot K_{NOD} L_{NOD}$$

where O = the concentration of dissolved oxygen

O^* = the saturation concentration of dissolved oxygen at the local temperature and pressure

K_2 = the aeration rate in accordance with the Fickian diffusion analogy

K_{BOD} = K_1 for biological oxygen demand

K_{NOD} = K for nitrogenous oxygen demand

α = oxygen uptake per unit of NH_3 and NO_2 oxidation; 4.57 mg-O/mg-NH_3-N

The saturation concentration of dissolved oxygen is computed at standard pressure (29.92 in. of Hg) by the equation:

$$O = 24.89 - 0.426T + 0.00373T^2 - 0.0000133T^3$$

where T = temperature of water of °F.

The areation rate is computed by the following equation at 20°C:

$$K_2^{20} = 5.026\ \bar{u}^{-0.969} d^{-1.673} \times 2.31$$

where $\bar{u}$ = average velocity in the stream, ft/sec.

d = average depth of the stream, ft.

K_2 = reaeration coefficient/day

$$K_2^T = K_2^{20}\ \theta^{(T-20)}$$

K_2^T = the value of K_2 at the local temperature, T(°C)

θ = 1.0159

The model allows for multiple waste discharges, withdrawals and tributary flows, but does not permit branching stream systems to be simulated.

EPA/QUAL- II

EPA/QUAL-II IS A quasi steady-state stream water quality model. It assumes that the major transport mechanisms, advection and dispersion, are significant only along the main direction of flow. Input waste loads must be held constant over time. QUAL-II can be operated in a steady-state or dynamic mode. Dynamic operation makes it possible to study dissolved oxygen and temperature as they are affected by diurnal variations in meterological data.

QUAL-II permits any branching, one-dimensional stream system to be simulated. The stream system is subdivided in reaches, which are stretches of stream that have uniform hydraulic characteristics. Each reach is further divided into computational elements of equal length so that all computational elements in all reaches are the same length. All reaches must consist of an integer number of computational elements.

Seven different types of computational elements are modeled.

1. Headwater elements
2. Standard elements
3. Elements just upstream from a junction
4. Junction elements
5. Last element in system
6. Input elements
7. Withdrawal elements

The model can simulate up to 13 variables in a desired combination. Variables which can be simulated are:

1. Dissolved Oxygen
2. Biochemical Oxygen Demand (BOD)
3. Temperature
4. Algae as Chlorophyll a
5. Ammonia as N
6. Nitrite as N
7. Nitrate as N
8. Dissolved Orthophosphate
9. Coliforms

10. Arbitrary non-conservative variable

11. Three conservative variables

Table A-1 gives a summary of differential equations to be solved by QUAL-II (except temperature). Table A-2 gives the definition of variables in the differential equations.

For more detail about EPA/QUAL-II see Roesner, et al. (1977).

Soltero's Regression Equation

As shown in Chapter 6, cause/effect analysis, Soltero's Regression Equation is

$$Chl\underline{a} = 9.93 \times (L_{\rho,R}) + 6.04$$

where

$Chl\underline{a}$ = mean growth season (June-November) in-lake Chlorophyll a concentration, MG/M^3

$L_{\rho,R} = \frac{L\,(1-R)}{\rho}$, total specific areal phosphorus loading rate in the growth season $g\text{-}p/M^2$

L = total areal phosphorus loading rate, $g\text{-}p/M^2$

R = phosphorus retention coefficient in the growth;

$$\frac{L - L\ out}{L}$$

ρ = number of times the lake is being flushed in the growth season

Table C-1

SUMMARY OF DIFFERENTIAL EQUATIONS TO BE SOLVED BY QUAL-II
(except temperature)

Constituent	Equation
Conservative mineral (c)	$\frac{\partial c}{\partial t} = \frac{\partial(A_x D_L \frac{\partial c}{\partial x})}{A_x \partial x} - \frac{\partial(A_x u c)}{A_x \partial x} + \frac{S_c}{A_x dx}$
Algae (A)	$\frac{\partial A}{\partial t} = \frac{\partial(A_x D_L \frac{\partial A}{\partial x})}{A_x \partial x} - \frac{\partial(A_x u A)}{A_x \partial x} + \frac{S_A}{A_x dx} + (\mu - \rho - \frac{\sigma_1}{d}) A$
Ammonia nitrogen (N_1)	$\frac{\partial N_1}{\partial t} = \frac{\partial(A_x D_L \frac{\partial N_1}{\partial x})}{A_x \partial x} - \frac{\partial(A_x u N_1)}{A_x \partial x} + \frac{S_{N_1}}{A_x dx} + (\alpha_1 \rho A - \beta_1 N_1 + \frac{\alpha_3}{A_x})$
Nitrite nitrogen (N_2)	$\frac{\partial N_2}{\partial t} = \frac{\partial(A_x D_L \frac{\partial N_2}{\partial x})}{A_x \partial x} - \frac{\partial(A_x u N_2)}{A_x \partial x} + \frac{S_{N_2}}{A_x dx} + (\beta_1 N_1 - \beta_2 N_2)$
Nitrate nitrogen (N_3)	$\frac{\partial N_3}{\partial t} = \frac{\partial(A_x D_L \frac{\partial N_3}{\partial x})}{A_x \partial x} - \frac{\partial(A_x u N_3)}{A_x \partial x} + \frac{S_{N_3}}{A_x dx} + (\beta_2 N_2 - \alpha_1 \mu A)$
Dissolved Orthophosphate (P)	$\frac{\partial P}{\partial t} = \frac{\partial(A_x D_L \frac{\partial P}{\partial x})}{A_x \partial x} - \frac{\partial(A_x u P)}{A_x \partial x} + \frac{S_P}{A_x dx} + (\alpha_2(\rho - \mu) A - \frac{\sigma_2}{A_x})$
Biochemical oxygen demand (L)	$\frac{\partial L}{\partial t} = \frac{\partial(A_x D_L \frac{\partial L}{\partial x})}{A_x \partial x} - \frac{\partial(A_x u L)}{A_x \partial x} + \frac{S_L}{A_x dx} - (K_1 + K_3) L$
Dissolved oxygen (ϕ)	$\frac{\partial \phi}{\partial t} = \frac{\partial(A_x D_L \frac{\partial \phi}{\partial x})}{A_x \partial x} - \frac{\partial(A_x u \phi)}{A_x \partial x} + \frac{S_\phi}{A_x dx} + [K_2(\phi^* - \phi) + (\alpha_3 \mu - \alpha_4 \rho) A - K_1 L - \frac{K_4}{A_x} - \alpha_5 \beta_1 N_1 - \alpha_6 \beta_2 N_2]$
Coliform (F)	$\frac{\partial F}{\partial t} = \frac{\partial(A_x D_L \frac{\partial F}{\partial x})}{A_x \partial x} - \frac{\partial(A_x u F)}{A_x \partial x} - \frac{S_F}{A_x dx} - K_5 F$
Arbitrary Nonconservative (R)	$\frac{\partial R}{\partial t} = \frac{\partial(A_x D_L \frac{\partial R}{\partial x})}{A_x \partial x} - \frac{\partial(A_x u R)}{A_x \partial x} - \frac{S_R}{A_x dx} - K_6 R$

TABLE C-2

DEFINITION OF VARIABLES USED IN TABLE C-1

C	concentration (M/L^3)
t	time (T)
X	Longitudinal distance (L)
A_x	Cross-sectional area (L^2/T)
D_L	Dispersion coefficient (L^2T)
U	mean stream velocity (L/T)
S_c	source or sink (M/L); subscript refers to the constituant c.
A	Algal biomass concentration
μ	specific growth rate of algae
ρ	respiration rate of algae
σ_1	settling rate for algae
d	average depth
N_1	Ammonia nitrogen concentration
α_1	The fraction of respired algal biomass which is resolubilized as ammonia nitrogen
β_1	rate constant for the biological oxidation of ammonia nitrogen
σ_3	The benthos sources rate for ammonia nitrogen
N_2	Nitrite nitrogen concentration
β_2	rate constant for the oxidation of nitrite nitrogen
N_3	Nitrate nitrogen concentration
P	Dissolved orthophosphate
α_2	the fraction of algal biomass that is phosphorus (P)

σ_2	the benthos source rate for phosphorus
L	carbonaceons BOD concentration
K_1	the rate of decay of carbonaceons BOD
K_3	the rate of loss of carbonaceons BOD due to settling
Ø	Dissolved oxygen concentration
Ø*	the saturation concentration of dissolved oxygen at the local temperature and pressure
K_2	the reaeration rate
α_3	the rate of oxygen production per unit of algae (photosynthesis)
α_4	the rate of oxygen uptake per unit of algae respired
K_4	constant benthic uptake rate
α_5	the rate of oxygen uptake per unit of ammonia oxidation
α_6	the rate of oxygen uptake per unit of nitrite nitrogen oxidation
F	coliform concentration
K_5	coliform die-off rate
R	an arbitrary non-conservative constituent
K_6	decay rate for the constituent

Seasonal Phosphorus Model

The seasonal phosphorus model is a simple phosphorus balance model for a well-mixed lake. It is used strictly for periods prior to the growing season when the lake is not stratified. Details of this model are given in Appendix C, Computation of Seasonal Total-P Concentration Patterns in Long Lake.

Battelle's Long Lake Reservoir Model

Battelle's Long Lake Reservoir Model (Baca, et al., 1976) is a dynamic lake model. A quasi-two dimensional approach based on segment (horizontally)/ layer (vertically) representation is employed. Each segment is broken down into a set of horizontal layers. The complete model consists of two general models: a hydrothermal model and a limnological model. The hydrothermal model considers a variety of physical processes including transport, (advection and dispersion), stratified flow, corrective and wind-induced mixing, formation and melting of ice cover, and atmospheric heating and cooling.

The objective of the hydrothermal model is to simulate temperature. The simulated temperature is a key input parameter in the limnological model, since it influences both chemical factors, such as reactivity and stabilization, and biological factors, such as uptake and respiration rates.

The hydrothermal model is based on the following heat balance equation:

$$\frac{\partial T}{\partial t} + \frac{Q_v}{A}\frac{\partial T}{\partial z} = \alpha \frac{\partial^2 T}{\partial z^2} + \frac{1}{A \Delta z} \cdot (Q_{h,i} T_i - Q_{h,o} T) + \frac{1}{\rho c} H$$

where

- T = temperature
- T_i = upstream inflow temperature
- α = eddy diffusivity
- A = horizontal area
- Δz = layer thickness
- H = internal heat source
- $Q_{h,i}$, $Q_{h,o}$ = horizontal inflow and outflow rates
- Q_v = vertical flow rate
- ρ = water density
- c = specific heat

At the interface between the atmosphere and the water, heat fluxes such as radiation, evaporation and convection are balanced. The empirical relationships developed for densimetric flow from laboratory experiments were used to model the stratified flow in the reservoir. These empirical relationships describe the effects of the complex interflows through the reservoir and the withdrawal patterns at the spillway, gates and other outlets.

Wind turbulence, eddy diffusion and density induced instabilities provide the other means of heat transport in the water body. The limnological model, formulated on the general principle of conservation of mass, is designed to integrate the important biological, chemical and physical processes in the reservoir.

The transport of a biotic or abiotic constituent through the reservoir is represented by a general one-dimensional convection-diffusion equation:

$$\frac{\partial C}{\partial t} = \left(V_s - \frac{Q_v}{A}\right)\frac{\partial C}{\partial z} + D_z \frac{\partial^2 C}{\partial z^2} + \frac{1}{A \Delta z}\left(Q_{h,i} C_i - Q_{h,o} C\right) + S_c$$

where C = concentration of a constituent

C_i = concentration of upstream inflow

D_z = effective diffusion coefficient

A = horizontal surface area for element

V_s = settling velocity

Q_v = vertical flow through element (layer)

$Q_{h,i}, Q_{h,o}$ = horizontal inflow and outflow to element

Δz = element thickness

S_c = source or sink term for the same constituent

The model is capable of modelling the following parameters:

1. phytoplankton

2. zooplankton

3. phosphorus (soluble organic, dissolved reactive, particulate, sediment)

4. nitrogen (ammonia, nitrite, nitrate, organic, sediment)

5. biochemical oxygen demand

6. dissolved oxygen

7. coliform bacteria

The dissolved oxygen levels are modeled using several interrelated factors. The most significant factors are: 1) temperature, 2) bacterial oxidation of suspended and dissolved organic matter, 3) benthic uptake, 4) reaeration, 5) algal photosynthesis, respiration and decomposition.

For details on the DO model and models of other parameters see Baca and Arnett (1976).

The computation procedure for the complete model consists of two steps. First, use the hydrothermal model to simulate the temperature and flow for the entire period of interest. Next, input these results to the limnological model and solve the mass balance equations, for each of the constitutents.

APPENDIX D PROGRAM LISTING - URS/SRM MODEL


```
      PROGRAM SRMS(INPUT,TAPE2,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C     ***** SPOKANE RIVER MODEL *****
C
C           "THIS MODEL SIMULATES WATER QUALITY CHANGES
C            (IN TERMS OF CONCENTRATIONS) IN THE SPOKANE
C            RIVER DUE TO VARIOUS INPUTS FROM:
C                   * MUNICIPAL TREATMENT PLANT EFFLUENTS
C                   * INDUSTRIAL DISCHARGES
C                   * COMBINED SEWER OVERFLOWS
C                   * AQUIFER/RIVER EXCHANGES
C                   .
C           "THE MODEL TREATS THE MASS TRANSPORT AS A PLUG
C            FLOW TRAVELS DOWNSTREAM ENROUTE SUBJECTED TO
C            MIXING AND DECAYING PROCESSES.
C
      COMMON/INPT/RM(50),RNAME(50,2),TITLE(10),WIDTH(50)
      COMMON/SOURCE/SRM,SFLOW,SBOD,STP,SZN,SCL,SPB,SCU,SDO,STEMP,FACTOR
      COMMON/RIVER/FLOW(50),BOD(50),TP(50),ZN(50),CL(50),PB(50)
     1             ,CU(50),DO(50),TEMP(50)
      COMMON/LOAD/LBOD(50),LTP(50),LZN(50),LCL(50),LPB(50),LCU(50)
     1            ,LDO(50),LTEMP(50)
      COMMON/MISC/TIMEP(50),TACC(50),KBOD(50),K220(50),KBOD20
     1            ,K2(50),Q,U(50),D(50),DOSAT(50)
      COMMON/NAME/SNAME(2)
C
      REAL KBOD20,KBOD,K220,K2
      REAL LBOD,LTP,LZN,LCL,LPB,LCU,LDO,LTEMP
C
C     *****READ FIRST INPUT FROM TAPE5
C
      READ(5,1) (TITLE(I),I=1,10)
      READ(5,100) Q,NREACH,KBOD20
C
      FLOW(1)=0.
      LBOD(1)=0.
      LTP(1)=0.
      LZN(1)=0.
      LCL(1)=0.
      LPB(1)=0.
      LCU(1)=0.
      LDO(1)=0.
      LTEMP(1)=0.
C
C     *****PERFORMING SIMULATIONS FOR EACH OF THE SELECT STATIONS
C
      DO 20 I=1,NREACH
C
C     *****READ PARAMETERS ASSIGNED TO EACH STATION FROM TAPE5
C
      READ(5,105) RM(I),RNAME(I,1),RNAME(I,2),TEMP(I),WIDTH(I)
      IM1=I-1
      REWIND 2
      IF(I.EQ.1) GO TO 10
      CALL DECAY(I)
C
C     *****NON-DECAYING PARAMETERS ARE UNCHANGED FROM UPSTREAM REACH
```

APPENDIX D (con)

```
      C
            FLOW(I)=FLOW(IM1)
            TP(I)=TP(IM1)
            ZN(I)=ZN(IM1)
            CL(I)=CL(IM1)
            PB(I)=PB(IM1)
            CU(I)=CU(IM1)
            CALL LOAD(I)
      C
      C     *****CHECK WHETHER ANY INPUT SOURCES ENTER INTO THE RIVER
      C          AT THIS STATION - TAPE2 CONTAINS THE SOURCE FILE
      C
      10    CONTINUE
            READ(2,115) SRM,SNAME(1),SNAME(2),SFLOW,SBOD,STP,SZN,SCL
           1            ,SPB,SCU,SDO,STEMP,FACTOR
            IF(EOF(2)) 20,15
      15    IF(RM(I).EQ.SRM) CALL MIXING(I)
            IF(RM(I).NE.SRM) GO TO 10
      20    CONTINUE
            CALL OUTPT(NREACH)
      1     FORMAT(10A8)
      100   FORMAT(F10.0,I5,F5.2)
      105   FORMAT(F5.1,2A10,2F5.1)
      115   FORMAT(F5.0,2A10,F10.0,9F5.0)
            STOP
            END
```

```
0
        SYMBOLIC REFERENCE MAP (R=1)

 ENTRY POINTS
  6217  SRMS

 VARIABLES      SN  TYPE           RELOCATION
    62  BOD         REAL       ARRAY    RIVER          310  CL         REAL       ARRAY    RIVER
   454  CU          REAL       ARRAY    RIVER          456  D          REAL       ARRAY    MISC
   536  DO          REAL       ARRAY    RIVER          540  DOSAT      REAL       ARRAY    MISC
    12  FACTOR      REAL                SOURCE           0  FLOW       REAL       ARRAY    RIVER
  6442  I           INTEGER                           6444  IM1        INTEGER
   144  KBOD        REAL       ARRAY    MISC           310  KBOD20     REAL                MISC
   311  K2          REAL       ARRAY    MISC           226  K220       REAL       ARRAY    MISC
     0  LBOD        REAL       ARRAY    LOAD           226  LCL        REAL       ARRAY    LOAD
   372  LCU         REAL       ARRAY    LOAD           454  LDO        REAL       ARRAY    LOAD
   310  LPB         REAL       ARRAY    LOAD           536  LTEMP      REAL       ARRAY    LOAD
    62  LTP         REAL       ARRAY    LOAD           144  LZN        REAL       ARRAY    LOAD
  6443  NREACH      INTEGER                            372  PB         REAL       ARRAY    RIVER
   373  Q           REAL                MISC             0  RM         REAL       ARRAY    INPT
    62  RNAME       REAL       ARRAY    INPT             2  SBOD       REAL                SOURCE
     5  SCL         REAL                SOURCE           7  SCU        REAL                SOURCE
    10  SDO         REAL                SOURCE           1  SFLOW      REAL                SOURCE
     0  SNAME       REAL       ARRAY    NAME             6  SPB        REAL                SOURCE
     0  SRM         REAL                SOURCE          11  STEMP      REAL                SOURCE
     3  STP         REAL                SOURCE           4  SZN        REAL                SOURCE
    62  TACC        REAL       ARRAY    MISC           620  TEMP       REAL       ARRAY    RIVER
1          PROGRAM SRMS        74/175  OPT=0 ROUND=+-*/ TRACE         FTN 4.8  508        80/12/09. 13.42.07         PAGE      3
0 VARIABLES     SN  TYPE           RELOCATION
     0  TIMEP       REAL       ARRAY    MISC           226  TITLE      REAL       ARRAY    INPT
   144  TP          REAL       ARRAY    RIVER          374  U          REAL       ARRAY    MISC
   240  WIDTH       REAL       ARRAY    INPT           226  ZN         REAL       ARRAY    RIVER

 FILE NAMES         MODE
     0  INPUT                  4130  OUTPUT                 2054  TAPE2     FMT              0  TAPE5     FMT
  4130  TAPE6

 EXTERNALS            TYPE   ARGS
        DECAY                  1                            EOF       REAL       1
```

```
        LOAD                 1                                  MIXING              1
        OUTPT                1

STATEMENT LABELS
 6424  1        FMT                     6322  10                              0  15        INACTIVE
 6340  20                               6426  100      FMT                 6431  105      FMT
 6434  115      FMT

LOOPS  LABEL    INDEX     FROM-TO     LENGTH     PROPERTIES
 6250  20       I           47 76        73B               EXT REFS

COMMON BLOCKS   LENGTH
       INPT        210
       SOURCE       11
       RIVER       450
       LOAD        400
       MISC        402
       NAME          2

STATISTICS
  PROGRAM LENGTH                   556B     366
  BUFFER LENGTH                   5667B    2999
  CM LABELED COMMON LENGTH        2703B    1475
          52000B CM USED
1       SUBROUTINE DECAY      74/175  OPT=0 ROUND=+-*/ TRACE         FTN 4.8  508         80/12/09. 13.42.07        PAGE      1
0
                      SUBROUTINE DECAY(I)
                C
                      COMMON/INPT/RM(50),RNAME(50,2),TITLE(10),WIDTH(50)
                      COMMON/RIVER/FLOW(50),BOD(50),TP(50),ZN(50),CL(50),PB(50)
                     1             ,CU(50),DO(50),TEMP(50)
                      COMMON/MISC/TIMEP(50),TACC(50),KBOD(50),K220(50),KBOD20
                     1            ,K2(50),Q,U(50),D(50),DOSAT(50)
                      COMMON/NAME/SNAME(2)
                C
                      REAL KBOD20,KBOD,K220,K2
                      IM1=I-1
                      TIMEP(1)=0.
                      TACC(I)=TPASS(RM(I),Q)
                      TIMEP(I)=TPASS(RM(I),Q)/24.-TIMEP(IM1)
                      DIST=(RM(IM1)-RM(I))*5280.
                      U(I)=DIST/(TIMEP(I)*24.*3600.)
                      D(I)=FLOW(IM1)/(U(I)*WIDTH(I))
                      IF(D(I).GT.15.) GO TO 100
                      K220(I)=5.026*(U(I)**0.969)*(D(I)**(-1.673))*2.31
                      K2(I)=K220(I)*1.0159**(TEMP(I)-20.)
                100   TF=TEMP(I)*1.8+32.
                      DOSAT(I)=24.89-0.426*TF+0.00373*(TF**2.)-.0000133*(TF**3.)
                      KBOD(I)=KBOD20*1.047**(TEMP(I)-20.)
                C
                C     *****INSTREAM CONCENTRATION AFTER DECAYING
                C
                      IF(D(I).GT.15.) 110,120
                110   K2(I)=0.
                      DO(I)=DO(IM1)-KBOD(I)*BOD(IM1)
                      GO TO 130
                120   DO(I)=DOSAT(I)+(DO(IM1)-DOSAT(I)+(KBOD(I)/K2(I))*BOD(IM1))
                     1      *EXP(-K2(I)*TIMEP(I))-(KBOD(I)/K2(I))*BOD(IM1)
                130   BOD(I)=BOD(IM1)*EXP(-KBOD(I)*TIMEP(I))
                      TIMEP(I)=TIMEP(I)+TIMEP(IM1)
                      RETURN
                      END
-
0
        SYMBOLIC REFERENCE MAP (R=1)
```

APPENDIX D (con)

```
 ENTRY POINTS
     4  DECAY

 VARIABLES      SN  TYPE            RELOCATION
    62  BOD         REAL       ARRAY    RIVER          310  CL         REAL       ARRAY     RIVER
   454  CU          REAL       ARRAY    RIVER          456  D          REAL       ARRAY     MISC
   234  DIST        REAL                               536  DO         REAL       ARRAY     RIVER
   540  DOSAT       REAL       ARRAY    MISC             0  FLOW       REAL       ARRAY     RIVER
     0  I           INTEGER              F.P.          233  IM1        INTEGER
   144  KBOD        REAL       ARRAY    MISC           310  KBOD20     REAL                 MISC
   311  K2          REAL       ARRAY    MISC           226  K220       REAL       ARRAY     MISC
   372  PB          REAL       ARRAY    RIVER          373  Q          REAL                 MISC
     0  RM          REAL       ARRAY    INPT            62  RNAME      REAL       ARRAY     INPT
     0  SNAME       REAL       ARRAY    NAME            62  TACC       REAL       ARRAY     MISC
1       SUBROUTINE DECAY       74/175  OPT=0 ROUND=+-*/ TRACE        FTN 4.8  508        80/12/09. 13.42.07       PAGE      2
0VARIABLES      SN  TYPE            RELOCATION
   620  TEMP        REAL       ARRAY    RIVER          235  TF         REAL
     0  TIMEP       REAL       ARRAY    MISC           226  TITLE      REAL       ARRAY     INPT
   144  TP          REAL       ARRAY    RIVER          374  U          REAL       ARRAY     MISC
   240  WIDTH       REAL       ARRAY    INPT           226  ZN         REAL       ARRAY     RIVER

 EXTERNALS           TYPE    ARGS
        EXP         REAL       1 LIBRARY                       TPASS      REAL        2

 STATEMENT LABELS
    76  100                                  0  110         INACTIVE                135  120
   151  130

 COMMON BLOCKS   LENGTH
        INPT         210
        RIVER        450
        MISC         402
        NAME           2

 STATISTICS
   PROGRAM LENGTH                 236B     158
   CM LABELED COMMON LENGTH      2050B    1064
           52000B CM USED
1         FUNCTION TPASS       74/175  OPT=0 ROUND=+-*/ TRACE        FTN 4.8  508        80/12/09. 13.42.07       PAGE      1
0
                      FUNCTION TPASS(RM,Q)
                      IF(Q.LE.1695.) GO TO 30
                      IF(Q.GT.1695..AND.Q.LE.3610.) GO TO 20
                      IF(Q.GT.3610..AND.Q.LE.7200.) GO TO 10
                C
                10    IF(RM.GT.90.4.AND.RM.LE.98.7) TPASS=-.265*(RM-98.7)
                      IF(RM.GT.85.3.AND.RM.LE.90.4) TPASS=-.339*(RM-90.4)+2.20
                      IF(RM.GT.82.6.AND.RM.LE.85.3) TPASS=-.585*(RM-85.3)+3.93
                      IF(RM.GT.78.0.AND.RM.LE.82.6) TPASS=-.754*(RM-82.6)+5.51
                      IF(RM.GT.74.9.AND.RM.LE.78.0) TPASS=-.910*(RM-78.0)+8.98
                      IF(RM.GT.72.9.AND.RM.LE.74.9) TPASS=-.365*(RM-74.9)+11.80
                      IF(RM.GT.66.2.AND.RM.LE.72.9) TPASS=-.415*(RM-72.9)+12.53
                      IF(RM.GT.61.9.AND.RM.LE.66.2) TPASS=-.379*(RM-66.2)+15.31
                      IF(RM.GT.58.1.AND.RM.LE.61.9) TPASS=-1.429*(RM-61.9)+16.94
                      IF(RM.GT.35.0.AND.RM.LE.58.1) TPASS=-17.965*(RM-58.1)+22.37
                      GO TO 999
                20    IF(RM.GT.90.4.AND.RM.LE.98.7) TPASS=-.373*(RM-98.7)
                      IF(RM.GT.85.3.AND.RM.LE.90.4) TPASS=-.533*(RM-90.4)+3.10
                      IF(RM.GT.82.6.AND.RM.LE.85.3) TPASS=-.796*(RM-85.3)+5.82
                      IF(RM.GT.74.9.AND.RM.LE.82.6) TPASS=-1.364*(RM-82.6)+7.97
                      IF(RM.GT.72.9.AND.RM.LE.74.9) TPASS=-.750*(RM-74.9)+18.47
                      IF(RM.GT.66.2.AND.RM.LE.72.9) TPASS=-.534*(RM-72.9)+19.97
                      IF(RM.GT.61.9.AND.RM.LE.66.2) TPASS=-.644*(RM-66.2)+23.55
                      IF(RM.GT.58.1.AND.RM.LE.61.9) TPASS=-2.466*(RM-61.9)+26.32
                      IF(RM.GT.35.0.AND.RM.LE.58.1) TPASS=-35.84*(RM-58.1)+35.69
                      GO TO 999
```

APPENDIX D (cont)

```
         30     IF(RM.GT.87.1.AND.RM.LE.[illegible]
                IF(RM.GT.79.8.AND.RM.LE.87.1) TPASS=-2.710*(RM-87.1)+8.66
                IF(RM.GT.69.8.AND.RM.LE.79.8) TPASS=-1.070*(RM-79.8)+28.48
                IF(RM.GT.65.0.AND.RM.LE.69.8) TPASS=-1.070*(RM-69.8)+39.18
                IF(RM.GT.58.1.AND.RM.LE.65.0) TPASS=-2.716*(RM-65.0)+44.32
                IF(RM.GT.35.0.AND.RM.LE.58.1) TPASS=-76.364*(RM-58.1)+63.06
        999     CONTINUE
                RETURN
                END
-
0 CARD NR. SEVERITY  DETAILS    DIAGNOSIS OF PROBLEM

        4     I      10        THIS IF DEGENERATES INTO A SIMPLE TRANSFER TO THE LABEL INDICATED.
-
0
          SYMBOLIC REFERENCE MAP (R=1)

   ENTRY POINTS
       5  TPASS

   VARIABLES      SN  TYPE           RELOCATION
       0  Q           REAL                F.P.          0  RM       REAL              F.P.
     400  TPASS       REAL
1           FUNCTION TPASS      74/175  OPT=0 ROUND=+-*/ TRACE         FTN 4.8  508        80/12/09. 13.42.07       PAGE      2
0  STATEMENT LABELS
       0  10           INACTIVE               125  20                            225  30
     277  999

   STATISTICS
     PROGRAM LENGTH                401B     257
             52000B CM USED
1         SUBROUTINE LOAD       74/175  OPT=0 ROUND=+-*/ TRACE         FTN 4.8  508        80/12/09. 13.42.07       PAGE      1
0
                SUBROUTINE LOAD(I)
          C
                COMMON/RIVER/FLOW(50),BOD(50),TP(50),ZN(50),CL(50),PB(50)
               1             ,CU(50),DO(50),TEMP(50)
                COMMON/LOAD/LBOD(50),LTP(50),LZN(50),LCL(50),LPB(50),LCU(50)
               1           ,LDO(50),LTEMP(50)
          C
                REAL LBOD,LTP,LZN,LCL,LPB,LCU,LDO,LTEMP
          C
                C1=5.40
                LBOD(I)=C1*FLOW(I)*BOD(I)
                LTP(I)=C1*FLOW(I)*TP(I)
                LZN(I)=C1*FLOW(I)*ZN(I)*.001
                LCL(I)=C1*FLOW(I)*CL(I)*.001
                LPB(I)=C1*FLOW(I)*PB(I)*.001
                LCU(I)=C1*FLOW(I)*CU(I)*.001
                LDO(I)=C1*FLOW(I)*DO(I)
                LTEMP(I)=C1*FLOW(I)*TEMP(I)
                RETURN
                END
-
0
          SYMBOLIC REFERENCE MAP (R=1)

   ENTRY POINTS
       4  LOAD

   VARIABLES      SN  TYPE           RELOCATION
      62  BOD         REAL      ARRAY    RIVER          310  CL       REAL      ARRAY    RIVER
     454  CU          REAL      ARRAY    RIVER           57  C1       REAL
     536  DO          REAL      ARRAY    RIVER            0  FLOW     REAL      ARRAY    RIVER
       0  I           INTEGER             F.P.            0  LBOD     REAL      ARRAY    LOAD
     226  LCL         REAL      ARRAY    LOAD           372  LCU      REAL      ARRAY    LOAD
```

D-5

APPENDIX D (con't)

```
   454  LDO        REAL        ARRAY    LOAD           310  LPB        REAL       ARRAY    LOAD
   536  LTEMP      REAL        ARRAY    LOAD            62  LTP        REAL       ARRAY    LOAD
   144  LZN        REAL        ARRAY    LOAD           372  PB         REAL       ARRAY    RIVER
   620  TEMP       REAL        ARRAY    RIVER          144  TP         REAL       ARRAY    RIVER
   226  ZN         REAL        ARRAY    RIVER

 COMMON BLOCKS   LENGTH
        RIVER      450
        LOAD       400

 STATISTICS
   PROGRAM LENGTH                   60B      48
   CM LABELED COMMON LENGTH      1522B     850
           52000B CM USED
1          SUBROUTINE MIXING     74/175  OPT=0 ROUND=+-*/ TRACE         FTN 4.8  508        80/12/09. 13.42.07       PAGE      1
0
                         SUBROUTINE MIXING(I)
                   C
                         COMMON/SOURCE/SRM,SFLOW,SBOD,STP,SZN,SCL,SPB,SCU,SDO,STEMP,FACTOR
                         COMMON/RIVER/FLOW(50),BOD(50),TP(50),ZN(50),CL(50),PB(50)
                        1             ,CU(50),DO(50),TEMP(50)
                         COMMON/LOAD/LBOD(50),LTP(50),LZN(50),LCL(50),LPB(50),LCU(50)
                        1            ,LDO(50),LTEMP(50)
                   C
                         REAL LBOD,LTP,LZN,LCL,LPB,LCU,LDO,LTEMP
                   C
                         IM1=I-1
                         IF(SFLOW.LT.0.) 1,2
                   1     SBOD=BOD(IM1)
                         STP=TP(IM1)
                         SZN=ZN(IM1)
                         SCL=CL(IM1)
                         SPB=PB(IM1)
                         SCU=CU(IM1)
                         SDO=DO(IM1)
                         STEMP=TEMP(IM1)
                   2     FLOW(I)=FLOW(I)+SFLOW
                         C1=5.40*FACTOR
                         BOD(I)=(LBOD(I)+C1*SFLOW*SBOD)/(C1*FLOW(I))
                         TP(I)=(LTP(I)+C1*SFLOW*STP)/(C1*FLOW(I))
                         ZN(I)=(LZN(I)+C1*.001*SFLOW*SZN)/(C1*.001*FLOW(I))
                         CL(I)=(LCL(I)+C1*.001*SFLOW*SCL)/(C1*.001*FLOW(I))
                         PB(I)=(LPB(I)+C1*.001*SFLOW*SPB)/(C1*.001*FLOW(I))
                         CU(I)=(LCU(I)+C1*.001*SFLOW*SCU)/(C1*.001*FLOW(I))
                         IF(SDO.NE.0.) 10,20
                   10    DO(I)=(LDO(I)+C1*SFLOW*SDO)/(C1*FLOW(I))
                   20    IF(STEMP.NE.0.)30,40
                   30    TEMP(I)=(LTEMP(I)+C1*SFLOW*STEMP)/(C1*FLOW(I))
                   40    CALL LOAD(I)
                         RETURN
                         END
-
0
           SYMBOLIC REFERENCE MAP (R=1)

 ENTRY POINTS
     4  MIXING

 VARIABLES       SN  TYPE            RELOCATION
    62  BOD          REAL        ARRAY    RIVER          310  CL         REAL       ARRAY    RIVER
   454  CU           REAL        ARRAY    RIVER          154  C1         REAL
   536  DO           REAL        ARRAY    RIVER           12  FACTOR     REAL                SOURCE
     0  FLOW         REAL        ARRAY    RIVER            0  I          INTEGER              F.P.
   153  IM1          INTEGER                               0  LBOD       REAL       ARRAY    LOAD
   226  LCL          REAL        ARRAY    LOAD           372  LCU        REAL       ARRAY    LOAD
   454  LDO          REAL        ARRAY    LOAD           310  LPB        REAL       ARRAY    LOAD
```

APPENDIX D (cont)

```
   536  LTEMP     REAL        ARRAY    LOAD             62  LTP        REAL        ARRAY     LOAD
   144  LZN       REAL        ARRAY    LOAD            372  PB         REAL        ARRAY     RIVER
     2  SBOD      REAL                 SOURCE            5  SCL        REAL                  SOURCE
     7  SCU       REAL                 SOURCE           10  SDO        REAL                  SOURCE
1           SUBROUTINE MIXING     74/175  OPT=0 ROUND=+-*/ TRACE        FTN 4.8  508        80/12/09. 13.42.07        PAGE     2
0  VARIABLES      SN  TYPE             RELOCATION
     1  SFLOW     REAL                 SOURCE            6  SPB        REAL                  SOURCE
     0  SRM       REAL                 SOURCE           11  STEMP      REAL                  SOURCE
     3  STP       REAL                 SOURCE            4  SZN        REAL                  SOURCE
   620  TEMP      REAL        ARRAY    RIVER           144  TP         REAL        ARRAY     RIVER
   226  ZN        REAL        ARRAY    RIVER

   EXTERNALS           TYPE   ARGS
        LOAD                    1

   STATEMENT LABELS
     0  1           INACTIVE                  44  2                                0  10            INACTIVE
   133  20                                     0  30          INACTIVE           143  40

   COMMON BLOCKS   LENGTH
        SOURCE        11
        RIVER        450
        LOAD         400

   STATISTICS
     PROGRAM LENGTH                 155B      109
     CM LABELED COMMON LENGTH      1535B      861
        52000B CM USED
1           SUBROUTINE OUTPT      74/175  OPT=0 ROUND=+-*/ TRACE        FTN 4.8  508        80/12/09. 13.42.07        PAGE     1
0
                          SUBROUTINE OUTPT(N)
                C
                          COMMON/INPT/RM(50),RNAME(50,2),TITLE(10),WIDTH(50)
                          COMMON/RIVER/FLOW(50),BOD(50),TP(50),ZN(50),CL(50),PB(50)
                         1              ,CU(50),DO(50),TEMP(50)
                          COMMON/LOAD/LBOD(50),LTP(50),LZN(50),LCL(50),LPB(50),LCU(50)
                         1             ,LDO(50),LTEMP(50)
                          COMMON/MISC/TIMEP(50),TACC(50),KBOD(50),K220(50),KBOD20,K2(50)
                         1             ,Q,U(50),D(50),DOSAT(50)
                          COMMON/NAME/SNAME(2)
                C
                          REAL KBOD20,KBOD,K220,K2
                          REAL LBOD,LTP,LZN,LCL,LPB,LCU,LDO,LTEMP
                C
                          WRITE(6,199) (TITLE(I),I=1,10)
                          WRITE(6,200)
                          REWIND 2
                1         READ(2,111)SRM,SNAME(1),SNAME(2),FACTOR
                          IF(EOF(2)) 3,2
                2         WRITE(6,112) SRM,SNAME(1),SNAME(2),FACTOR
                          GO TO 1
                3         WRITE(6,201)
                          WRITE(6,202)
                          REWIND 2
                5         READ(2,115) SRM,SFLOW,SBOD,STP,SZN,SCL,SPB,SCU,SDO,STEMP
                          BODL=5.40*SFLOW*SBOD
                          TPL=5.40*SFLOW*STP
                          ZNL=5.40*SFLOW*SZN*.001
                          CLL=5.40*SFLOW*SCL*.001
                          PBL=5.40*SFLOW*SPB*.001
                          CUL=5.40*SFLOW*SCU*.001
                          IF(EOF(2)) 20,10
                10        WRITE(6,120) SRM,SFLOW,SBOD,STP,SZN,SCL,SPB,SCU,SDO,STEMP
                         1            ,BODL,TPL,ZNL,CLL,PBL,CUL
                          GO TO 5
                20        WRITE(6,203)
```

```
              WRITE(6,204)
              DO 30 I=1,N
              WRITE(6,130) RM(I),RNAME(I,1),RNAME(I,2),TEMP(I),KBOD(I)
             1            ,K2(I),TACC(I),U(I),D(I),DOSAT(I)
           30 CONTINUE
              WRITE(6,205)
              WRITE(6,206)
              WRITE(6,202)
              DO 40 I=1,N
              WRITE(6,120) RM(I),FLOW(I),BOD(I),TP(I),ZN(I),CL(I),PB(I)
             1            ,CU(I),DO(I),TEMP(I),LBOD(I),LTP(I),LZN(I)
             2            ,LCL(I),LPB(I),LCU(I)
           40 CONTINUE
          110 FORMAT(F5.1)
          111 FORMAT(F5.0,2A10,50X,F5.2)
          112 FORMAT(//,13X,F7.2,5X,2A10,5X,F5.2)
          115 FORMAT(F5.0,20X,F10.0,8F5.0)
          120 FORMAT(1X,F5.1,1X,F7.2,F6.2,F7.3,6F7.2,2X,6F8.1)
          130 FORMAT(1X,F5.1,2A10,2X,F5.1,2X,F5.2,2X,F5.2,3X,F5.2,4X,F5.2,4X,F5.
             10,3X,F5.2)
          C
1    SUBROUTINE OUTPT      74/175  OPT=0 ROUND=+-*/ TRACE         FTN 4.8  508         80/12/09. 13.42.07        PAGE      2
0
          C   *****HEADERS
          199 FORMAT(/,1X,10A8)
          200 FORMAT(/,1X,*///// INPUT SOURCES /////*,/,10X,
             1*LOCATION(RM)      NAME*,19X,*FACTOR*)
          201 FORMAT(//,14X,55H******************  CONCENTRATIONS   ************
             1******,2X,50H*******************    LOADS    *******************)
          202 FORMAT(*  STA    FLOW   BOD   TOT-P   ZN    CL     PB    CU
             1DO     TEMP      BOD    TOT-P     ZN       CL       PB      CU   *,/,*
             2  (RM)   (CFS) (MG/L) (MG/L) (UG/L) (UG/L) (UG/L) (UG/L) (MG/L) DEG
             3-C   (#/DAY) (#/DAY) (#/DAY) (#/DAY) (#/DAY) (#/DAY)*)
          203 FORMAT(/,1X,28H///// INPUT PARAMETERS /////)
          204 FORMAT(/,*  STA   STATION                  TEMP    KBOD    K2    TPASS
             1  VELOCITY   DEPTH   O2SAT *,/,*  (RM)  NAME                   DEG-C
             2 (/DAY) (/DAY)  (HOUR)  (FT/SEC)   (FT)   (MG/L)*)
          205 FORMAT(/,1X,30H///// SIMULATION RESULTS /////)
          206 FORMAT(//,14X,55H**************     CONCENTRATIONS      *********
             1******,2X,50H************   RIVER CARRYING LOADS   ************)
              RETURN
              END
-
0
```

SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
4 OUTPT

VARIABLES		SN TYPE		RELOCATION					
62	BOD	REAL	ARRAY	RIVER	563	BODL	REAL		
310	CL	REAL	ARRAY	RIVER	566	CLL	REAL		
454	CU	REAL	ARRAY	RIVER	570	CUL	REAL		
456	D	REAL	ARRAY	MISC	536	DO	REAL	ARRAY	RIVER
540	DOSAT	REAL	ARRAY	MISC	551	FACTOR	REAL		
0	FLOW	REAL	ARRAY	RIVER	547	I	INTEGER		
144	KBOD	REAL	ARRAY	MISC	310	KBOD20	REAL		MISC
311	K2	REAL	ARRAY	MISC	226	K220	REAL	ARRAY	MISC
0	LBOD	REAL	ARRAY	LOAD	226	LCL	REAL	ARRAY	LOAD
372	LCU	REAL	ARRAY	LOAD	454	LDO	REAL	ARRAY	LOAD
310	LPB	REAL	ARRAY	LOAD	536	LTEMP	REAL	ARRAY	LOAD
62	LTP	REAL	ARRAY	LOAD	144	LZN	REAL	ARRAY	LOAD
0	N	INTEGER		F.P.	372	PB	REAL	ARRAY	RIVER
567	PBL	REAL			373	Q	REAL		MISC
0	RM	REAL	ARRAY	INPT	62	RNAME	REAL	ARRAY	INPT
553	SBOD	REAL			556	SCL	REAL		

APPENDIX D (con)

```
     560  SCO       REAL                                 561  SDO      REAL
     552  SFLOW     REAL                                   0  SNAME    REAL      ARRAY    NAME
     557  SPB       REAL                                 550  SRM      REAL
     562  STEMP     REAL                                 554  STP      REAL
     555  SZN       REAL                                  62  TACC     REAL      ARRAY    MISC
     620  TEMP      REAL       ARRAY    RIVER              0  TIMEP    REAL      ARRAY    MISC
     226  TITLE     REAL       ARRAY    INPT             144  TP       REAL      ARRAY    RIVER
     564  TPL       REAL                                 374  U        REAL      ARRAY    MISC
     240  WIDTH     REAL       ARRAY    INPT             226  ZN       REAL      ARRAY    RIVER
     565  ZNL       REAL
1         SUBROUTINE OUTPT      74/175  OPT=0 ROUND=+-*/ TRACE        FTN 4.8  508        80/12/09. 13.42.07       PAGE     3
0  FILE NAMES        MODE
          TAPE2     FMT                 TAPE6      FMT

   EXTERNALS          TYPE    ARGS
          EOF       REAL        1

   STATEMENT LABELS
      16  1                               0  2          INACTIVE               27  3
      36  5                               0  10         INACTIVE               75  20
       0  30                              0  40                               355  110      FMT  NO REFS
     357  111     FMT                   362  112      FMT                     366  115      FMT
     372  120     FMT                   377  130      FMT                     407  199      FMT
     411  200     FMT                   422  201      FMT                     437  202      FMT
     472  203     FMT                   477  204      FMT                     522  205      FMT
     527  206     FMT

   LOOPS  LABEL     INDEX     FROM-TO     LENGTH    PROPERTIES
     103  30        I           38 41       25B               EXT REFS
     140  40        I           45 49       34B               EXT REFS

   COMMON BLOCKS    LENGTH
          INPT        210
          RIVER       450
          LOAD        400
          MISC        402
          NAME          2

   STATISTICS
     PROGRAM LENGTH                574B      380
     CM LABELED COMMON LENGTH     2670B     1464
          52000B CM USED
EOI.
ESQ
N>PURGE,SRMDAY,SRMOUT
N>
```

D-9

APPENDIX E

RECOMMENDED MONITORING PROGRAM

I. PHOSPHORUS ALLOCATION

A. Routine Survey - Sampling will coincide with WSU's schedule:

1. Sampling stations (Figure A-1) will be established on the Spokane River above (Fort Wright Bridge) and below (Seven Mile Bridge and below Nine Mile Dam) the AWT plant effluent, at the effluent, at the mouths of Hangman Creek and the LIttle Spokane River, and at the outlet below Long Lake Dam.

a. The above sampling stations will be sampled monthly except during the period from June through September when they will be sampled (bi-weekly). The following determinations will be made:

1. Temperature
2. pH
3. Dissolved oxygen
4. Turbidity
5. Total alkalinity/ hardness
6. Sulfate
7. Chloride
8. Calcium
9. Magnesium
10. Sodium
11. Potassium
12. Nitrate nitrogen
13. Nitrite nitrogen
14. Ammonia nitrogen
15. Total nitrogen
16. Total soluble nitrogen
17. Orthophosphate
18 Total phosphate
19. Total soluble phosphate
20. Silica
21. Conductivity
22. Total Suspended solids

b. Additional data for IIb.

Trace metals	23.	Pb
total and	24.	Zn
dissolved fractions	25.	Cu
	26.	Hg
	27.	Cd

c. Additional data for IIIb.

Oxygen demand	28.	COD
	29.	BOD

d. Additional data for IVb.

Fecal contamination	30.	Fecal coliform

2. The reservoir will be sampled monthly except during the period from June through September when it will be sampled biweekly. The reservoir will be sampled at eight kilometer intervals (five stations).

   a. At each sampling station, the following will be determined at three meter depth intervals from the survace to the bottom of the reservoir.

1.	Temperature	7.	Nitrate nitrogen
2.	Dissolved oxygen	8.	Nitrite nitrogen
3.	pH	9.	Ammonia nitrogen
4.	Conductivity	10.	Total phosphate
5.	Turbidity and total suspended solids	11.	Total soluble phosphate
6.	Orthophosphate	12.	Secchi depth

   b. At each sampling station the depth at which light intensity becomes 1 percent of surface intensity will determine the euphotic zone. A composite sample of phytoplankton will be collected throughout the euphotic zone for cell volume-counts by species, chlorophyll determinations.

   c. Additional data for IIb.

Trace metals total and dissolved fractions	13.	Pb
	14.	Zn
	15.	Cu
	16.	Hg
	17.	Cd

   d. Additional data for IIIb.

Oxygen demand	18.	COD
	19.	BOD

   e. Additional data of IVb.

Fecal contamination	20.	Fecal Coliform

   f. Sedimentation of particulate matter will be determined from sediment traps placed at each of the five reservoir stations. Three replicate samples for sedimentation will be collected at monthly intervals.

II. TOXICANT ALLOCATION

A. Water Quality

Water quality shall be monitored at stations shown in Figure E-1. Samples shall be collected monthly during the winter period and bi-weekly during the summer growth period. Parametric coverage at each station shall include:

1. Temperature
2. pH
3. Specific Conductance
4. Dissolved Oxygen
5. Chlorine Residual
6. Total Phosphorus
7. Ortho Phosphorus
8. Nitrate
9. Nitrite
10. Total Kjeldahl Nitrogen
11. Ammonia
12. Total Suspended Solids
13. Fecal Coliform
14. COD
15. BOD

Trace metals - total and dissolved fractions

16. Pb
17. Zn
18. Cu
19. Hg
20. Cd

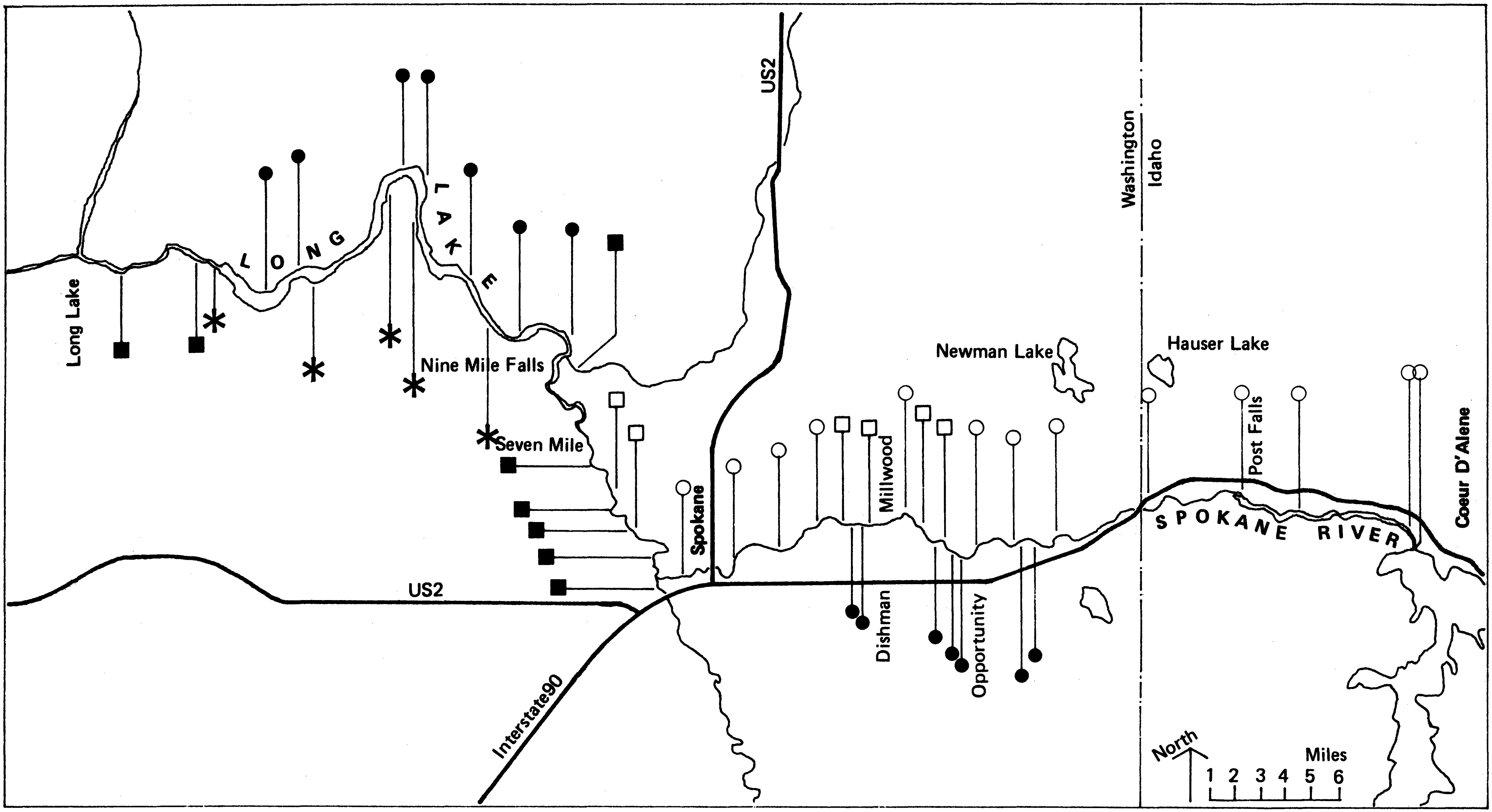
Other

21. Total alkalinity/hardness

23. Cl^-
24. Ca^{++}
25. Mg^{++}
26. Na^+
27. K^+

B. Additional data for III b.

28. Total soluble nitrogen
29. Total soluble phosphorus
30. Turbidity
31. Silica



SAMPLING SITE

- Point Sources & CSO & Urban Runoff IIc, IIIb, IVb
- Long Lake Reservoir Ia, Ib, IIb, IIc, IIIa, IVa, IVb
- Swimming Beaches IVb
- Lower Spokane River Sites Ia, IIb, IIc, IVa, IIIb, IVb
- Upper Spokane River Sites IIa, IIb, IIc, IIIa, IIIb

FIGURE E-1
RECOMMENDED SAMPLING LOCATIONS

APPENDIX F

EXAMINATION OF PHOSPHORUS PRODUCTIVITY MODEL

Soltero's regression model (Soltero, et al., 1979) is based on work developed by Dillon (1975). Dillon uses a steady-state in-lake phosphorus concentration rather than phosphorus supply as a measure of a lake's degree of eutrophy. The quantitative basis of this concept originated in a simple steady-state phosphorus budget:

Mass in - Mass loss - Mass out = 0

or $\frac{d(PV)}{dt} = 0$; P = in-lake P conc.; V = lake volume

t = time

The net change of in-lake phosphorus content in the period is zero. Soltero has selected June to November as the steady-state period for Long Lake because June and November mark the end and the beginning of the low algal productivity period.

The above equation can be written as:

$$M_{in} - R \times M_{in} - Q_o \langle P \rangle = 0$$

M_{in} = input phosphorus load in the time period

R = Sedimentation factor, a fraction

Q_o = outflow

$\langle P \rangle$ = steady-state in-lake phosphorus concentration

$$\langle P \rangle = \frac{M_{in}(1-R)}{Q_o} = \frac{LA\ (1-R)}{Q_o} = \frac{LV\ (1-R)}{ZQ_o};\ A = \frac{V}{Z}$$

$$\text{and } \langle P \rangle = \frac{L\ (1-R)}{Z\frac{Q_o}{V}} = \frac{L\ (1-R)}{Z\rho} = \frac{Lp}{Z}$$

L = specific areal loading rate

Lp = normalized areal loading rate

Z = mean depth

ρ = flushing rate in the time period

Dillon uses the plot of $\frac{L\ (1-R)}{\rho}$ vs Z to formulate the lake trophic state. Soltero used the same normalized areal loading rate, $L\ (1-R)/\rho$, regressed it against the mean chl a concentration in the same period and found an excellent correlation for all the data collected in past years. The regression equation takes the form of:

chl a = a (Lp) + b

If we multiply both sides of the equation by the mean depth, z, we get:

chl a (z) = a (<P>) + bz where <P> = z (Lp)

So the equation actually relates the mean chl a concentration with the steady state in-lake P concentration.

One of the difficulties of using this model is the problem of defining the sedimentation factor, R. (R is the fraction of the input load that is lost due to settling.) For example, we have plotted the average R in the period of June to November against the mean seasonal flow rate Q_o, measured at the Long Lake Dam for the same period (Figure F-1).

The plot shows two things:

1) For the years before AWT, the R correlates very well with the flow (higher the flow, the lower the R), with the exception of 1975 data.

2) After AWT, R shifted to a lower value even with low flow.

One possible explanation for the latter observation is that advance treatment removes a major portion of the settleable-P (which otherwise would have settled in the lake).

Vollenweider uses a similar loading parameter as Dillon, an areal phosphorus load Lp normalized by mean depth (Z) and hydraulic residence time (τ_w), to correlate with the mean chl a concentration.

Mathematically, this loading parameter is described as

$(Lp/q_s)/(1+\tau_w^{1/2})$ with unit $g\text{-}P/m^3$ (concentration).

q_s = overflow rate = Q_o/A

A = mean surface area of the lake

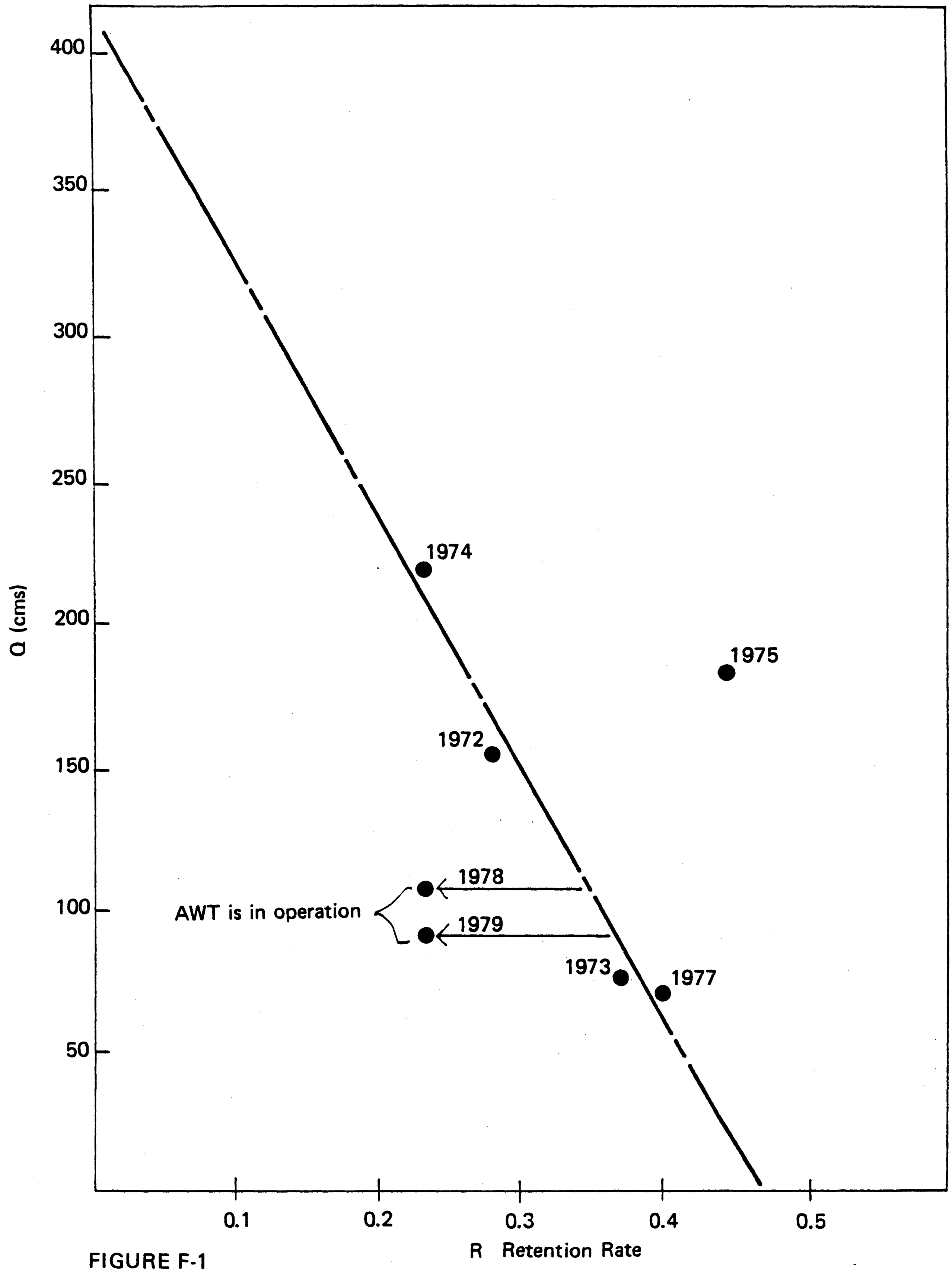


FIGURE F-1
Seasonal (June - November) phosphorus retention rate in Long Lake vs. Mean seasonal discharges at Long Lake Dam

$$\tau_w = \frac{V}{Q_o}$$

V = volume of the lake

Q_o = volume of the outflow in the period of the analysis

$$\tau_w = \frac{z}{z} \cdot \frac{V}{Q_o} = Z \cdot \frac{A}{Q_o} = A/q_s$$

So the parameter can be written as:

$$Lp/q_s/(1 + \sqrt{z/q_s})$$

Vollenweider conducted the regression analysis of these two parameters, $Lp/q_s/(1 + \sqrt{z/q_s})$ and chl a, using logrithms.

The resulting regression equation takes the form:

$$\log(\text{chl } \underline{a}) = a\,(\log [Lp/q_s/(1 + \sqrt{z/q_s})] + b$$

If we equate the loading parameter in each model:

$$\frac{Lp\,(1 - R)}{\rho z} = \frac{Lp/q_s}{1 + \sqrt{z/q_s}}$$

we can show how Vollenweider treats the settling factor,

R, in his model.

$$\frac{1 - R}{\rho z} = \frac{1}{q_s\,(1 + \sqrt{z/q_s})}$$

$$\rho = \frac{Q}{V} = \frac{Q}{z.A} = \frac{q_s}{z}$$

$$\frac{1 - R}{\rho z} = \frac{1 - R}{q_s} = \frac{1}{q_s\ (1 + \sqrt{z/q_s})}$$

$$1 - R = \frac{1}{1 + \sqrt{z/q_s}}$$

$$R = 1 - \frac{1}{1 + \sqrt{z/q_s}} \quad \text{or} \quad 1 - \frac{1}{1 + \sqrt{\tau_w}}$$

It is obvious that Vollenweider's R is strictly a function of the flushing rate, τw.

The following table compares the R calculated from the lake budget (as is done in Dillon's model) and from the Vollenweider's implicit formulation.

Year	Q_o CMS	τ_w	$\tau_w^{1/2}$	$\frac{1}{(1 + \tau_w^{1/2})}$	$R_{Vollenweider}$	$R_{Calculated}$
1972	170.6	0.113	0.336	0.75	0.25	0.28
1973	76.2	0.2532	0.503	0.67	0.33	0.37
1974	220.5	0.0875	0.296	0.77	0.23	0.23
1975	183.9	0.1048	0.324	0.76	0.24	0.44 (abnormality)
1976	---	---	---	---	---	---
1977	72.2	0.2674	0.517	0.66	0.34	0.40
1978	108.2	0.1783	0.422	0.70	0.30	0.23
1979	90.7	0.2128	0.461	0.68	0.32	0.23

Because Vollenweider's treatment of R does not account for wastewater treatment effects, it's R value in post AWT data is a little higher than that calculated (see 1978, 1979's R values in the table).

Because of this difference in R, Dillon's model yields a higher correlation coefficient value than Vollenweider's model, $r^2 = 0.944$ and 0.871, respectively.

Dillon's Model

$$chl\underline{a} = 12.47 + 9.925\ (Lp_d - 0.6482)$$

$$= 12.47 + 9.925\ Lp - 6.43$$

$$chl\underline{a} = 9.925\ Lp + 6.04$$ June to November

$$r^2 = 0.9443$$

where:

$$Lp_d = \frac{L\ (1-R)}{\rho}$$

Vollenweider's Model

$$\log chl\underline{a} = 1.0814 + 0.3831\ (\log Lp_v + 1.3978)$$

$$= 1.0814 + 0.3831 \log Lp + 0.5355$$

$$\log chl\underline{a} = 0.3831 \log Lp + 1.6169$$ June to November

$$r^2 = 0.8712$$

where:

$$Lp_v = \frac{L/q_s}{1 + \sqrt{z/q_s}}$$

APPENDIX G

DESIGN FLOW ANALYSIS

DESIGN FLOW ANALYSIS AT LONG LAKE*

Year	June - October (5 mo.)		June - November (6 mo.)	
	Total	Average	Total	Average
1939	14888	2978	16947	2825
1940	13172	2934	15861	2644
1941	15040	3008	19355	3226
1942	16779	3356	21792	3632
1943	26651	5330	29683	4947
1944	12362	2472	14933	2489
1945	17636	3527	21657	3610
1946	20361	4072	25689	4282
1947	18848	3770	23797	3966
1948	38383	7677	41431	6905
1949	17496	3499	21410	3568
1950	41368	8274	47235	7873
1951	18990	3798	24244	4041
1952	18454	3691	21435	3573
1953	25435	5087	28538	4764
1954	29237	5847	34194	5699
1955	30593	6119	37408	6235
1956	28587	5717	33000	5500
1957	23802	4760	27562	4594
1958	16784	3357	23282	3880
1959	29037	5807	38102	6350
1960	22485	4497	25940	4323
1961	23312	4662	26526	4421
1962	19623	3925	24022	4004
1963	11705	2341	15211	2535
1964	35430	7086	39548	6591
1965	22298	4460	26406	4401
1966	14407	2881	17709	2952
1967	25757	5151	29248	4875
1968	17813	3563	24752	4125
1969	20516	4103	23364	3894
1970	26274	5255	29812	4969
1971	32096	6419	35584	5931
1972	33429	6686	36134	6022
1973	11972	2394	16145	2691
1974	43212	8642	46700	7783
1975	34274	6855	38949	6492
1976	23862	4772	26904	4484
1977	12196	2439	15286	2548
1978	20055	4011	22927	3821
1979	16445	3289	19212	3202

* Monthly summary is provided by Rod Williams (USGS - Tacoma)

SPOKANE R. AT LONG LAKE

Ranking	Flow	P	1-P (probability of being equalled or exceeded)
1	2489	0.024	0.976
2	2535	0.049	0.951
3	2548	0.073	0.927
4	2644	0.098	0.902
5	2691	0.122	0.878
6	2825	0.146	0.854
7	2952	0.171	0.829
8	3226	0.195	0.805
9	3568	0.220	0.780
10	3573	0.244	0.756
11	3610	0.268	0.732
12	3632	0.293	0.707
13	3821	0.317	0.683
14	3880	0.342	0.658
15	3894	0.366	0.634
16	3966	0.390	0.610
17	4004	0.415	0.585
18	4041	0.439	0.561
19	4125	0.463	0.537
20	4282	0.488	0.512
21	4323	0.512	0.488
22	4401	0.537	0.463
23	4421	0.561	0.439
24	4484	0.585	0.415
25	4594	0.610	0.390
26	4764	0.610	0.390
27	4875	0.659	0.341
28	4947	0.683	0.317
29	4969	0.707	0.293
30	5500	0.732	0.268
31	5699	0.756	0.244
32	5931	0.781	0.219
33	6022	0.805	0.195
34	6235	0.829	0.171
35	6350	0.854	0.146
36	6492	0.878	0.122
37	6591	0.902	0.098
38	6905	0.927	0.073
39	7783	0.951	0.049
40	7873	0.976	0.024

SPOKANE R. AT POST FALLS

Year	June - October (5 mo.) Total	Average	June - November (6 mo.) Total	Average
1913	30533	6107	34126	5688
1914	9826	1965	13952	2325
1915	10866	2173	12387	2065
1916	33685	6737	35417	5903
1917	37039	7408	38367	6395
1918	12712	2542	14475	2413
1919	12676	2535	13831	2305
1920	14423	2885	18275	3046
1921	14841	2968	16388	2731
1922	16095	3219	17442	2907
1923	19111	3822	20486	3414
1924	6669	1334	8618	1436
1925	13730	2746	14898	2483
1926	6787	1357	11392	1899
1927	28634	5727	41764	6961
1928	12343	2469	13492	2249
1929	9561	1912	10533	1756
1930	7748	1550	8713	1452
1931	6080	1216	6963	1161
1932	16827	3365	21758	3626
1933	29424	5885	35961	5994
1934	5363	1073	9476	1579
1935	14568	2914	15195	2533
1936	9904	1981	10691	1782
1937	12049	2410	14078	2346
1938	11770	2354	13085	2181
1939	8390	1678	9057	1510
1940	6364	1273	7681	1280
1941	8866	1773	12152	2025
1942	10407	2081	14326	2388
1943	18777	3755	20475	3413
1944	6559	1312	7969	1328
1945	10460	2092	13275	2213
1946	12369	2474	16646	2774
1947	11372	2274	15074	2512
1948	27963	5593	29543	4924
1949	9475	1895	12284	2047
1950	32772	6554	37266	6211
1951	11018	2204	14894	2482
1952	10991	2198	12682	2114
1953	17840	3568	19822	3304
1954	22477	4495	26364	4394
1955	24612	4922	30709	5118
1956	20027	4005	22936	3823
1957	15529	3106	17968	2995
1958	8912	1782	14551	2425
1959	21326	4265	29495	4916
1960	14686	2937	16754	2792

SPOKANE R. AT POST FALLS

Year	June - October (5 mo.) Total	Average	June - November (6 mo.) Total	Average
1961	15383	3077	17386	2898
1962	12486	2497	15948	2658
1963	5631	1126	8051	1342
1964	28486	5697	31619	5270
1965	14659	2932	17530	2922
1966	8153	1631	10290	1715
1967	19547	3909	21988	3665
1968	12854	2571	19023	3171
1969	14209	2842	15951	2659
1970	20129	4026	22590	3765
1971	25886	5177	28258	4710
1972	27675	5535	29159	4860
1973	7729	1546	10792	1799
1974	36479	7296	38586	6431
1975	27153	5431	30642	5107
1976	17081	3416	18812	3135
1977	7714	1543	9812	1635
1978	14164	2833	15737	2623

SPOKANE R. AT POST FALLS

n = 66 $\quad P = \frac{m}{n+1} \quad Tr = \frac{n+1}{m}$

Ranking (m)	Flow	P	(probability of being equaled or exceeded) 1-P
1	1161	0.015	0.985
2	1280	0.030	0.970
3	1328	0.045	0.955
4	1342	0.060	0.940
5	1436	0.075	0.925
6	1452	0.090	0.910
7	1510	0.105	0.895
8	1579	0.119	0.881
9	1635	0.134	0.866
10	1715	0.149	0.851
11	1756	0.164	0.836
12	1782	0.179	0.821
13	1799	0.194	0.806
14	1899	0.209	0.791
15	2025	0.224	0.776
16	2047	0.239	0.761
17	2065	0.254	0.746
18	2114	0.269	0.731
19	2181	0.284	0.716
20	2213	0.299	0.711
21	2249	0.313	0.687
22	2305	0.328	0.672
23	2325	0.343	0.657
24	2346	0.358	0.642
25	2388	0.373	0.627
26	2413	0.388	0.612
27	2425	0.403	0.597
28	2482	0.418	0.582
29	2483	0.433	0.567
30	2512	0.448	0.552
31	2533	0.463	0.537
32	2623	0.478	0.522
33	2658	0.493	0.507
34	2659	0.508	0.492
35	2731	0.522	0.478
36	2774	0.537	0.463
37	2792	0.552	0.448
38	2898	0.567	0.433
39	2907	0.582	0.418
40	2922	0.597	0.403
41	2995	0.612	0.388

SPOKANE R. AT POST FALLS

Ranking (m)	Flow	P	(probability of being equaled or exceeded) 1-P
42	3046	0.627	0.373
43	3135	0.642	0.358
44	3171	0.657	0.343
45	3304	0.672	0.328
46	3413	0.687	0.313
47	3414	0.702	0.298
48	3626	0.716	0.284
49	3665	0.731	0.269
50	3765	0.746	0.254
51	3823	0.761	0.239
52	4394	0.776	0.224
53	4710	0.791	0.209
54	4860	0.806	0.194
55	4916	0.821	0.179
56	4924	0.836	0.164
57	5107	0.851	0.149
58	5118	0.866	0.134
59	5270	0.881	0.119
60	5688	0.896	0.104
61	5903	0.910	0.090
62	5994	0.925	0.075
63	6211	0.940	0.060
64	6395	0.955	0.045
65	6431	0.970	0.030
66	6961	0.985	0.015

LITTLE SPOKANE RIVER AT DARTFORD n = 35

Year	June to November Total Flow	Mean Seasonal Flow
1929	701	117
1930	580	97
1931	532	89
1932	---	---
1947	900	150
1948	1812	302
1949	1037	173
1950	1309	218
1951	1243	207
1952	1242	207
1953	1209	202
1954	1095	183
1955	1100	183
1956	1293	216
1957	1112	185
1958	1074	179
1959	1305	218
1960	1453	242
1961	1232	205
1962	1138	190
1963	994	166
1964	1040	173
1965	1030	172
1966	850	142
1967	961	160
1968	855	143
1969	1081	180
1970	1023	171
1971	1098	183
1972	968	161
1973	797	133
1974	1371	229
1975	1350	225
1976	1101	184
1977	739	123
1978	944	157

LITTLE SPOKANE RIVER AT DARTFORD

$$p = \frac{m}{n + 1} = \frac{m}{36}$$

Ranking (m)	Flow	P	(probability of being equaled or exceeded) 1-P
1	89	0.028	0.972
2	97	0.056	0.946
3	117	0.083	0.917
4	123	0.111	0.889
5	133	0.139	0.861
6	142	0.167	0.833
7	143	0.194	0.806
8	150	0.222	0.778
9	157	0.250	0.750
10	160	0.278	0.722
11	161	0.306	0.694
12	166	0.333	0.667
13	171	0.361	0.639
14	172	0.389	0.611
15	173	0.417	0.583
16	173	0.417	0.583
17	179	0.472	0.528
18	180	0.500	0.500
19	183	0.528	0.472
20	183	0.528	0.472
21	183	0.528	0.472
22	184	0.611	0.389
23	185	0.639	0.361
24	190	0.667	0.333
25	202	0.694	0.306
26	205	0.722	0.278
27	207	0.750	0.250
28	207	0.750	0.250
29	216	0.806	0.194
30	218	0.833	0.167
31	218	0.833	0.167
32	225	0.889	0.111
33	229	0.917	0.083
34	242	0.944	0.056
35	302	0.972	0.028

HANGMAN CREEK AT SPOKANE   n = 29

Year	June to November Total Flow	Mean Seasonal Flow
1948	619	103
1949	124	21
1950	299	50
1951	183	31
1952	156	26
1953	206	34
1954	162	27
1955	259	43
1956	192	32
1957	268	45
1958	159	27
1959	268	45
1960	146	24
1961	101	17
1962	117	20
1963	107	18
1964	115	19
1965	165	27
1966	76	13
1967	143	24
1968	98	16
1969	206	34
1970	152	25
1971	431	72
1972	119	20
1973	118	20
1974	215	36
1975	260	43
1976	152	25
1977	---	--
1978	---	--

LITTLE SPOKANE RIVER AT DARTFORD n = 29

$$p = \frac{m}{n + 1}$$

Ranking (m)	Flow	P	(probability of being equaled or exceeded) 1-P
1	13	0.033	0.967
2	16	0.067	0.933
3	17	0.100	0.900
4	18	0.133	0.867
5	19	0.167	0.833
6	20	0.200	0.800
7	20	0.200	0.800
8	20	0.200	0.800
9	21	0.300	0.700
10	24	0.333	0.667
11	24	0.333	0.667
12	25	0.400	0.600
13	25	0.400	0.600
14	26	0.467	0.533
15	27	0.500	0.500
16	27	0.500	0.500
17	27	0.500	0.500
18	31	0.600	0.400
19	32	0.633	0.367
20	34	0.667	0.333
21	34	0.667	0.333
22	36	0.733	0.267
23	43	0.767	0.233
24	43	0.767	0.233
25	45	0.833	0.167
26	45	0.833	0.167
27	50	0.900	0.100
28	72	0.933	0.067
29	103	0.967	0.033

DESIGN FLOW CONDITIONS AT VARIOUS BOUNDARIES UNDER THREE STATISTICAL LEVELS - FLOW EXCEEDED 95%, 90% and 80% OF TIMES

	Statistical Level		
	95%	90%	80%
return period	1/20 yr	1/10 yr	1/5 yr
Post Falls:	1600 cfs	1700 cfs	2100 cfs
Groundwater/ river exchange at location			
1	-28 cfs	-27 cfs	-31 cfs
2	219	203	221
3	-46	-48	-46
4	275	261	267
5	-208	-214	-216
6	120	119	119
7	-12	-12	-13
8	20	19	19
9	-23	-23	-25
10	45	43	45
11	-41	-42	-40
12 (to LSR)	256	225	258
boundary flow to Long Lake	110	110	110
Hangman Creek*	14	17	30
LSR*	124	127	160
design flow at Long Lake	2535	2644	3226

* Estimated flow from historical records that give similar design flow at Long Lake