EPP

OKANAGAN BASIN IMPLEMENTATION AGREEMENT

AN ESTIMATE OF PHOSPHORUS LOADINGS FROM FORESTRY ACTIVITIES IN THE OKANAGAN

BY

D. GARRY ALEXANDER

AND

JOHN H. WIENS

TERRESTRIAL STUDIES BRANCH

MINISTRY OF ENVIRONMENT

VICTORIA, BRITISH COLUMBIA

SEPTEMBER, 1982

ABSTRACT

Phosphorus loadings to the Okanagan main valley lakes from forestry activities were estimated as part of the Okanagan Basin Implementation Agreement to determine loadings from this source compared to other sources in the Okanagan, and to identify watersheds with higher loadings for control purposes.

The study consisted of monitoring nutrient concentrations and flow rates during 1980/81 in unlogged and previously logged drainage basins in Vaseux and Shingle Creeks. Annual loadings calculated from these studies were extrapolated to other unmonitored areas of the Okanagan Basin based on an inventory of logging for the Okanagan. Finally, the proportion of phosphorus loadings available for biological production was calculated for each lake sub-basin.

This study has shown that logging contributes an estimated 10 tonnes of biologically available phosphorus (BAP) annually to the lakes which is approximately 20% of the BAP from the total of cultural sources. Tributaries vary in terms of their contribution of BAP from those tributary drainages with less than 5% of logged area which may produce significant loadings only during years of above average runoff to those drainages with greater than 20% logging which produce the largest contribution in most years.

Finally, methods of identifying problem areas and controlling nutrient losses from logging sites are discussed.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The following are gratefully acknowledged for their assistance in carrying out this study: Gordon Oliphant and Andy Guest for their diligence in collecting samples and help in organizing data; Gordon Clark, Ken Walker and Bud Skinner for their advice and support in measuring flows; Margaret Moccia for her tireless efforts in typing these drafts; and Dennis Peaker and Paul MacNamara for their help in providing information for the logging inventory. Thanks to Colin Gray and Jack Cheng for reviewing this manuscript. A special note of appreciation is extended to Olas Slaymaker for his valuable advice in the planning and design of this study.

INTRODUCTION

One of the major water quality concerns in the Okanagan is that of accelerated eutrophication or enrichment of the Okanagan main valley lakes due to cultural inputs of nutrients, such as nitrogen and phosphorus (1). Nuisance algal blooms, rotting vegetation and changes in sport fisheries are several of the direct effects of eutrophication which detract from recreational and other uses of the Okanagan Lakes. The identification and control of major sources of nutrients such as municipal wastes, agricultural and forestry activities is one of the major thrusts of the Okanagan Basin Implementation Agreement (2).

Estimates of the amounts of nutrients reaching the Okanagan Lakes have been completed for a number of sources. Point sources such as municipal waste and most non-point sources such as livestock, agricultural fertilizer and septic tanks have been either measured or estimated (3). On the other hand, nutrient loadings from forestry activities such as road building, logging and grazing have remained elusive for several reasons: 1) nutrient loadings from most forestry activities unlike other sources mentioned do not result from the application of nutrients which can be measured directly, but rather result from the release of naturally occurring nitrogen and phosphorus compounds associated with soil and organic matter which are more difficult to measure; 2) the impression that phosphorus loadings from forestry activities, are not as available for in-lake biological growth as loadings from municipal waste and, therefore, forestry was not a significant problem. This impression fails to account for the overall loading contribution from forested land and the significance of the proportion of total loadings that is biologically available.

The objectives of this paper are to determine the relative impact of phosphorus loadings from forestry activities compared to other sources based on studies carried out in the Okanagan, and to suggest methods of reducing nutrients from this source that are applicable to the Okanagan situation. Although, technically, a part of forest management, grazing by livestock and the effects produced, are not included in this paper. The major forestry activity of concern is, therefore, logging which includes the associated effects of road building.

1. Review of Forestry Activities and Effects on Nutrient Export

Forestry activities can cause a number of changes in the nutrient regime of forested areas. An obvious effect of forest harvesting, for example, is the removal of nutrients contained in the harvested fibre and the redistribution of nutrients in branches and limbs as slash. Studies have demonstrated that major losses of nutrients such as nitrogen, occurred with the removal of fibre (4); however, the loss of nutrients in this fashion has more to do with site productivity. From the perspective of nutrient loadings to the lakes the most important effects of forestry activities are disturbances to ground cover and established drainage patterns with the consequences of increased erosion and increased leaching of nutrients through the soil.

Activities which expose mineral soil or which lower infiltration capacity of the soil to below precipitation intensities and increase overland flow are responsible for soil erosion and sediment production. Sediment contains inorganic and organic forms of nitrogen and phosphorus. A major component of sediment phosphorus is Apatite which is biologically unavailable. Of all activities associated with logging, road construction is most often cited as responsible for the greatest amount of erosion (5). Construction of roads not only results in exposure of mineral soil and reduced infiltration of road surfaces, but it also concentrates runoff along the surface of the road and in roadside ditches. This concentration increases the erosive force of the water, especially where gradients are high (6). On steeper slopes, road cuts may result in serious slope instability from side casting of excavated soil and disturbance of subsurface flow patterns.

Logging also may result in increased erosion; however, the effects produced depend on the type of logging, such as clearcut or selection system cut; the method of logging, such as cable or tractor, and the season in which logging is carried out. Removing timber by selection system or shelterwood harvest would have less impact than clearcuts because of reduced soil disturbance, as well as maintaining a protective cover of vegetation. Studies carried out in south-western Oregon showed that shelterwood and small clearcuts of less than 2 hectares resulted in lower concentrations of total phosphorus, orthophosphorus and nitrate instreams draining the watersheds than did clearcuts of 50 hectares (7).

In addition to nutrients associated with sediment from erosion it should be noted that losses of dissolved nutrients may result due to logging and other disturbances. For example, nitrate from the mineralization of organic nitrogen in decomposing plant material is formed more rapidly following logging. Nitrate may be readily leached from the soil since there is reduced nutrient demand from plants.

Methods of removal of felled timber also affect the degree of disturbance. Yarding with crawler tractors, for example, may compact the soil and reduce infiltration capacity, thus leading to increased overland flows. Skid trails, in turn, may become rutted and concentrate surface runoff or may criss-cross streams with obvious results. It has been reported that 80% of the disturbance associated with tractor and ground cable systems was caused by skid trails (8). Other methods such as cable logging and helicopter logging have substantially less effect due to the reduction in soil disturbance. A comparison of yarding methods (6) found that on average tractors caused soil disturbance on 28% of the sites, as compared to 23% for ground cables, 5% for suspended cables and 2% for helicopters.

The season during which road building and logging occur also determines the impact on erosion. Road building in the Okanagan is usually carried out during the late summer or early fall when the soil has stabilized and soil moisture levels are usually low. Logging carried out on frozen or snow covered ground apparently decreases the level of disturbance. Winter logging reduced the degree of soil disturbance by 45% compared to summer logging from a study of tractor logging in the Nelson forest region (8). Also, failure to measure substantial effects of logging on stream chemistry in the Okanagan may have been due to the reduced impact of winter logging (9).

The method of site preparation following logging such as scarification and slash burning will influence the release of nutrients in two main ways. Firstly, slash burning and scarification may increase the rate of erosion. The role of scarification in producing erosion is generally considered to be minor with the exception of steep slopes since infiltration of precipitation would likely prevent serious overland flow. However, the effects of burning are more complex. Depending on the intensity and extent of slash burning there may be a decrease in infiltration capacity of the soil due to reduced soil porosity and increase in overland flow and surface erosion. Secondly, slash burning causes the rapid mineralization of plant and litter material containing nutrients which leaves these nutrients more susceptible to leaching. In a study, broadcast burning increased soil solution concentrations of a number of chemicals, including nitrate and phosphate, six times over that of an undisturbed forest (10). Other studies have reported a similar increase in nutrients in streams draining areas affected by wildfire (11).

The duration of leaching of nutrients from disturbed areas will be determined in part by the amount of time for revegetation to occur. Regeneration through natural means or planting will increase the uptake of plant nutrients and establish a groundcover that will reduce erosion. Studies such as that reported in western Oregon (12) have shown a reduction in nutrient losses after one year following logging.

There is a potential for increased nutrient loss from other aspects of reforestation such as: indirectly from the use of herbicides to control weeds and brush; and directly from nutrients applied as fertilizer. Herbicides eliminate certain types of vegetation and can reduce plant uptake of nutrients and increase leaching of existing nutrients from decomposing plant material.

Fertilization if applied to the requirements of the stand would not be expected to result in increased concentrations in stream flow. Fertilizer applied to established stands would be taken up and incorporated as plant material since it is probably added to compensate for an inadequate natural supply of the nutrient. Residual fertilizer, if present, would likely remain above or within the root zone of the stand until eventually taken up. Presumably, only fertilizer directly entering streams or areas prone to flooding would reach surface water and this would be expected to be a small percentage of the total.

2. Review of Watershed Studies of Forestry Activities and Nutrient Loading

The classical study with regard to water quality effects of logging was conducted at Hubbard Brook, a hardwood forest in the northeastern United States. In this study substantial increases in nutrient concentrations such as nitrate and ammonium occurred following clearcutting and herbicide application (13). Although large increases in nutrients occurred it was noted that the treatment of clearcutting and herbicide use was extreme and that the concentrations of nutrients were higher in precipitation than in streams draining the control watershed.

Subsequent studies in the northwestern United States have shown increased concentrations of nitrogen and phosphorus in watersheds that have been clearcut and, in some cases, burned compared to control watersheds (14).

The only study carried out in the Okanagan on Dennis Creek near Penticton, reported that there was no significant difference in concentrations of nitrogen and phosphorus forms following clearcutting (9). This study measured the change in concentrations of a number of chemical parameters upstream and downstream of an area clearcut the preceeding year. An undisturbed creek was monitored also for comparison.

However, conclusions from this study may have overlooked a possible increase in the export of total amounts of nutrients due to logging. For example, the concentrations of total kjeldahl nitrogen measured were greater below the logged area than above the logged area for most of the sampling period. This was particularly true for the period during April and May in freshet when stream flows would have been high. Although discharge was not measured as a part of this study, it is conceivable that increased discharges could have occurred for the logged watershed compared to the undisturbed watershed as have been reported for other clearcut areas (15). Thus, the difference in nutrient loading between stations would likely have been substantially greater than the concentration differences actually reported. Although similar data for other forms of nitrogen and phosphorus were not shown in the report, the same situation may apply. Therefore, when the data are examined from the point of view of nutrient loadings, which are the major concern for management of the Okanagan Lakes, loadings of at least some of the nutrient forms are apparently greater following logging.

METHODS AND RESULTS

Measurement of Nutrient Loads from Forestry Activities in the Okanagan

From the preceeding review it was apparent that forestry activities may be an important source of nutrients to the Okanagan lakes and that further

TABLE 1: CHARACTERISTICS OF STUDY AREA

STATION NO.		TREATMENT	AREA OF WATERSHED (ha)	AREA LOGGED (ha)	PERCENTAGE LOGGED	PERIOD OF LOGGING; Year Percentage of Total Cut Exceeded or Equalled			ANNUAL DISCHARGE m^3x10^3	ASPECT	APPROXIMATE MEAN ELEVATION (metres)
						25%	50%	75%			
	Vaseux Creek										
1.	Water Survey of Canada Station	Logged	10,800*	1,110	10	1974	1975	1976	31,300	West	1,500
2.	Underdown Creek	Logged	2,320	180	8	1975	1976	1978	6,300	North	1,600
3.	Wabash Creek	Logged	1,120	60	5			1981	2,300	South	1,700
4.	Upper Vaseux Creek	Control	2,310	0	0				6,000	South	1,600
5.	McIntyre Creek	Logged	2,020	520	26	1974	1975	1976	10,800	North	1,700
	Shingle/Shatford Creek										
6.	Upper Shatford	Control	5,900	0	0				9,800	East	1,500
3.	Upstream Ranch Area	Logged	5,000	681	14	1973	1978	1979	9,400	East	1,500
2.	Downstream Ranch Area	Logged	9,200*	1,670*	18	1977	1977	1978	8,500	South-East	1,400

* Includes the total of all upstream areas.

work was necessary to estimate the magnitude of loadings for the Okanagan basin. Under the Okanagan Basin Implementation Agreement the following work was carried out in 1980-81 to estimate nutrient loadings due to logging in the Okanagan: 1) monitoring of nutrient concentrations and flows from unlogged and previously logged drainage basins in Shingle and Vaseux Creeks for one year; 2) extrapolation of results from Shingle and Vaseux Creeks to remaining areas of the Okanagan based on an inventory of area logged for the Okanagan between 1970 and 1980; and 3) estimation of the proportion of phosphorus loading from logging available for biological growth in the Okanagan Lakes.

1. Stream Monitoring

1.1 Description of Study Area

Nutrient concentration and flow data were collected between September 1980 and August 1981 at several stations in the upper sub-basins of Vaseux and Shingle Creeks (Figures 1 and 2). Stations were selected primarily on the basis of the age and extent of logging and access. Stations were located with respect to acceptable criteria for measurement of stream flow based on judgement of staff of the Planning and Surveys Section of the Ministry of Environment; however, problems in maintaining an adequate control during spring freshet affected measurement in approximately half of the stations.

Table 1 compares the physical characteristics of areas sampled. Elevation ranged from 1,200 m to 2,300 m and 900 m to 2,200 m for Vaseux and Shingle Creeks, respectively. The topography of the areas studied as it affects stream flow differs for the two sub-basins. The study area for Vaseux Creek is plateau-like with low to moderate stream gradients; whereas, in Shingle Creek stream gradients are high for the upper reaches sampled. Also, glacial

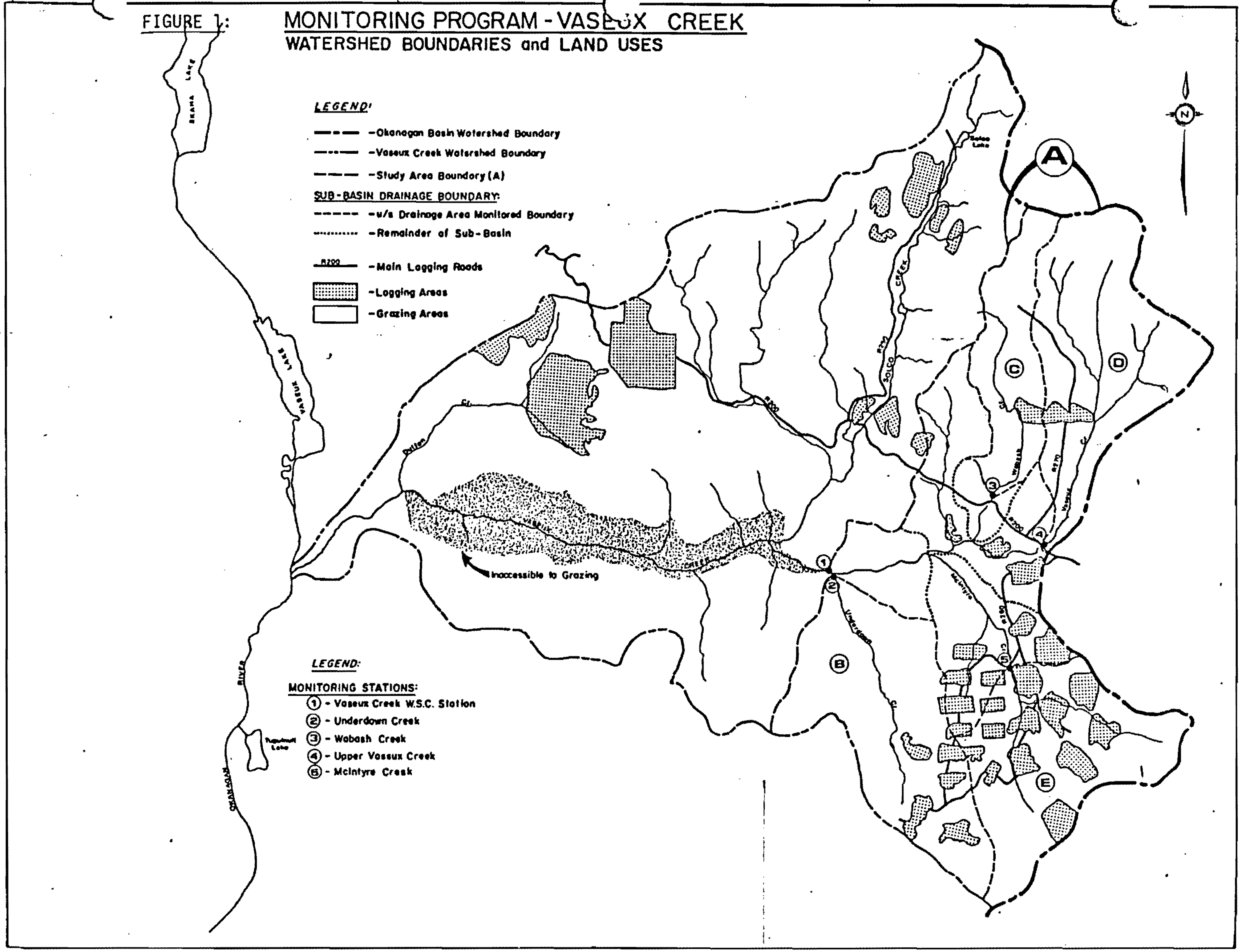
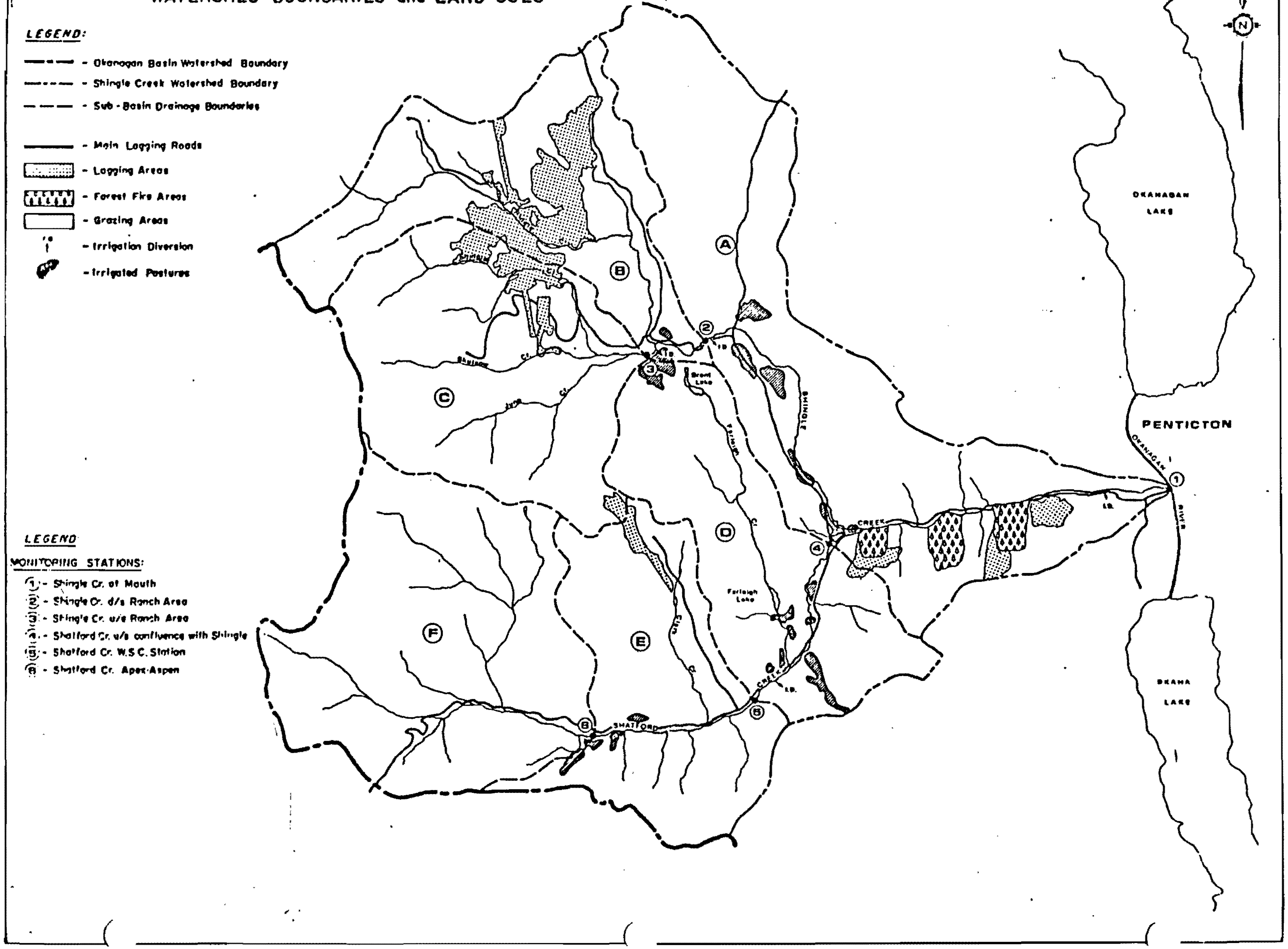


FIGURE 1: MONITORING PROGRAM - VASEUX CREEK
WATERSHED BOUNDARIES and LAND USES

FIGURE 2: MONITORING PROGRAM - SHINGLE CREEK
WATERSHED BOUNDARIES and LAND USES



action has resulted in a variety of surficial materials in the sub-basins. The upper plateau area of Vaseux Creek is overlain mainly by glacial outwash material, whereas, Shingle Creek is overlain largely by glacial till.

As indicated from records of the Water Survey of Canada stations on Upper Vaseux Creek and Shatford Creek, the major period of runoff as snowmelt occurs on average from the beginning of April to the end of July or early August. The peak of freshet occurs usually during the end of May or early June.

The type of logging conducted in the study areas was clearcutting with openings ranging in size from 40 ha to 250 ha and comprising from 5 to 26% of the total watershed area. Areas that had not been logged previously were used as control watersheds, although road development and other land use activities such as cattle grazing occurred within these watersheds.

1.2 Sampling Design

Since the time frame of the program was limited to one year it was likely that only gross effects of forestry activities would be measurable with samples collected on a regular or routine basis. Therefore, sample collection was weighted on the basis of hydrology. During the low flow period from August to March samples were collected approximately monthly. During the period from the onset of freshet to the peak of freshet samples were collected weekly. Following the peak samples were collected biweekly. In addition, 2 to 3 samples were collected during periods of intense rainfall in the Shingle/Shatford sub-basin on three occasions.

Grab samples were collected at each station and filtered in the field through 0.45 micron membrane filters for later dissolved phosphorus determination. Samples for particulate nitrogen determination were filtered in the laboratory through glass-fiber filters using a vacuum flask. All samples were packed in coolers with ice and sent to the Water Quality Branch Laboratory, of the Inland Waters Directorate, North Vancouver, for analyses.

Stream flow measurements were made using a Price & Smith current metre (model no. 622AA) according to the procedure set out in (16). Flow rates were calculated by the Planning and Surveys Section according to (17). Ten to fifteen measurements were conducted over a range of flows to develop a rating curve for each of the stations. A recording gauge was used at Station No. 4 (upper Vaseux Creek). The remaining stations had staff gauges for level record which were read at the same frequency as the collection of water samples. Station No. 1 (lower Vaseux Creek) coincides with Water Survey of Canada Station No. 08NM171.

Data analyses consisted of the calculation of daily loads where concentration and flow data were available. The mean daily load was calculated for each month and this figure multiplied by the number of days in each month. Monthly loading values were summed to obtain annual loading.

1.3 Results of Stream Monitoring

Annual unit area loadings of nitrogen and phosphorus for each sub-basin are shown in Table 2. Results for a major storm event during the peak of freshet were not available due to difficulties in measuring stream flows under these extreme conditions. For this reason, annual loadings are not complete and are, therefore, an underestimate of actual loadings for the year.

For the present, only phosphorus loadings are determined with respect to forestry activities since this is the nutrient recommended for controlling lake productivity. Also, since forestry activities impact largely on the basis of erosion of

TABLE 2: AREAL NUTRIENT LOADINGS FOR SHINGLE AND VASEUX CREEKS

STATION	PERCENTAGE OF DRAINAGE AREA LOGGED	NUMBER OF SAMPLES	KG/HA/YR PHOSPHORUS Total Dissolved Phosphorus	KG/HA/YR PHOSPHORUS Particulate Phosphorus	KG/HA/YR NITROGEN Ammonia	KG/HA/YR NITROGEN Nitrite/ Nitrate	KG/HA/YR NITROGEN Total Dissolved Nitrogen	KG/HA/YR NITROGEN Particulate Nitrogen
Vaseux Creek Station No.								
1 (V-4)	0	24	0.03	0.06	0.018	0.008	0.53	0.077
2 (V-3)	5	24	0.02	0.01	0.009	0.011	0.38	0.028
3 (V-2)	8	21	0.04	0.06	0.013	0.008	0.62	0.079
4 (V-1)	10	22	0.05	0.14	0.016	0.074	0.66	0.107
5 (V-5)	26	23	0.08	0.28	0.026	0.078	0.95	0.127
Shingle Creek Station No.								
1 (S-6)	0	28	0.01	0.009	0.008	0.018	0.27	0.031
2 (S-3)	14	34	0.03	0.05	0.028	0.044	0.41	0.052
3 (S-2)	18	37	0.02	0.12	0.009	0.079	0.30	0.103

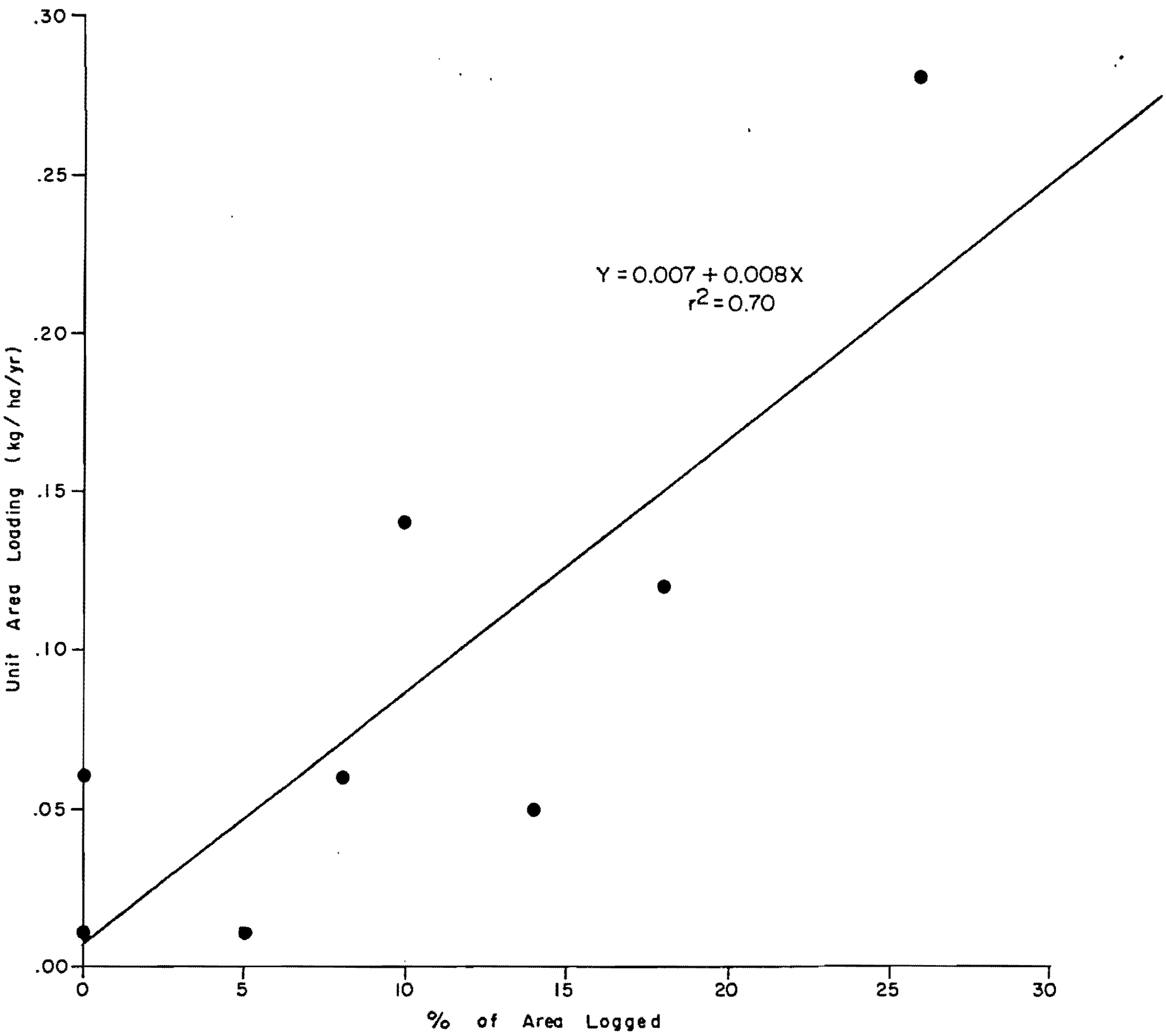
surficial material as discussed, particulate phosphorus loads are assumed to be most representative of the effects of these activities, although it is realized that desorption of phosphorus from eroded sediment in solution may occur and thus reported results may underestimate total phosphorus loading.

Areal particulate phosphorus values are plotted against percentage of basin logged (Figure 3). A line joining the points was fitted using least squares regression. This relationship was used together with information from the logging inventory, described in the following section, to estimate particulate phosphorus loadings to the Okanagan Basin from logging.

2. Extrapolation of Results to the Okanagan Basin

2.1 Logging Inventory

The logging inventory was based on the Ministry of Forests records for the Penticton and Vernon forest districts and information from Crown Zellerbach Ltd. and Weyerhaeuser Canada Ltd. for Tree Farm Licences 9 and 15, respectively. In most cases, this involved transferring plans of cut blocks from Ministry of Forest - Forest Cover Series Maps, to maps showing drainage basin boundaries. Where available, areas for each block were obtained from the Ministry of Forests; otherwise, areas were measured using a planimetre. Areas logged from 1970 to 1980 for each of the sub-basins are shown in Table 3. To determine the percentage of the tributary sub-basins logged, sub-basin areas above 800 m (2,500 feet) were measured from 1:50,000 topographic maps using a planimetre. Area above this elevation was assumed to represent largely forested area. Percentage of sub-basin logged was then calculated from these areas and shown in Table 3.



RELATIONSHIP BETWEEN PERCENTAGE OF WATERSHED LOGGED AND PHOSPHORUS LOADINGS.

Figure 3

TABLE 3: AREA LOGGED FROM 1970 TO 1980 AS A PERCENTAGE OF THE FORESTED AREA* OF THE WATERSHED

TRIBUTARY SUB-BASIN	AREA OF TOTAL FORESTED* DRAINAGE (ha)	AREA LOGGED (ha)	PERCENTAGE OF SUB-BASIN LOGGED
Nashwhito	6,850	90	1
BX	5,850	43	1
Park Rill	11,250	155	1
Deep	8,150	155	2
McDougall	4,250	80	2
Swan Lake (direct drainage)	1,305	38	3
Okanagan Lake (direct drainage)	640	16	3
Trepanier	23,300	800	3
Peachland	14,050	474	3
Lebanon	5,700	161	3
Robinson	14,200	455	3
Wood Lake (direct drainage)	3,900	153	4
Coldstream	14,850	579	4
Penticton	17,400	722	4
Ellis	15,250	584	4
Irish	2,350	110	5
Equesis	17,350	1,010	6
Mission	79,200	4,600	6
Powers	12,600	750	6
Shorts	17,400	1,160	7
Shingle	26,750	2,030	8
Inkaneep	15,850	1,250	8
Vaseux	28,300	2,200	8
Kelowna	14,000	1,290	9
Oyama	4,250	400	9
Whiteman	19,000	1,640	9
Trout	67,400	6,200	9
Osoyoos Lake (direct drainage)	980	93	9
Shuttleworth	8,550	860	10
Vernon (upper)	11,500	1,090	10
Naramata	3,450	390	11
Okanagan Landing (direct drainage)	770	92	12
Matheson	5,050	680	14
Lambly	27,800	5,500	20
Turnbull	3,900	1,020	26

* Area above 800 m.

2.2 Estimate of Phosphorus Loadings for the Okanagan Basin

Drainage basin areas with greater than 5% of the basin logged from Table 3 were multiplied by the appropriate areal loading value from Figure 3 and shown in Table 4. The decision to restrict the calculation of loadings to basins having greater than 5% logged area, was made on the basis of results for Wabash Creek (Station 3 - Vaseux Creek) where logging of 5% of the watershed produced no apparent increase in phosphorus over background levels. Natural (unlogged) loadings calculated from the areal loading value at the intercept (.01 kg/ha/yr) (Figure 3), were subtracted to produce loadings from forestry activities. However, it is acknowledged that on the basis of the previous argument, natural loadings may vary from 0.01 to 0.05 kg/ha/yr (loading for 5% logged area) which would decrease the loadings attributable to logging. Phosphorus loadings for the lake sub-basins are shown in Table 4.

3. Bioavailable Phosphorus Loads

Estimated phosphorus loadings from forestry activities available for biological production (BAP) are shown in Table 5 for each of the lake sub-basins. BAP values were calculated by multiplying the loadings from Table 4 by the percentage of BAP estimated for each of the sub-basins. Estimates of available phosphorus from analysis of suspended sediment phosphorus components are reported in (18) for selected Okanagan tributaries. These values were averaged for tributary sub-basins set out in Table 4. As shown, Okanagan Lake has the largest contribution of BAP loadings from forestry activities with 7,500 kg. Kalamalka has less than 100 kg from forestry sources. Total loadings of BAP to the main valley lakes from forestry is approximately 10 tonnes.

TABLE 4: ANNUAL PARTICULATE PHOSPHORUS LOADING TO THE OKANAGAN MAIN VALLEY LAKES FROM FORESTRY ACTIVITIES

			ANNUAL PARTICULATE PHOSPHORUS LOADING kg/yr			
			(Minus)		(Equal)	
LAKE SUB-BASIN	TRIBUTARY	PERCENTAGE LOGGED	Total	Natural	Annual Loading due to Forestry Acitivites	Total Loading to Lake Sub-Basin
Wood	Vernon	10	1,001	115	886	890
Kalamalka	Oyama	9	336	43	293	290
Okanagan	Equesis	6	954	174	780	
	Mission	6	4,356	792	3,564	
	Powers	6	693	126	567	
	Shorts	7	1,096	174	922	
	Kelowna	9	1,106	140	966	
	Whiteman	9	1,501	190	1,311	
	Trout	9	5,325	674	4,651	
	Naramata	11	328	35	293	
	Okanagan Lake (direct drainage)	12	79	8	71	
	Matheson	14	601	51	550	
	Lambly	20	4,643	278	4,365	
	Turnbull	26	839	39	800	18,800
Skaha	Shingle	8	1,899	268	1,631	1,600
Osoyoos	Inkaneep	8	1,125	159	966	
	Vaseux	8	2,009	283	1,726	
	Osoyoos Lake (direct drainage)	9	77	10	67	
	Shuttleworth	10	744	86	658	3,400

TABLE 5: PROPORTION OF PARTICULATE PHOSPHORUS LOADINGS FROM FORESTRY ACTIVITIES AVAILABLE FOR BIOLOGICAL PRODUCTION

LAKE SUB-BASIN	ANNUAL LOADING kg/yr	PERCENTAGE AVAILABLE PHOSPHORUS*	BIOAVAILABLE PHOSPHORUS LOADING
Wood	890	50	450
Kalamalka	290	20	60
Okanagan	18,800	40	7,500
Skaha	1,600	40	640
Osoyoos	3,400	30	1,000
TOTAL TO OKANAGAN BASIN			9,700 kg

* From a ranking of tributaries within each lake sub-basin as reported in (18) based on the bioavailability of particulate phosphorus.

DISCUSSION

1. Comparison with Other Loading Estimates

Particulate phosphorus areal loads from Table 2 are within the range of loadings or land use export coefficients reported for forested areas in Washington and Oregon (19). For example, a study in the Hills Creek Reservoir region in west central Oregon measured a range of particulate* phosphorus loadings from 0.07 to 0.11 kg/ha/yr for watersheds with 13-24% of forested areas cleared. A study near Lake Chelan, east of the Cascades in Washington, reported a lower range of particulate loadings from 0.01-0.06 kg/ha/yr for various cleared areas. In both these studies the ratio of dissolved to particulate phosphorus is much greater than present monitoring indicated which would suggest that failure to monitor periods of higher flow may have led to an underestimate of actual loadings. The conclusion is that given the possible sources of variability between studies our estimates of phosphorus loading are comparable to others in the literature.

2. Discussion of Factors Affecting the Estimates

Basin-wide estimates of loadings from logging are subject to a number of sources of variability which are discussed. These are grouped into two main categories, those sources of variability affecting the loadings measured in Vaseux and Shingle Creeks, and the extrapolation of measured loadings to the remainder of the Okanagan Basin. Firstly, with respect to loadings measured in Vaseux and Shingle Creeks, only one year of data were available, and information to assess loadings prior to logging were estimated from adjacent unlogged areas. With regard to the first point, the loadings in Vaseux and Shingle Creeks may vary from year to year depending on the hydrology. For example, annual discharge and maximum instantaneous discharge for Vaseux and Shingle Creeks in 1981 were above average compared to previous years which suggests that loadings measured in 1981 may have been higher than

* Particulate loadings calculated by subtacting orthophosphorus values from total phosphorus values.

previous years, however, other factors such as runoff conditions prior to 1981 and timing of runoff during 1981, as well as the inability to measure loadings during peak flows, affect loadings and thus confound conclusions regarding the representativeness of 1981 loadings.

Another concern with loadings measured in Vaseux and Shingle Creeks was that a number of drainage basins were required to obtain unlogged areas and a range of areas logged. As a result, variables other than logging such as elevation, aspect, soil factors, and geology differed between the basins and complicated the measurement of loadings due to logging alone.

Basin-wide estimates of logging effects from studies carried out in selected sub-basins are also subject to a number of sources of error. Probably the most significant concerns the differences in loading that exist due to time since logging. Studies in coastal areas have generally reported a return to pretreatment or natural conditions following logging after regeneration has occurred. In the present study, period of logging which varied from the late 1970's to early 1980's in Shingle/Shatford Creeks to early to mid 1970's in Vaseux Creek was not related to phosphorus loading. This suggests that regeneration may be slower in high altitude interior clearcuts than in coastal areas, or that other factors such as roads, which continue to erode for many years, are having a greater effect. Although differences in loadings with age of logging were not apparent for these two basins the likelihood is that differences do exist for the Okanagan within the ten-year span of the inventory. Areas of more recent logging would contribute greater loadings than areas of older logging. Therefore, extrapolation of results ignoring logging history as has been done is likely an over-simplification.

Another concern is the extrapolation of results from headwaters of the tributary sub-basins such as the upper plateau area of Vaseux Creek, to produce estimates for the Okanagan Basin at lake level. Stream gradients and sediment carrying capacity are less in the upper areas. However, most tributaries have downcut channels from the plateau to lake level. In these reaches, gradients and potential for stream channel erosion increase considerably. Similarly, some tributaries flow through a flood plain before entering the lake. In these reaches deposition of material would be expected. Differences in loadings would likely occur between the headwaters and mouths of the tributaries due to instream processes and extrapolation of results for different parts of the watershed will increase the variability of the final estimate, particularly for the short term.

A logging effect that is not considered in unit area loading estimates is the increased stream channel erosion and associated nutrients due to increases in peak flows from harvesting. In a report on the Graystoke's area of Mission Creek (20) modelling indicated that a 13% increase in peak flows may occur using large clearcuts and extensive logging of this high elevation watershed. Other lower elevation clearcuts also would be expected to contribute to peak flows depending on the aspect and size of clearcut because of a reduction in evapotranspiration. Studies carried out in the lower elevation of Coldstream Creek near Vernon (21) indicated that any increases in peak stream flows would be expected to increase bank erosion due to the natural instability of the channel in the lower reaches. Streambank instability occurs in other tributaries in the Okanagan such as Shuttleworth and Trout Creeks. Therefore, estimates of nutrient loadings due to logging effects alone may underestimate actual contributions to the lakes.

The estimate of bioavailable phosphorus loading to the lakes of approximately 10 tonnes is subject to a number of sources of variability as discussed. These are essentially unquantifiable at present, however, on balance, it is suggested that this estimate may be an underestimate of actual loadings from forestry activities due to the failure to account for the downstream effects of increased flows discussed above; the possibility of increased dissolved phosphorus loading which has been alluded to; the inability to quantify a large proportion of particulate loadings during high flows, and the contribution of phosphorus from sub-basins having less than 6% of the area logged. These sub-basins, while no doubt having more localized effects of logging, may become significant contributors of phosphorus during years of above average runoff.

The 10 tonnes of phosphorus from forestry activities compares with estimates of 12, 15 and 20 tonnes of BAP from septic tanks, agriculture and municipal waste sources, respectively (3). Although not one of the largest sources of BAP, forestry is nevertheless, a substantial source that should be controlled.

3. Methods of Controlling Nutrient Loadings from Forestry Activities

From the point of view of controlling nutrient export due to forestry activities it is the total nutrient contribution from all aspects of forestry that is of concern for lake management. However, it is realized that certain practices in a few locations generate the largest percentage of nutrients and that the remainder probably contributes an amount that would be difficult to separate from natural loadings. Therefore, controls should be applied on a site specific basis depending on forestry and environmental requirements.

Methods of reducing the effects of forestry activities on nutrient loading focuses on two main aspects: 1) the use of adequate climate, soils, terrain and vegetation data integrated as a planning tool to avoid areas sensitive to increased nutrient export; and 2) restrictions on forestry practices in sensitive areas to reduce loadings.

Avoidance of environmentally sensitive areas require that these same areas be located and described to determine their potential effects if disturbed. Existing definition of these areas as Environmental Protection Areas (22) on the Ministry of Forests, "Forest Cover Maps", are very general and usually lack the field data to predict actual impacts; however, these designations serve as a useful warning of sensitive areas for more detailed site evaluation.

Another approach being taken by the Ministry of Forests is the development of the biogeoclimatic mapping which indirectly provides information to predict effects of disturbances. This approach is based on the interdependence of trees, shrubs, climate, soil, and terrain on a given site and the transfer of information on environmental conditions to other sites. The floral association, for example, composed of cedar or red alder, may indicate areas of high water table where clearcut logging likely would have considerable effect on soil structure and later regeneration with possible consequences regarding loss of nutrients. Also soils associated with certain sites and plant communities may be more susceptible to compaction from heavy equipment and thus indicate a need for different yarding systems. The advantage of the biogeoclimatic approach is that the forester or other professional can make an onsite evaluation of impacts before road construction and logging begin based on a few key indicators from the plant community and the terrain.

A more detailed and integrative approach to determine erosion sensitivity to various land use practices including forestry, has been conducted in the Okanagan by the Ministry of Environment for the Okanagan Basin Implementation Agreement (21, 23). This approach which has been modified from the original method developed in Oregon (24) was completed for Vaseux and Coldstream watersheds on a trial basis. Essentially, the method consists of supplementing existing soils and terrain information by additional field work to develop more detailed maps (1:20,000) describing the potential for erosion under undisturbed or natural conditions. Estimates of erosion potential are based on the modified Universal Soil Loss Equation. Various cultural activities such as logging (separated on the basis of type of yarding, e.g. skidding or cable) and road construction which are occurring or likely to occur in the watershed are ranked in terms of their degree of disturbance and imposed on the natural sensitivity of the watershed. The change in erosion sensitivity due to the particular activity is then mapped for the watershed. Stream channel stability was assessed also and integrated with the erosion potential maps. The advantage of these maps is that they can provide the forest operator or planner with sufficiently detailed information to avoid disturbing areas with a high risk of erosion or, alternatively, indicate where restrictions may be required to reduce the risk of erosion. The disadvantage of the method is the cost and time required to complete the mapping. Maps completed for the Coldstream watershed are being used in the Vernon Forest District by the Ministry of Forests on a trial basis.

The use of specific guidelines or restrictions to ameliorate the effects of forestry practices in the Okanagan are referred to in a number of reports (20, 25). Most of these concern the reduction of erosion from haul roads through acceptable design, construction, drainage, and maintenance.

Other guidelines refer to the type of cut which, for example, may be selection system or shelterwood to preserve the soil in certain areas. The report on the Graystokes (20) recommended cutting narrow strips in an east-west direction in southern slopes to reduce snowmelt and, consequently, downstream peak flows. In steeper areas cable logging may replace the conventional skidding as a yarding technique. Guidelines also refer to the burning of slash and the possible leaching of mineralized nutrients from the site, such as not burning close to streams where nutrients may more easily enter surface water, and not allowing burning to reduce the organic layer on exposed slopes.

As discussed, there are many possible methods of controlling nutrient export which can be applied on a site specific basis as required. There are advantages to both the forest industry in terms of the preservation of site productivity and to lake recreation in terms of improved water quality by ensuring that adequate controls are in place to reduce nutrient export.

CONCLUSIONS

The results of this study indicate that logging and associated road construction are a significant source of phosphorus available for biological production in the Okanagan main valley lakes. The estimated 10 tonnes of biologically available phosphorus (BAP) due to logging is approximately 20% of the BAP from all cultural sources to the lakes and this percentage will likely increase in the future due to reduction of phosphorus from municipal waste sources.

Loadings from forestry activities should be controlled, particularly for those tributary sub-basins with a high percentage of area logged such as Lambly Creek. Identification of areas sensitive to disturbances with a greater potential for erosion, such as that conducted in Coldstream and Vaseux Creeks on a trial basis, should proceed for other areas of the Okanagan. Restrictions on logging in these sensitive areas should be implemented to reduce nutrient loadings.

REFERENCES

1. Canada-British Columbia Okanagan Basin Agreement. 1974. Main Report of the Consultative Board. Published by the Office of the Study Director, Box 458, Penticton, B. C.

2. Canada-British Columbia Okanagan Basin Implementation Agreement. 1977. First Annual Report of the Okanagan Basin Implementation Agreement. Published by the Office of the Coordinator, Box 458, Penticton, B. C.

3. Canada-British Columbia Okanagan Basin Implementation Agreement. In preparation. Final Report of the Okanagan Basin Implementation Agreement Published by the Office of the Coordinator, Box 458, Penticton, B. C.

4. Kimmins, J. P. 1977. Evaluation of the Consequences for Future Tree Productivity of the Loss of Nutrients in Whole-Tree Harvesting. Forest Ecol. and Manag. 1:169-183.

5. Brown, G.W. and J.T. Krygier. 1971. Clearcut Logging and Sediment Production in the Oregon Coast Range. Water Resources Research 7:1189-1198.

6. Megahan, W.F. 1981. Effects of Silvicultural Practices on Erosion and Sedimentation in the Interior West - A Case for Sediment Budgeting. In Proc. of Symposium on Interior West Watershed Management. Ed. D. B. Baumgartner. April 8-19, 1980. Spokane, Washington. pp. 169-181.

7. Fredriksen, R.L. 1977. Data Reported in Mulkey, L.A. 1980. An Approach to Water Resources Evaluation of Non-Point Silvicultural Sources (A Procedural Handbook). EPA-600/8-80-012. Env. Res. Laboratory. Office of Research and Development. U.S. Env. Prot. Agency. Athens, Georgia. p. X33.

8. Smith, R.B. 1979. Steep Slope Logging. J. Logging Manage. 10 (1): 1794-1796.

9. Heatherington, E.D. 1976. Dennis Creek - A Look at Water Quality following Logging in the Okanagan Basin. Forest Service, Environment Can.

10. Hart, G. E., N.V. DeByle and R.W. Hennes. 1980. Soil Solution Chemistry and Slash Disposal. In Symposium on Watershed Management. July 21-23, 1980. Boise, Idaho. Published by the American Society of Civil Engineers. pp. 318-325.

11. Tiedemann, A.R. 1981. Stream Chemistry, Nutrient Economy, and Site Productivity Consequences of Wildland Management and Wildfire. In Proc. of Symposium on Interior West Watershed Management. Ed. D. B. Baumgartner, April 8-10, 1980; Spokane, Washington. pp. 183-201.

12. Brown, G.W., A.R. Gahler and R.B. Marston. 1973. Nutrient Losses after Clear-cut Logging and Slash Burning in the Oregon Coast Range. Data reported in Mulkey, L.A. 1980. An Approach to Water Resources Evaluation of Non-Point Silvicultural Sources (A Procedural Handbook). EPA-600/8-80-012. Env. Res. Laboratory. Office of Research and Development. U.S. Env. Prot. Agency. Athens, Georgia. p. X33.

13. Likens, G.E., F.H. Bosmann, and N.M. Johnson and others. 1970. Effects of Forest Cutting and Herbicide Treatment on Nutrient Budgets in the Hubbard Brook Watershed-Ecosystem. Ecol. Mono. 40:23-47.

14. Mulkey, L.A. 1980. An Approach to Water Resources Evaluation of Non-Point Silvicultural Sources (A Procedural Handbook). EPA-600/8-80-012. Env. Res. Laboratory. Office of Research and Development. U.S. Env. Prot. Agency. Athens, Georgia. pp. X31-X36.

15. Golding, D.L. 1981. Hydrologic Relationships in Interior Canadian Watersheds. In Proc. of Symposium on Interior West Watershed Management. Ed. D. B. Baumgartner. April 8-10, 1980; Spokane, Washington. pp. 107-115.

16. Terzi, R.A. 1981. Hydrometric Field Manual - Measurement of Stream Flow. Water Resources Branch, Inland Waters Directorate, Ottawa.

17. Ozga, W.G. 1980. Manual of Hydrometric Data - Computation and Publication Procedures. Fifth Edition. Water Resources Branch, Inland Waters Directorate, Ottawa.

18. Gray, C.B.J. 1982. Nutrient Composition of the Major Tributaries and Interconnecting Rivers of the Okanagan Basin. Progress Report of the Okanagan Basin Implementation Agreement, Box 458, Penticton, B. C.

19. Omernik, J.M. 1977. Non-Point Source - Stream Nutrient Level Relationships: A Nation-wide Study. EPA-600/3-77-105. Corvallis Env. Res. Lab. U.S. Env. Protection Agency. Corvallis, Oregon.

20. Ministry of Environment, Ministry of Forests. 1981. Resources of the Graystokes. Prepared by the Technical Subcommittee, Ministry of Environment, Victoria, B. C.

21. Hawthorn, R.S. and E. Karanke. 1982. Analysis of Channel Stability and Sediment Sources in the Coldstream and Vaseux Creek Watersheds. Ministry of Environment, Assessment and Planning Division, Victoria, B. C.

22. Ministry of Forests. 1978. Forest Inventory, Environmental Protection Guidelines. Forest Inventory Division, Victoria, B. C.

23. Kowall, R. In Prep. Soil Erosion Potential for the Coldstream and Vaseux Watershed Areas. Ministry of Environment, Assessment & Planning Division, Kelowna, B. C.

24. Brown, W.M., W.G. Hines, D.A. Rickert and G.L. Beach. 1979. A Synoptic Approach for Analyzing Erosion as a Guide to Land Use Planning. U.S. Geological Survey Circular 715-L.

25. Cheng, J.D. 1981. Technical Measures for Minimizing Detrimental Hydrlogic Impacts of Logging in Community Water Supply Watersheds of the Kamloops Forest Region. Unpublished manuscript of the Research Branch, Ministry of Forests, Kamloops, B. C.