

en 83222

Canadian Technical Report of  
Fisheries and Aquatic Sciences No. 2074

**Canadian Technical Report of  
Fisheries and Aquatic Sciences**

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

**Rapport technique canadien des  
sciences halieutiques et aquatiques**

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

1995

**A DISCUSSION OF SUSPENDED SEDIMENT IN THE TAKLA LAKE REGION: THE  
INFLUENCE OF WATER DISCHARGE AND SPAWNING SALMON**

by

MINISTRY OF ENVIRONMENT, LANDS AND FORESTS  
MINISTRY LIBRARY  
PO BOX 9348 STN PROV GOVT  
VICTORIA BC V8W 9M1

A. L. Cheong<sup>1</sup>, J. C. Scrivener<sup>2</sup>, J. S. Macdonald<sup>1</sup>, B. C. Andersen<sup>2</sup>, and  
E. M. Choromanski<sup>1</sup>

<sup>1</sup>Department of Fisheries and Oceans  
Science Branch, Pacific Region  
West Vancouver Laboratory  
4160 Marine Drive  
West Vancouver, British Columbia  
V7V 1N6

<sup>2</sup>Department of Fisheries and Oceans  
Science Branch, Pacific Region  
Pacific Biological Station  
Nanaimo, British Columbia  
V9R 5K6

TABLE OF CONTENTS

List of Tables .....	iv
List of Figures .....	v
Abstract .....	vii
Resumé .....	vii
Introduction.....	1
Study Area .....	2
Methodology .....	2
Results.....	2
Discussion .....	3
Hysteresis and the Snowmelt Event .....	5
Concerns with the Calculation of Sediment Yield from Rating Curves .....	5
Conclusions .....	6
Acknowledgements .....	7
References .....	8

© Minister of Supply and Services Canada 1995  
Cat. No. Fs 97-6/2074 ISSN 0706-6457

Correct citation for this publication:

Cheong, A. L., J. C. Scrivener, J. S. Macdonald, B. C. Andersen, and E. M. Choromanski.  
1995. A discussion of suspended sediment in the Takla Lake region: the influence of  
water discharge and spawning salmon. Can. Tech. Rep. Fish. Aquat. Sci. 2074: 25 p.

## LIST OF TABLES

Table 1:	Geomorphological characteristics of the Takla Lake watersheds.....	10
Table 2:	Discharge - suspended sediment regression analysis.....	11

## LIST OF FIGURES

Figure 1:	Five tributaries of the Stuart-Takla drainage basin that have been chosen for fishery/forestry interaction experimentation .....	12
Figure 2:	A typical example of discharge characteristics in the Takla tributaries (e.g., Gluskie Creek). Precipitation information comes from the DFO camp on Middle River. ....	13
Figure 3:	O'Ne-eil Creek suspended sediment and discharge characteristics (1992). Period of sockeye salmon spawning is indicated.....	14
Figure 4:	Gluskie Creek suspended sediment and discharge characteristics (1992). Period of sockeye salmon spawning is indicated.....	15
Figure 5:	Forfar Creek suspended sediment and discharge characteristics (1992). Period of sockeye salmon spawning is indicated.....	16
Figure 6:	Forfar Creek suspended sediment and discharge characteristics (1993). Period of sockeye salmon spawning is indicated.....	17
Figure 7:	Gluskie Creek suspended sediment-discharge relation for 1992 and 1993. Data collected during spawning periods are indicated .....	18
Figure 8:	Forfar Creek suspended sediment-discharge relation for 1992 and 1993. Data collected during spawning periods are indicated .....	19
Figure 9:	Sediment transport curve for Flynn Creek, based on instantaneous values from 24 storms having peak flows $\geq 1.1 \text{ m}^3/\text{s}$ (VanSickle and Beschta, 1993) .....	20
Figure 10:	Counts of sockeye salmon from a fence at the mouth of Gluskie Creek and suspended sediment (1992). Suspended sediment levels predicted from sediment-discharge relations are typically below 5mg/L for this period .....	21
Figure 11:	Counts of sockeye salmon from a fence at the mouth of Forfar Creek and suspended sediment (1992). Suspended sediment levels predicted from sediment-discharge relations are typically below 5mg/L for this period .....	22
Figure 12:	Definition sketch of mean velocity and suspended sediment distributions in convergent streamflow over a gravel bed (Alonso and Mendoza, 1992) .....	23

- Figure 13:** Forfar Creek event hysteresis (May/June, 1993). Sequential discharge levels ( $\text{m}^3/\text{s}$ ) and their respective suspended sediment concentrations ( $\text{mg}/\text{L}$ ) are presented for the rising limb (solid line) and falling limb (dashed line) for the snowmelt event, resulting in a clockwise loop .....24
- Figure 14:** Gluskie Creek rating curve (1993). Flow predictions are more variable at the higher water levels. Water levels were measured using an electronic data logger .....25

## ABSTRACT

Cheong, A. L., J. C. Scrivener, J. S. Macdonald, B. C. Andersen, and E. M. Choromanski. 1995. A discussion of suspended sediment in the Takla Lake region: the influence of water discharge and spawning salmon. Can. Tech. Rep. Fish. Aquat. Sci. 2074: 25 p.

Suspended sediment characteristics were analysed in three watersheds of the Takla Lake region. The hydrology of the area is dominated by a snowmelt peak followed by summer and fall low flows during which salmon spawning occurs. Snowmelt and spawning contribute to the high variability in sediment concentrations. The highest suspended sediment concentrations in 1992 and 1993, from  $53\text{mg}/\text{L}$  in Forfar Creek to  $122\text{mg}/\text{L}$  in O'Ne-eil Creek, occurred during the June snowmelt peak. Spawning salmon appear to have caused a secondary peak in suspended sediment concentration in 1992 during the summer flow. Sediment concentrations in 1993 were confounded by a series of summer storm flows. High concentration variability due to hydrologic and biologic controls and limited data restrict an accurate assessment of suspended sediment yield.

## RESUMÉ

Cheong, A. L., J. C. Scrivener, J. S. Macdonald, B. C. Andersen, and E. M. Choromanski. 1995. A discussion of suspended sediment in the Takla Lake region: the influence of water discharge and spawning salmon. Can. Tech. Rep. Fish. Aquat. Sci. 2074: 25 p.

On a analysé les caractéristiques des matières en suspension dans trois bassins hydrographiques de la région du lac Takla. L'hydrologie régionale est dominée par un débit de pointe causé par la fonte des neiges, suivi de débits d'étiage durant l'été et l'automne, période où le saumon vient frayer. Ce sont la fonte des neiges et la fraie qui expliquent la grande variabilité de la concentration des matières en suspension. En 1992 et 1993, les plus fortes concentrations, de  $53\text{ mg.L}^{-1}$  dans le ruisseau Forfar à  $122\text{ mg.L}^{-1}$  dans le ruisseau O'Ne-eil, ont été observées à la pointe de la fonte des neiges en juin. Le saumon qui frayait à l'été était à l'origine d'un maximum secondaire de concentration en 1992, durant la période d'étiage, mais qui a été masqué à l'été de 1993 par une série de débits d'orage. L'importante variabilité de la concentration et l'inexistence d'une relation entre le débit et celle-ci, qui serait attribuable à des facteurs contrôlants d'origine biologique ou hydrologique, ainsi que le manque de données rendent impossible une évaluation précise de la charge en matières en suspension.

## INTRODUCTION

The presence of suspended sediment in river water is an important physical characteristic. Such sediment can have both a direct effect on aquatic life through damage to organisms and their habitat and an indirect effect through its influence on turbidity and light penetration (Walling and Webb, 1992). Recent information suggests that juvenile salmonids actively seek relief from high suspended sediment concentrations during their out migration (Scrivener et al., 1994). When sediments exceed 200mg/L juvenile chinook foraging rates are known to decline (Gregory, 1990) and concentrations of 50-99mg/L reduced feeding efficiency among juvenile coho salmon (Berg and Northcote, 1985). Adult chinook salmon have avoided sediment concentrations of 350mg/L (Gregory, 1990). Elevated stress levels, increased coughing rates (gill damage), increased fright behaviour, and downstream displacement have also been associated with increased suspended sediments in freshwater fish habitats (MacLeay et al., 1987; Servizi, 1990; Servizi and Martens, 1992).

Many studies in forested watersheds have shown disturbances of the forest may contribute a significant increase in sediment export (Brown and Krygier, 1971; Swanston and Swanson, 1976; Beschta, 1978). Changes in suspended sediment due to logging have been documented in Oregon (Beschta, 1978) and British Columbia (Slaney et al., 1977).

The suspended sediment load of a river represents the fine-grained material transported in suspension, supported by the upward component of fluid turbulence. The suspended sediment load may come from a variety of sources: channel and bank erosion; gully erosion; sheet and rill erosion of basin slopes; and the removal of sediment delivered to the channel through mass movement (Walling and Webb, 1992). The load of a small stream typically exhibits considerable variability over time as it responds in a highly sensitive, non-linear fashion to changes in streamflow and sediment availability (VanSickle and Beschta, 1983).

Because the majority of the sediment load is usually carried during brief, infrequent periods of high flow and the problems associated with identifying the processes which link runoff and sediment transport, the most practical sediment transport models are empirical relations between sediment load and streamflow. The most elementary model of this type is the sediment transport/rating curve:

$$C=aQ^b$$

in which Q represents the stream discharge, C is either suspended sediment concentration or yield, and the values of *a* and *b* are determined from data through a linear regression between log(C) and log(Q).

Information presented in this paper describes sediment-discharge relations from the first two years of the pre-forestry phase of a multi-year, multi-disciplinary fishery/forestry interaction project (Macdonald et al., 1992). The sediment data are to be used to assess natural and human induced changes in the sediment budget through the course of the project. It is the intent of this paper to assess the 1992 and 1993 sediment rating curves with respect to the estimation of pre-forestry sediment budgets, the sampling procedure, and baseline data characteristics, in order to improve measurement methodology and data quality in the future.

## STUDY AREA

The Takla Lake area in the upper Fraser basin, British Columbia, is a region of extensive sockeye salmon (*Oncorhynchus nerka*) spawning where fine lacustrine soils are extensive and much of the sediment moved by the tributaries is likely transported in suspension (Macdonald et al., 1992). Three creeks which flow into the Middle River were analysed: Gluskie, O'Ne-eil and Forfar (see figure 1). Geomorphological characteristics of the basins are shown in table 1. The hydrographs of creeks in this region are dominated by a snowmelt event in late May/early June; comparatively, precipitation has little effect on discharge (e.g., Gluskie Creek, figure 2).

## METHODOLOGY

Water levels were measured continuously (hourly, during the ice-free months) using Unidata data loggers in Gluskie, O'Ne-eil and Forfar creeks and discharge rates from May through September were taken at nearby channel cross-sections with a velocity meter (Platts et al., 1983). At the rating sites, velocity measurements were taken at 0.5m intervals across the stream (or closer, depending upon the complexity of the channel) at 40% of the depth when the creek was <1m deep. For flows with greater depths, velocity measurements were recorded at 20% and 80% of the depth.

A DH48 sampler was used to collect paired water samples from two sites in each stream. The sampler was swept across the channel over the full depth range to produce an integrated collection of suspended sediment (Thomas, 1985). Sampling sites were established immediately upstream and downstream ( $\pm 10$ m) of the logging road bridges on Gluskie (0.4km), Forfar (1.4km), and O'Ne-eil (1.5km) creeks (see 900 and 700 road on fig. 1). Total filterable residues were determined by "Standard Methods" using the sample volume and glass fiber filters dried to 105°C (Greenberg, 1981). The paired concentrations of suspended sediment were then averaged.

Streamflow and suspended sediment concentration hydrographs are plotted and sediment rating curves calculated using standard linear regression techniques on log-transformed data. This conforms to the approach adopted by many previous researchers (Bennett and Sabol, 1973; Walling, 1977; VanSickle and Beschta, 1983) and can also be justified in terms of data normality, linearity of the relation, and homoscedasticity. Data are analysed based on groupings by stage classifications: rising limb (proportion of the hydrograph where discharge is increasing) versus falling limb (decreasing discharge); and high flow ( $>1\text{m}^3/\text{s}$ ) versus low flow ( $<1\text{m}^3/\text{s}$ ). A simple regression analysis was used to assess relations between variables.

## RESULTS

The basins displayed typical sediment-discharge relation characteristics (figures 3 through 6). In general, suspended sediment concentration usually increased with increasing discharge. Peak concentration occurred near the times of peak discharge. Most sediment-discharge relationships were statistically significant ( $p < 0.05$ ) regardless of collection period or location (table 2, figures 7 and 8). Both upstream and downstream of bridge sites exhibited similar characteristics in relation to streamflow. Differences in upstream and downstream sediment concentrations were not analysed due to inadequacy of the downstream site location and the minimal amount of downstream data.

Base discharges (low flows) and base sediment concentrations were similar for the three basins. Discharge was generally below  $1.5\text{m}^3/\text{s}$  for much of the year. During the period of

summer low flow, suspended sediment concentrations were below 5mg/L except when the salmon are spawning (figures 3 to 5) or discharge increased due to storms (figure 6). The bulk of suspended sediment transport coincided with snowmelt generated discharges from April to July. Annual peaks of 53mg/L, 97mg/L and 122mg/L were obtained for May in Gluskie, Forfar and O'Ne-eil creeks, respectively, during snowmelt. Peak discharges were about  $9.0\text{m}^3/\text{s}$ ,  $9.4\text{m}^3/\text{s}$ , and  $12.0\text{m}^3/\text{s}$  in Forfar, Gluskie, and O'Ne-eil creeks, respectively. Absolute peak discharges were not available for Forfar Creek during 1992 and for O'Ne-eil Creek during 1993 as the water level exceeded the capability of the measuring instruments.

## DISCUSSION

The characteristics of the suspended sediment rating curves in the Takla Lake region were influenced by flow stage and sediment production. The reliability with which sediment concentrations can be correlated with stream discharges ( $r^2$  from 0.006 to 0.884, table 2, figures 7 and 8) were typical of those found in other studies. VanSickle and Beschta (1993) obtained a correlation of 0.708 when assessing the relation at Flynn Creek, Oregon, for flows greater than  $1.1\text{m}^3/\text{s}$  over a period of thirty years (figure 9). A study in southern Chile (Iroume, 1990) produced a correlation of 0.771 for ninety data points. Thompson et al. (1987) used a variety of submodelling methods and achieved  $r^2$  values of 0.020 to 0.880 for the Fraser River, British Columbia.

A higher correlation existed between suspended sediments at high discharges ( $>1.0\text{m}^3/\text{s}$ ) than the lower flows (Table 2) because sediment concentrations at low discharges were extremely variable (figures 7 and 8). Sidle and Campbell (1985) sampling in coastal Alaska, attributed greater variability in sediment concentration on the rising limb when compared to the falling limb, to samples collected at flows less than  $0.7\text{m}^3/\text{s}$ . They also demonstrated that for all storms, the regression relations between suspended sediment and discharge had higher slopes at high flows ( $>1\text{m}^3/\text{s}$ ) than at low flows ( $<1\text{m}^3/\text{s}$ ). Thompson et al. (1987) by limiting their sediment-discharge analysis to different combinations of spring and summer months and produced a higher  $r^2$  than was produced from analysis of annual flow. They suggested that the logarithmic relation assumed between sediment load and stream flow is more applicable during high flow periods than over an annual cycle.

Spawning salmon seem to be an important influence on the variability of suspended sediment concentrations at low flows in the Takla watersheds (figures 7, 8, 10, and 11). Salmon winnow fine sediment from the gravels during construction of their redds, increasing suspended sediment concentrations. Kondolf et al. (1993) found that in the western United States, the relation between the percentage of sediments finer than 1mm before spawning ( $P_1$ ) and after spawning ( $P_2$ ) is,

$$P_2 = 0.63 P_1 \quad r^2 = 0.93$$

indicating that approximately 35% of the fine sediment was winnowed from the gravels by spawning salmon (pink, chinook, sockeye and coho) and trout (brown and steelhead). Because spawning generally occurs at low flow stages when suspended sediment concentrations are typically low, fish can have an obvious impact on stream sediment concentrations (c.f. the supply based model, see below). The effects of the fish on suspended sediment concentration on the Takla Lake tributaries appeared to be more prominent in 1992 than in 1993 (figures 5 and 6) despite there being fewer sockeye spawners. A series of storm flows during the entire spawning activity period in 1993 (which occurred around Julian days 180, 215 and 238, c.f. figure 6) increased suspended sediment thus masking the effects of the salmon. Removal of the fine sediments from the channel gravels by the storms, resulted in less being available during the later portion of the



spawning season, to be winnowed during redd construction. Therefore, it is difficult to compare the impact of salmon between years. A more detailed analytical approach is needed in order to distinguish the effects of the spawning salmon from other natural erosive events.

Features such as pools, gravel bars, and debris jams may act as sediment storage sites at low flows whereas at high flows they may act as supply sources. A model relation between sediment supply, sediment availability and concentrations, which may be used to explain additional variability in our discharge-sediment concentration relation, was presented by VanSickle and Beschta (1983),

$$C(t) = aQ^b \cdot p \cdot \exp[r_s S(t)/S_0]$$

where  $S(t)$  is the sediment supply;  $a$  and  $b$  are associated with characteristics of the channel system (e.g., channel morphology, gradient, and relations between flow and width, depth, and velocity) which determine transport rates at a given discharge and level of sediment availability;  $p$  is an empirically derived parameter;  $r_s$  is an index of sediment availability; and  $S_0$  is the initial maximum of sediment available. The  $r_s$  value in the supply based model, is possibly the most important parameter when assessing low flow variability. For a large value of  $r_s$ , concentrations are sensitive to small decreases in  $S(t)$ ; i.e., sediment supply is not readily available. Thus,  $r_s$  is likely to be a function of the bed composition and of the overall effectiveness of storage sites in retaining sediment (VanSickle and Beschta, 1983). In the study streams, at low flow, the  $r_s$  value is probably large because the discharge is not strong enough to erode fine sediment from the streambed or from other instream storage sites. The input of sediment from redd construction at a time when sediment availability (c.f.,  $r_s$ ,  $a$ , and  $b$ ) would otherwise be low, causes a more noticeable increase in sediment concentration than during periods of greater availability - small inputs of sediment cause proportionally large changes in concentration when background levels and water levels are low. Given the many potential sources of sediment during high flows, such as scour from instream storage sites (pools, bars, and debris jams), erosion of channel banks, release of suspended sediments from riffles, and erosion of watershed slopes or roads, sediment supply ( $S(t)$ ) is also highly variable at high flows. Therefore, variability in concentrations at high flow could be caused by variability in the source of sediment, whereas variability at low flows may be caused by the salmon.

A third influence on the variability at low flows is the effects of the sampling procedure. At low flows, the sampling device is more likely to come closer or possibly in contact with the bed surface than at higher flows. Alonso and Mendoza (1992) showed that suspended sediment concentration increased non-linearly with depth (figure 12). In the lower Fraser River, the sand concentration may be virtually zero near the water surface and may increase to several thousand parts per million near the river bed (McLean and Church, 1986). As the depth of the water may decrease to below 30cm in the study streams during low flows, error may be introduced into the sampling procedure when the intake is allowed to get too near the bed surface. Also, as samples are integrated across the channel and at depth by moving the sampling intake so that the sampling container is filled as the entire cross-section is sampled, samples from high flows must be taken much more quickly leading to errors in the data (Dr. M. Hassan, pers. comm., U.B.C., Vancouver) - i.e., if the sampling intake is moved too slowly, the sample container is full before the entire cross-section is sampled. The concentrations of sand (>0.18mm) vary not only with depth, but also change across the channel - higher concentrations of sand at one side of the channel depending upon the locus of movement due to forces as the water moves around bends (Dr. M. Hassan, pers. comm.) while concentrations of the silt/clay portion of the suspended sediment are similar throughout the discharge cross-section.

## HYSTERESIS AND THE SNOWMELT EVENT

The Takla Lake basin hydrology is dominated by a single snowmelt event occurring during May. Small storms throughout the year are of less significance. During the snowmelt peak flow, an analysis of hysteresis, the relation between the peak sediment concentration time series and the discharge hydrograph, indicated that the 1992 and 1993 sediment records had different hysteresis characteristics. In 1992, a small discharge peak in mid-May in the Gluskie watershed (figure 4) winnowed fine sediment from the streambed gravels before the snowmelt peak. With less fine sediment available during the latter portion of the hydrograph, there was less opportunity for differences in the concentrations between rising and falling limbs. This pattern has been classified by Williams (1989) as a type 1A hysteresis curve - a linear relation between suspended sediment and discharge. The data for 1993, on the other hand, showed a slight hysteresis (figure 13) and can be classified as type 2A. Williams (1989) notes that this type (2A) of clockwise loop relation may be caused by a depletion of sediment (either a small supply available or intense flood) or by the formation of an armoured layer preceding the discharge peak limiting the sediment supply. Lack of high flow data in this analysis limits any further assessment.

## CONCERNS WITH THE CALCULATION OF SEDIMENT YIELD FROM RATING CURVES

One of the primary purposes for the analysis of suspended sediment was to aid in assessing the sediment budgets of the project watersheds. Many studies use the analysis of flow and suspended sediment relations to calculate the sediment yield from a basin. Thompson et al. (1978) noted that all studies they analysed had problems with underestimating the load, even with a bias correction, when assuming that the daily relation between concentration ( $\ln(C)$ ) and discharge ( $\ln(Q)$ ) over the year or over the high flow period is described by the model

$$\ln C = B_0 + B_1 \ln Q + E$$

Thompson et al. (1987) also recognised that some researchers have found that sediment transport in small rivers is more unpredictable than in large rivers. The rationale is that sediment transport in small rivers is more strongly governed by short-term, synoptic events such as a storm, whereas in large rivers, the effect of these events tended to be "averaged" (Thompson et al., 1987). The sediment transport in larger rivers is more significantly regulated by larger events such as snowmelt and seasonal yield of sediment from land surface erosion.

Estimates of sediment yield based on rating curve calculations usually involve greater errors than those obtained from direct measurements. Errors associated with rating curves from various studies range from -26% to +238% (Walling, 1977). Many researchers (see Walling, 1987) who have analysed such scatter in detail, describe controls associated with season, water temperature, hysteretic effects related to rising and falling stage, relative timing of water and sediment hydrographs, exhaustion effects, and varying patterns of tributary inflow (which may be affected by logging). The unexplained variation in discharge increases as water levels rise (figure 14). This will lead to greater error introduced into the sediment discharge calculations during periods when most of the sediment is leaving the system. The technique that is used to construct the rating curve and the adequacy of the number of data points are also known to significantly control the accuracy of resultant calculations of sediment load (Bennett and Sabol, in Walling, 1977). These factors must be taken into account when calculating sediment load.

There are two annual pulses of sediment in the Takla study streams; one from snowmelt and the other from salmon. The snowmelt sediment concentrations are more accurately predicted by the rating curve (see table 2) and account for the bulk of the suspended sediment yield. Approximately two thirds of the annual load in the lower Fraser River is transported in May and June while the period from October and March accounts for less than 6% of the total (McLean and Church, 1986). The suspended sediment concentrations during low discharge in the Takla tributaries (which coincide with periods of salmon spawning) were highly variable (figures 7 and 8). Rating curves are not an accurate predictor of suspended sediment concentrations/yield at low flow. Less than two percent of the variation was accounted for by discharge and sediment discharge regressions during low flow periods were not significant (table 2). During low flow periods an assessment of the fine sediments in the streambeds before and after spawning may provide a more reliable method of measuring sediment yields (Kondolf et al. 1993).

During an investigation in southern Alberta, MacPherson (1975) found no reason to construct separate rating curves for different times of the year. However, it may be inferred from table 2 and the work of Thompson et al. (1987) that separate rating curves or rating methods should be used to more accurately assess seasonal suspended sediment concentrations and seasonal sediment yield. Additional factors relevant to sediment production (e.g., spawning activities) must also be considered.

Spawning activity can produce sediment concentrations upwards of 20mg/L (figures 10 and 11). However, attempts to predict sediment concentrations from daily fish counts were not successful. Predictive power may improve in the future as water samples are being collected daily using automated sampling devices. Future predictive models must also consider the delay that occurs between the time of the fish entry to the creek (where they were counted) and the time of spawning.

The value of more frequent sampling have been discussed by Bennett and Sabol (1993). They suggested sampling on a five day interval was better than sampling every ten days because it reduced the standard error of the estimate. The sampling interval used in the Takla study streams in 1992 and 1993 ranged from daily to weekly depending upon flow conditions. As a result a minimal amount of data were collected during the snowmelt events limiting high flow data. A fixed frequency sampling strategy with a minimum sampling interval of three or four days with a higher frequency of sampling during periods of interest (high flow and spawning) would be an improvement. The exact procedure of integration of the sample across the channel should also be considered - suspended sediment of different sizes are not distributed along the channel's cross-section equally (Hassan, pers. comm., U.B.C., Vancouver).

## CONCLUSIONS

Suspended sediment concentration data for 1992 and 1993 were analysed for experimental tributaries of the Stuart-Takla region. Greater variability in the concentration-discharge relation was found at lower flows ( $<1\text{m}^3/\text{s}$ ) than at higher flows. This is speculated to be due to the effects of spawning salmon, sampling error, and the erosional characteristics of the watershed. High variability in the suspended sediment concentrations can be expected in the experimental streams due to sediment supply characteristics, hysteresis (event and seasonal), and fish activity. Given the amount of variability accounted for in the regression equations, the limited data (some high flow data missing), and the effects of salmon, any estimate of sediment load from the rating curves may be inaccurate. More data is needed, especially during the snowmelt peak when the majority of sediment transport occurs, in order to obtain a more accurate estimate of suspended sediment yield. Given that the hydrographs

of the two years in question appear different, additional years of data would be helpful in the analysis. Further, a detailed analysis of the sampling technique should be investigated as all sizes of suspended sediment are not transported uniformly through the channel. More frequent sampling during the 1994 field season will permit and initial assessment of sediment yield and its associated errors.

## ACKNOWLEDGEMENTS

The authors wish to acknowledge Dr. Marwan Hassan of the U.B.C. Geography Department for his review and comments and Glenn Smith of the Department of Fisheries and Oceans who provided the sockeye enumeration data. Other contributors include David Patterson and Antigone Dixon-Warren who helped collect the data, and Dan Hogan of the Ministry of Forests who provided comments. Funding for this project was provided by the Fraser River Sustainable Development Program. The manuscript was improved after reviews by M. Bradford and C.D. Levings.



## REFERENCES

- Alonso, C. V. and C. Mendoza. 1992. Near-bed sediment concentration in gravel-bedded streams. *Water Resour. Res.* 28: 2459-2468.
- Bennett, J. P. and G. V. Sabl. 1973. Investigation of sediment transport curves constructed using periodic and aperiodic samples. Symposium on River Mechanics, International Association of Hydraulic Research, Delft, Netherlands, 2: 49-60.
- Berg, L. and T. G. Northcote. 1985. Changes in territorial, gill-flaring and feeding behaviour in juvenile coho salmon (*Onchorhynchus kisutch*) following short-term pulses of suspended sediment. *Can. J. Fish. Aquat. Sci.* 42: 1410-1417.
- Beschta, R. L. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. *Water Resour. Res.* 14: 1011-1016.
- Brown, G. W. and J. T. Krygier. 1971. Clearcut logging and sediment production in the Oregon Coast Range. *Water Resour. Res.* 7:1189-1198.
- Greenberg, A.E. 1981. Standard methods for the examination of water and wastewater. 15th ed. Amer. Pub. Health Ass., Washington, D.C. 1134 p.
- Gregory, R. S. 1990. Effects of turbidity on benthic foraging and predation risk in juvenile chinook salmon. p. 64-73. In C. A. Simenstad (ed.) Effects of dredging on anadromous Pacific coast fishes: Workshop proceedings, Sept. 8-9, 1988. Washington Sea Grant Publication WSG-W090-1. University of Washington, Seattle, WA.
- Iroume, A. 1990. Assessment of runoff and suspended sediment yield in a partially forested catchment in southern Chile. *Water Resour. Res.* 26: 2637-2642.
- Kondolf, G. M., M. J. Sale and M. G. Gordon. 1993. Modification of fluvial gravel size by spawning salmonids. *Water Resour. Res.* 29: 2265-2274.
- Lisle, T. E. 1989. Sediment transport and resulting deposition in spawning gravels, north, coastal California. *Water Resour. Res.* 25: 1303-1319.
- Macdonald, J. S., J. C. Scrivener, and G. Smith. 1992. The Stuart-Takla fisheries/forestry interaction project: Study description and design. *Can. Tech. Rep. Fish. Aquat. Sci.* 1899: 39 p.
- MacLeay, D. J., I. K. Birtwell, G. F. Hartman, and G. L. Innis. 1987. Responses to arctic grayling (*Thymallus arcticus*) to acute and prolonged exposure to Yukon placer mining sediment. *Can. J. Fish. Aquat. Sci.* 44: 658-673.
- McLean, D. G. and M. C. Church. 1986. A re-examination of sediment transport observations in the lower Fraser River. Fraser River Project, Water Survey of Canada, Inland Water Directorate, Environment Canada, Progress Report No. 4. Report IWD-HQ-WRB-SS-86-6.
- McPherson, H. J. 1975. Sediment yields from intermediate-sized stream basins in southern Alberta. *J. of Hydrol.* 25: 243-257.

- Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U. S. Forest Service Intermountain Forest Range Experimental Station General Technical Report INT-138: 49 p.
- Ryder, J. M. 1995. Stuart-Takla watersheds: Terrain and sediment sources. Research Branch, B.C. Ministry of Forests, Victoria, B.C. Work. Pap. 03/1995: 48 p.
- Scrivener J. C., T. G. Brown and B. C. Andersen. 1994. Juvenile chinook salmon (*Onchorhynchus tshawytscha*) utilisation of Hawks Creek, a small nonnatal tributary of the upper Fraser River. *Can. J. Fish. Aquat. Sci.* 51: 1139-1146.
- Servizi, J. A. 1990. Sublethal effects of dredged sediments on juvenile salmon, p. 57-63. In C. A. Simenstad (ed.) Effects of dredging on anadromous Pacific coast fishes: Workshop proceedings, Sept. 8-9, 1988. Washington Sea Grant Publication, WSG-W090-1. University of Washington, Seattle, WA.
- Servizi, J. A. and D. W. Martens. 1992. Sublethal responses of coho salmon (*Oncorhynchus kisutch*) to suspended sediments. *Can. J. Fish. Aquat. Sci.* 49: 1389-1395.
- Slaney, P. A., T. G. Halsey, and H. A. Smith. 1977. Some effects of forest harvesting on salmonid rearing habitat in two streams in the central interior of British Columbia. Province of British Columbia, Ministry of Recreation and Conservation, Fisheries Management Report 71: 26 p.
- Swanston, D. N. and F. J. Swanson. 1976. Timber harvesting, mass erosion, and steepland geomorphology in the Pacific Northwest. In *Geomorphology and Engineering*. Dowden, Hutchinson, and Ross Inc., Pennsylvania. p. 199-221.
- Thomas, R.B. 1985. Measuring suspended sediment in small mountain streams. U.S. Forest Service Pacific Southwest Experimental Station General Technical Report PSW-83: 9 p.
- Thompson, M. P., H. Hoe and M. Church. 1987. Statistical modelling of sediment concentration. Water Resources Branch, Inland Waters Directorate, Environment Canada. Report IWD-HQ-WRB-SS-88-1. 60 p.
- VanSickle, J. and R. L. Beschta. 1983. Supply-based models of suspended sediment transport in streams. *Water Resour. Res.* 19: 768-778.
- Walling, D. E. 1977. Assessing the accuracy of suspended sediment rating curves for a small basin. *Water Resour. Res.* 13: 531-538.
- Walling, D. E. and B. W. Webb. 1992. Water quality. 1. Physical characteristics, p. 48-72. In P. Calow and G. E. Petts (ed.) *The rivers handbook*. Blackwell Scientific Publications, Boston.
- Williams, G. P. 1989. Sediment concentration versus water discharge during single hydrological events in rivers. *J. of Hydro.* 111:89-106.

Table 1: Geomorphological characteristics of the Takla Lake region

Parameter	Gluskie	Forfar	O'Ne-eil
Area (km <sup>2</sup> )	49.3	37.4	73.3
Mean gradient	0.286	0.247	0.182
Relief (m)	1215	1215	1250
Network Order	3	3	4
Surficial material <sup>1</sup>	till	lacustrine	lacustrine

<sup>1</sup> Ryder, 1995

Table 2: Sediment rating curves resulting from the regression analysis of stream discharge and suspended sediments. Separate regressions were performed for periods of high and low water flow, on rising and falling limbs of the hydrograph and for different time periods. Levels of significance are also presented.

Creek	Data Used	Regression Equation	N
Combined 1992/1993 data			
Forfar	all	$C = 4.591 Q^{0.497}$	$r^2=0.280^a$ 80
	u.s./lo	$C = 2.163 Q^{-0.184}$	$r^2=0.018$ 17
	u.s.	$C = 3.972 Q^{0.607}$	$r^2=0.357^a$ 53
	u.s./hi	$C = 2.143 Q^{1.240}$	$r^2=0.530^a$ 36
O'Ne-eil	all	$C = 3.800 Q^{0.634}$	$r^2=0.407^a$ 30
	u.s./lo	$C = 2.018 Q^{0.132}$	$r^2=0.010$ 18
	u.s.	$C = 3.027 Q^{0.731}$	$r^2=0.520^a$ 84
	u.s./hi	$C = 2.296 Q^{0.940}$	$r^2=0.470^a$ 66
Gluskie	all	$C = 4.111 Q^{0.529}$	$r^2=0.318^a$ 92
	u.s./lo	$C = 2.203 Q^{-0.120}$	$r^2=0.006$ 18
	u.s.	$C = 3.999 Q^{0.522}$	$r^2=0.293^a$ 57
	u.s./hi	$C = 1.510 Q^{1.511}$	$r^2=0.699^a$ 39
Forfar	u.s./rise	$C = 2.133 Q^{1.220}$	$r^2=0.799^a$ 20
	u.s./fall	$C = 4.178 Q^{0.476}$	$r^2=0.223^a$ 33
	u.s./fall/hi	$C = 2.104 Q^{1.300}$	$r^2=0.412^a$ 18
O'Ne-eil	u.s./rise	$C = 4.018 Q^{0.706}$	$r^2=0.448^a$ 28
	u.s./fall	$C = 2.716 Q^{0.701}$	$r^2=0.548^a$ 56
Gluskie	u.s./rise	$C = 2.286 Q^{1.150}$	$r^2=0.235^b$ 20
	u.s./fall	$C = 4.102 Q^{0.424}$	$r^2=0.195^a$ 37
	u.s./fall/hi	$C = 1.560 Q^{1.500}$	$r^2=0.767^a$ 21
1992 data			
Forfar	u.s.	$C = 3.589 Q^{0.445}$	$r^2=0.129^b$ 24
	u.s./rise	$C = 2.877 Q^{0.749}$	$r^2=0.884^a$ 7
	u.s./fall	$C = 4.083 Q^{0.357}$	$r^2=0.167$ 17
Gluskie	u.s.	$C = 3.483 Q^{0.483}$	$r^2=0.129^b$ 30
	u.s./rise	$C = 1.355 Q^{1.420}$	$r^2=0.764^a$ 7
	u.s./fall	$C = 4.217 Q^{0.254}$	$r^2=0.092$ 23

<sup>a</sup> significant at the 99% confidence level<sup>b</sup> significant at the 95% confidence levelabbreviations: u.s. - upstream of bridge, rise - rising limb, fall - falling limb, hi - flows >1.0m<sup>3</sup>/s, lo - flows <1.0m<sup>3</sup>/s

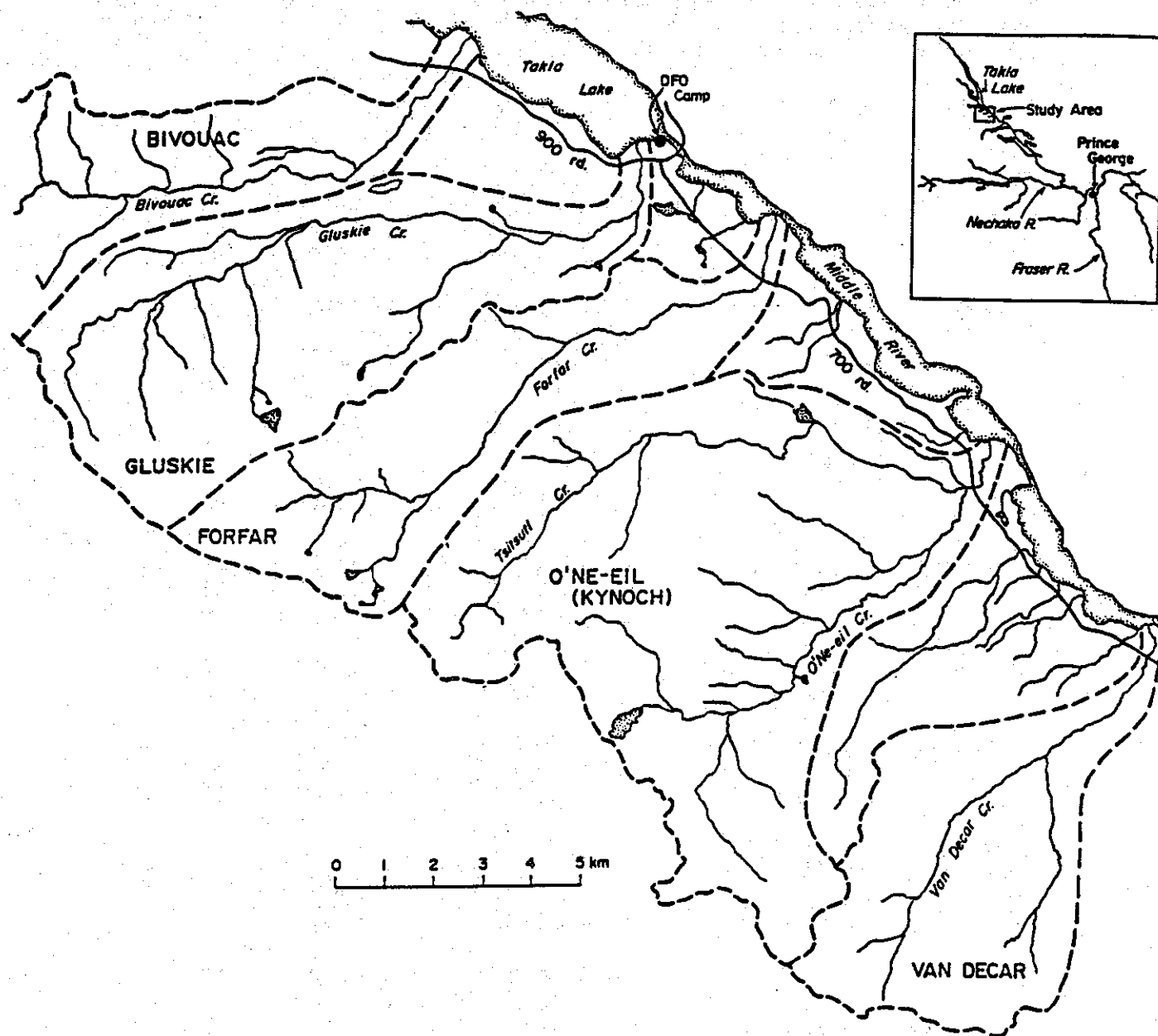


Figure 1: Five tributaries of the Stuart-Takla drainage basin that have been chosen for fishery/forestry interaction experimentation.

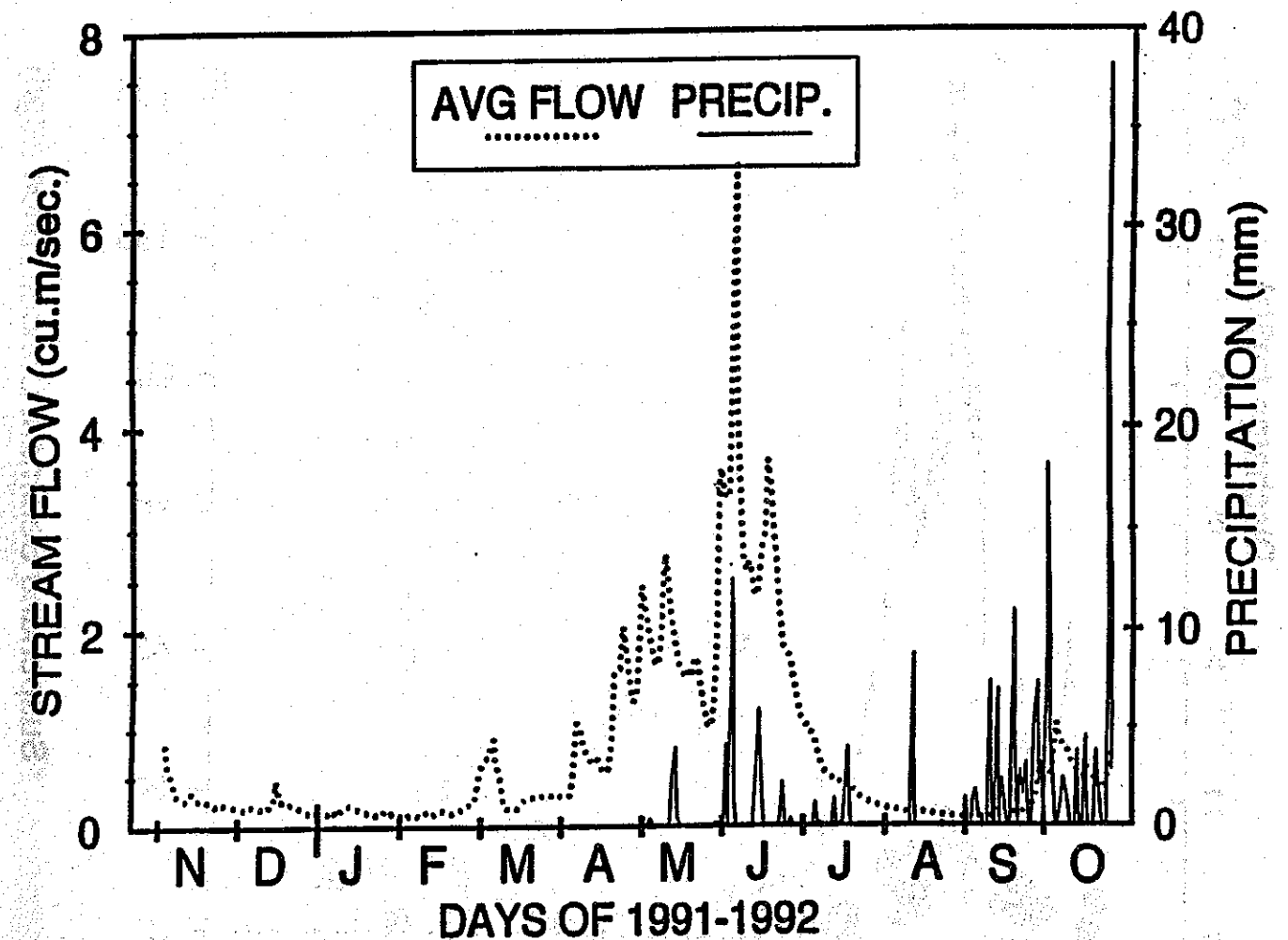


Figure 2: A typical example of discharge characteristics in the Takla tributaries (e.g., Gluskie Creek). Precipitation information comes from the DFO camp on Middle River.

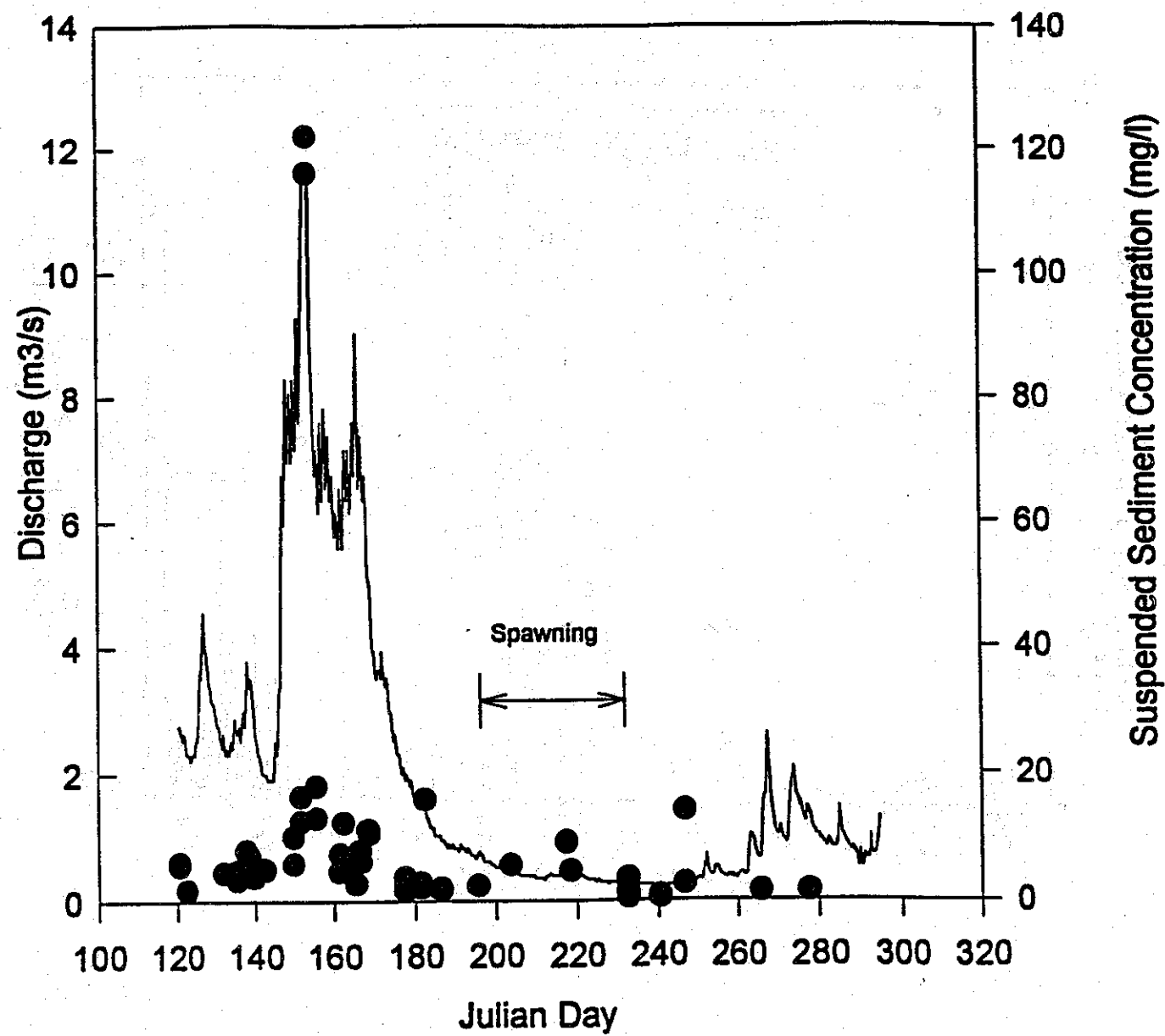


Figure 3: O'Ne-el Creek suspended sediment and discharge characteristics (1992). Period of sockeye salmon spawning is indicated.

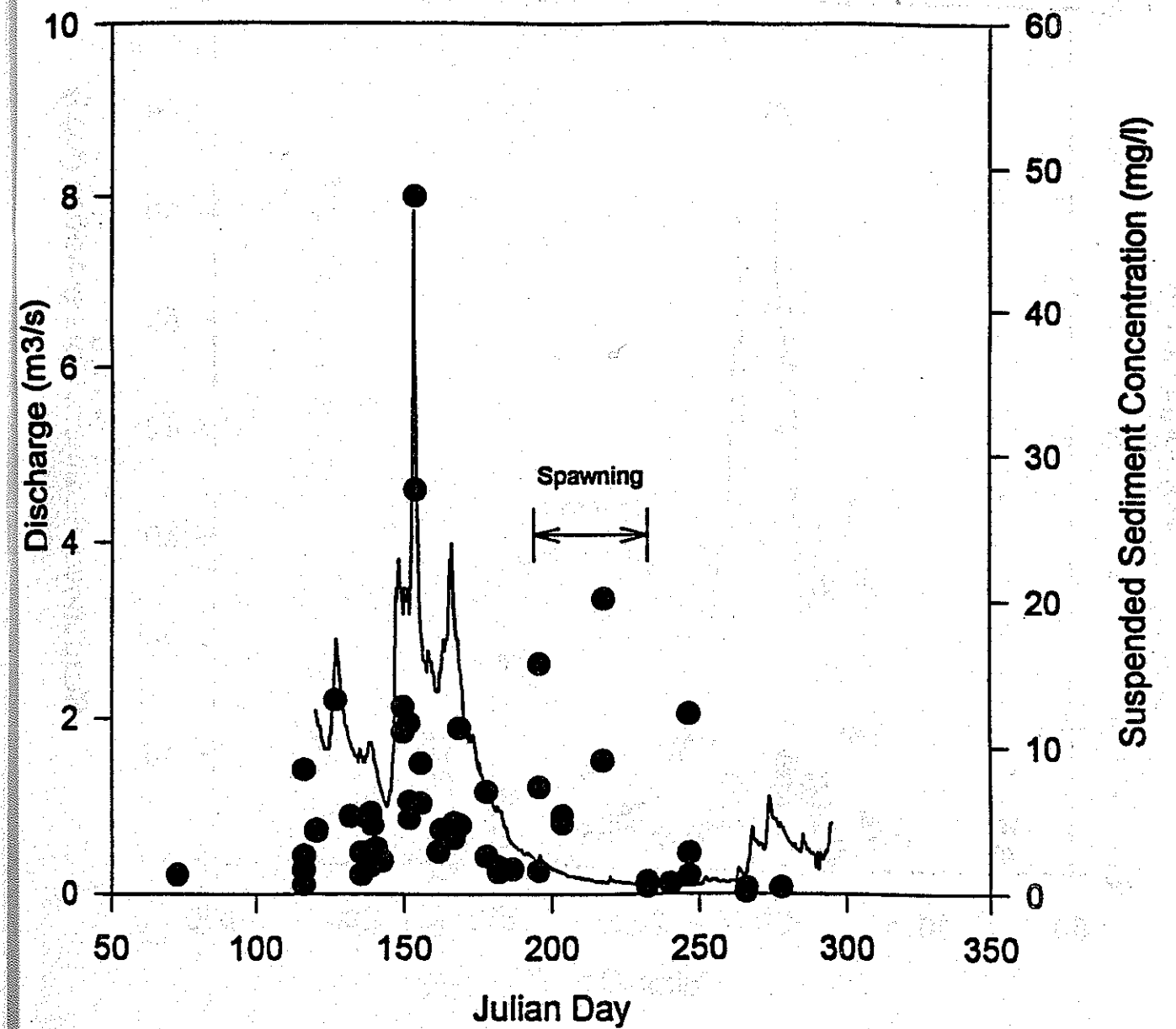


Figure 4: Gluskie Creek suspended sediment and discharge characteristics (1992). Period of sockeye salmon spawning is indicated.

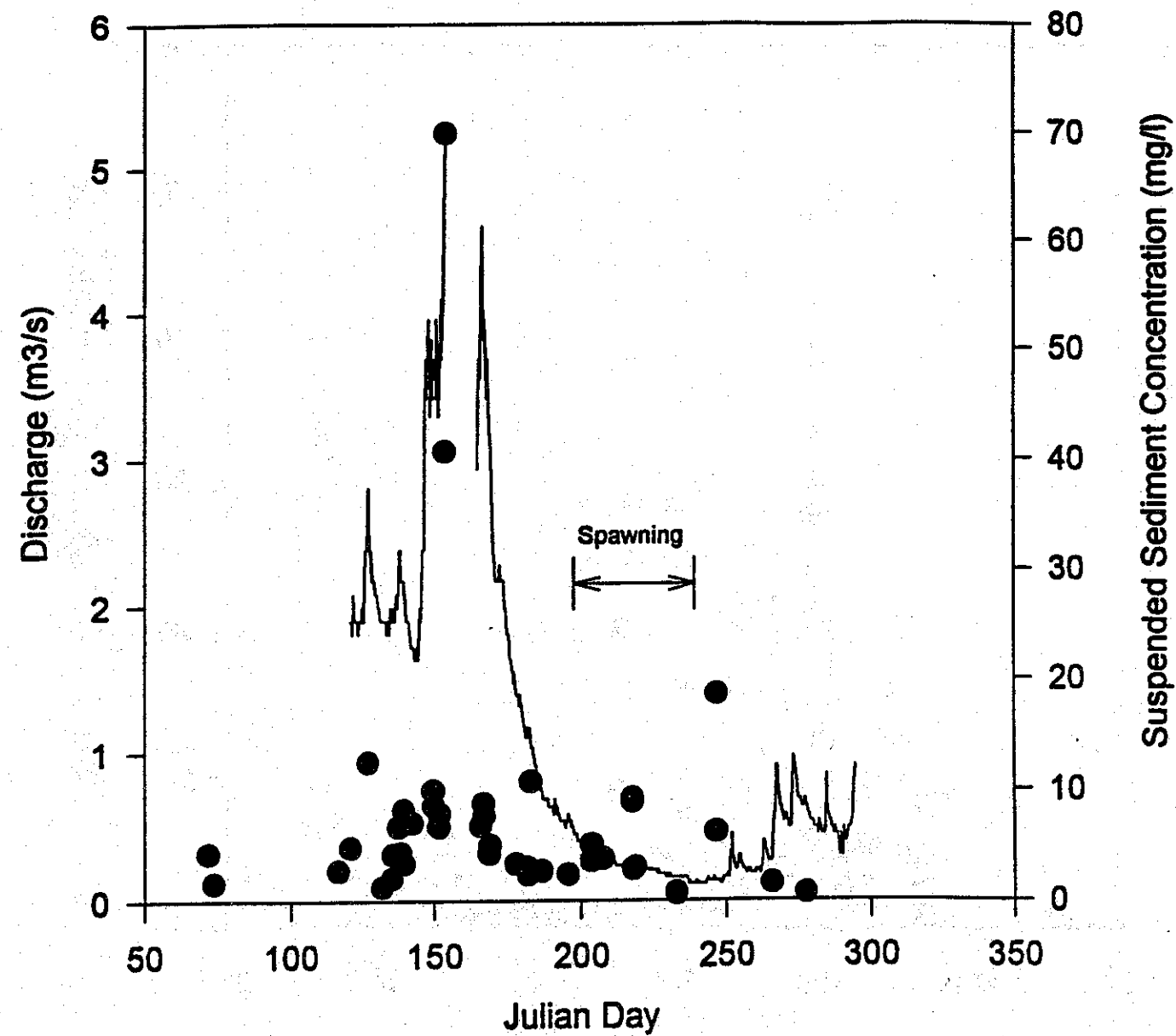


Figure 5: Forfar Creek suspended sediment and discharge characteristics (1992). Period of sockeye salmon spawning is indicated.

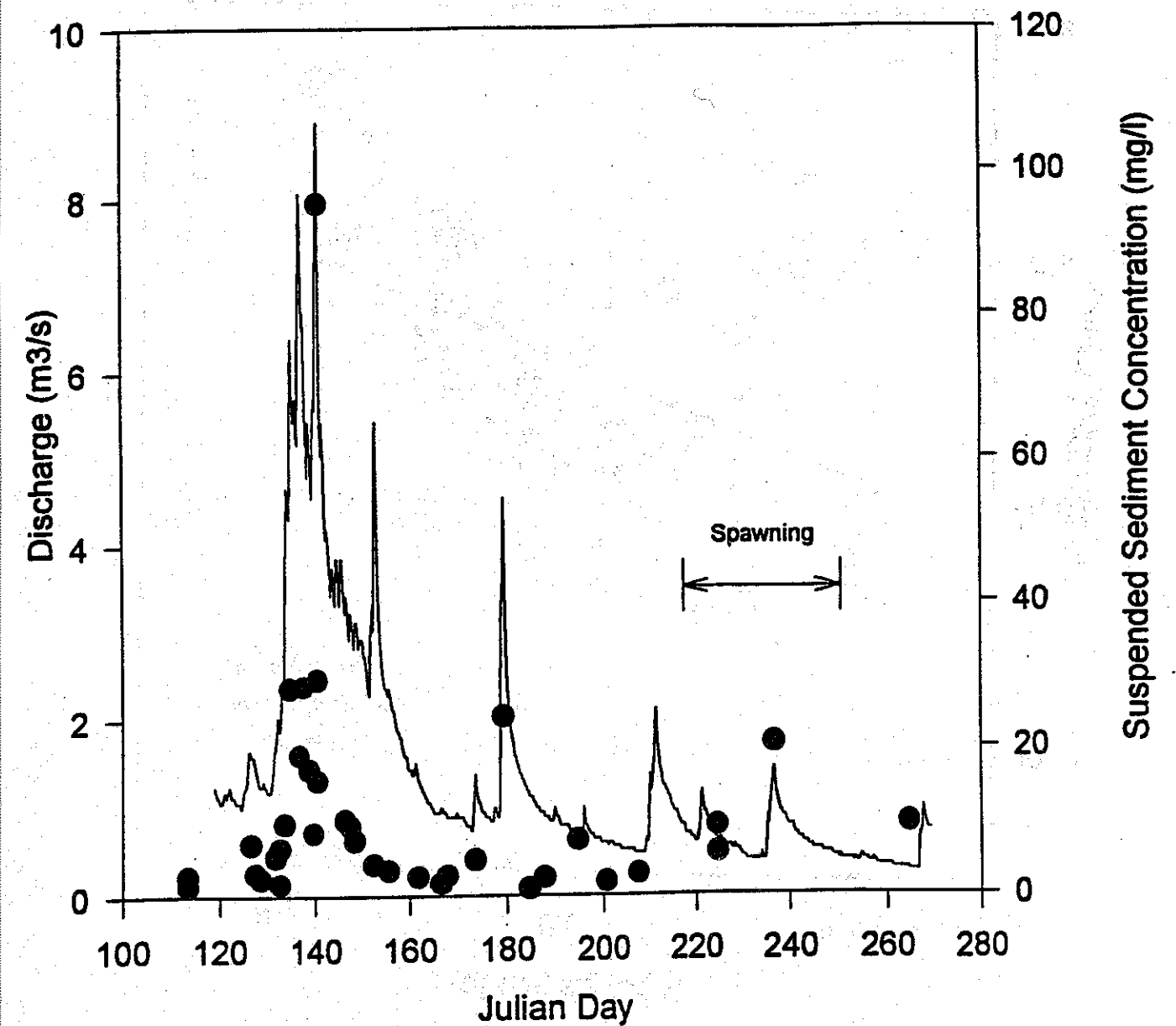


Figure 6: Forfar Creek suspended sediment and discharge characteristics (1993). Period of sockeye salmon spawning is indicated.

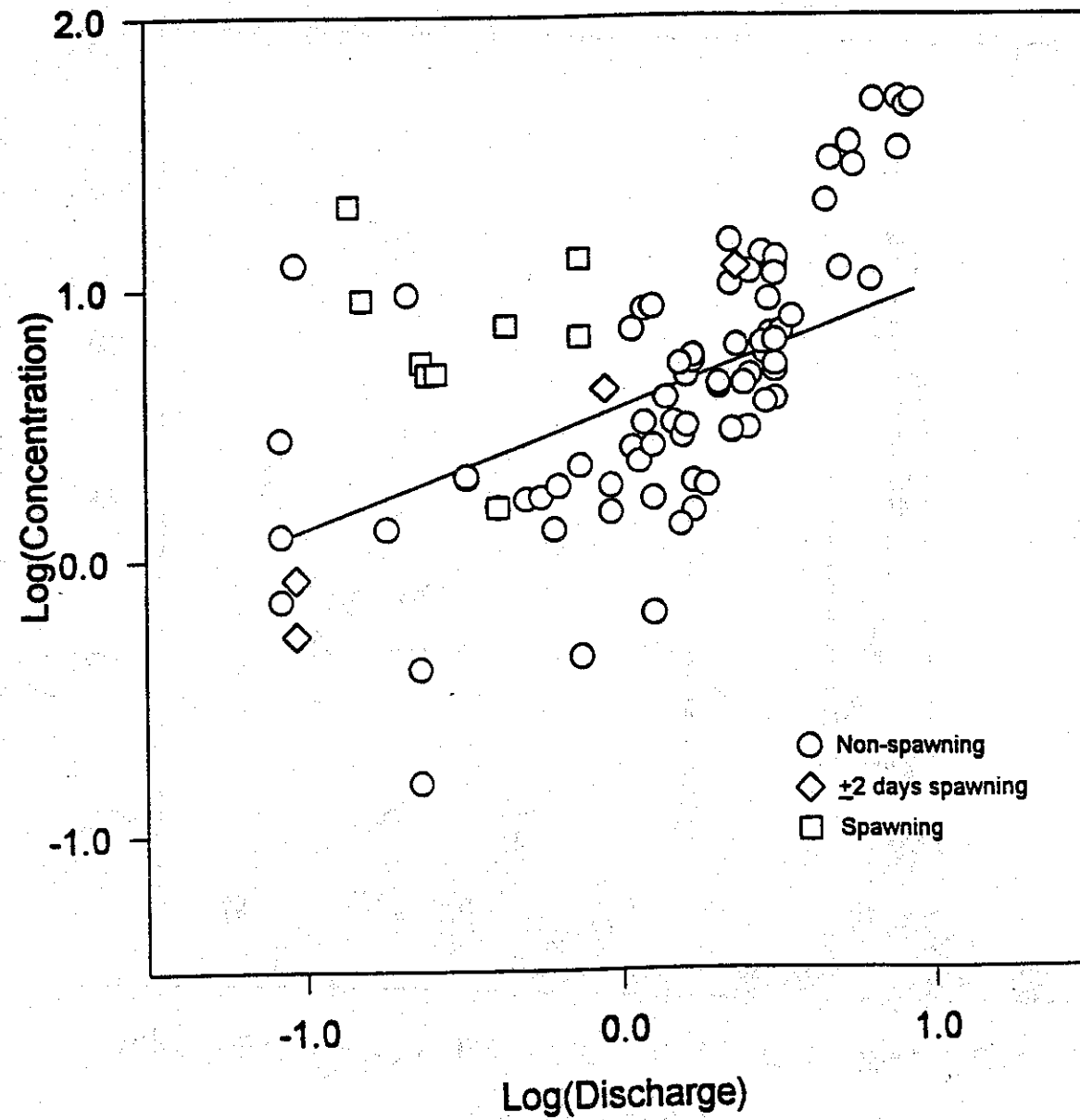


Figure 7: Gluskie Creek suspended sediment-discharge relation for 1992 and 1993. Data collected during spawning periods are indicated.

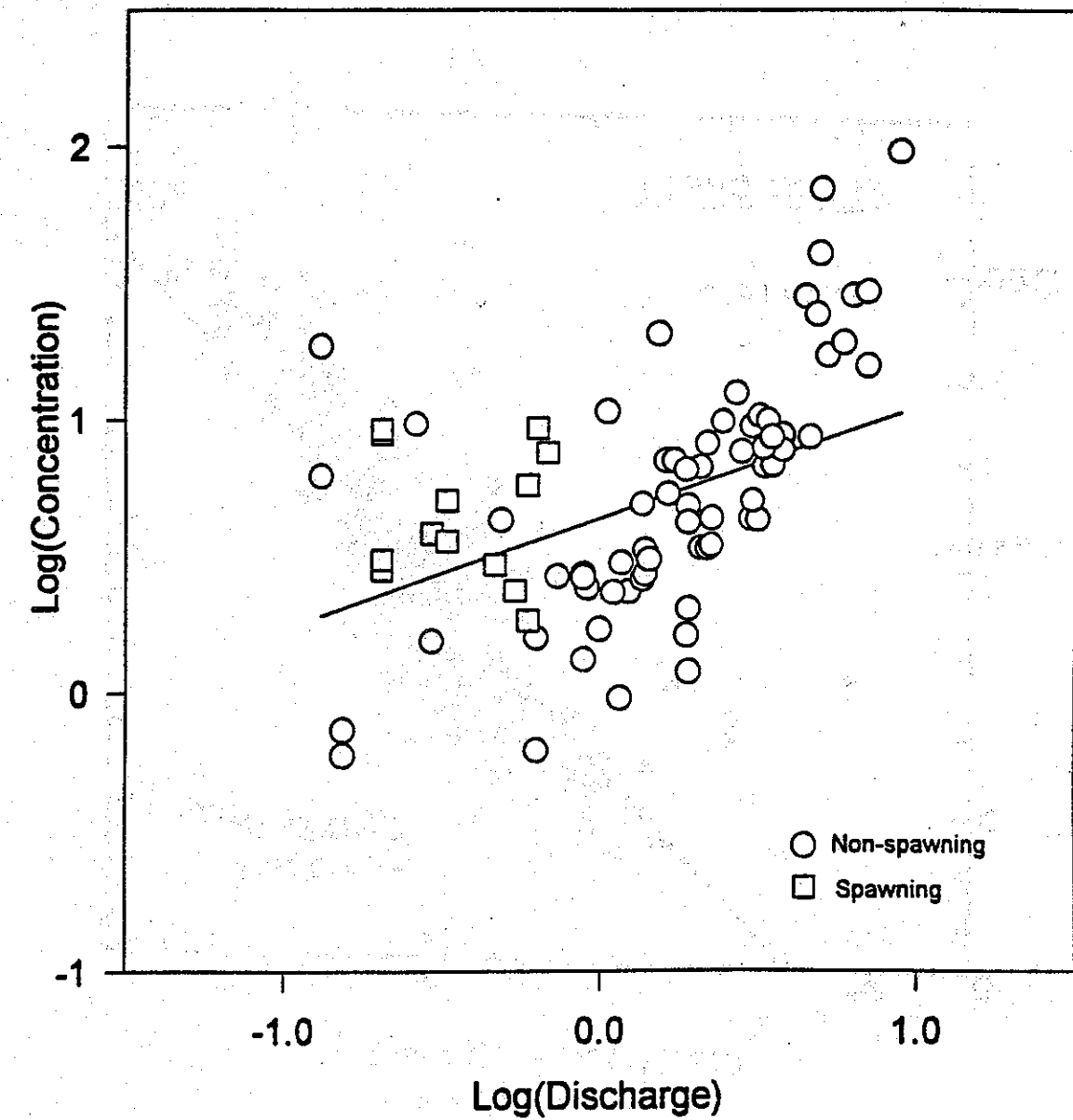


Figure 8: Forfar Creek suspended sediment-discharge relation for 1992 and 1993. Data collected during spawning periods are indicated.



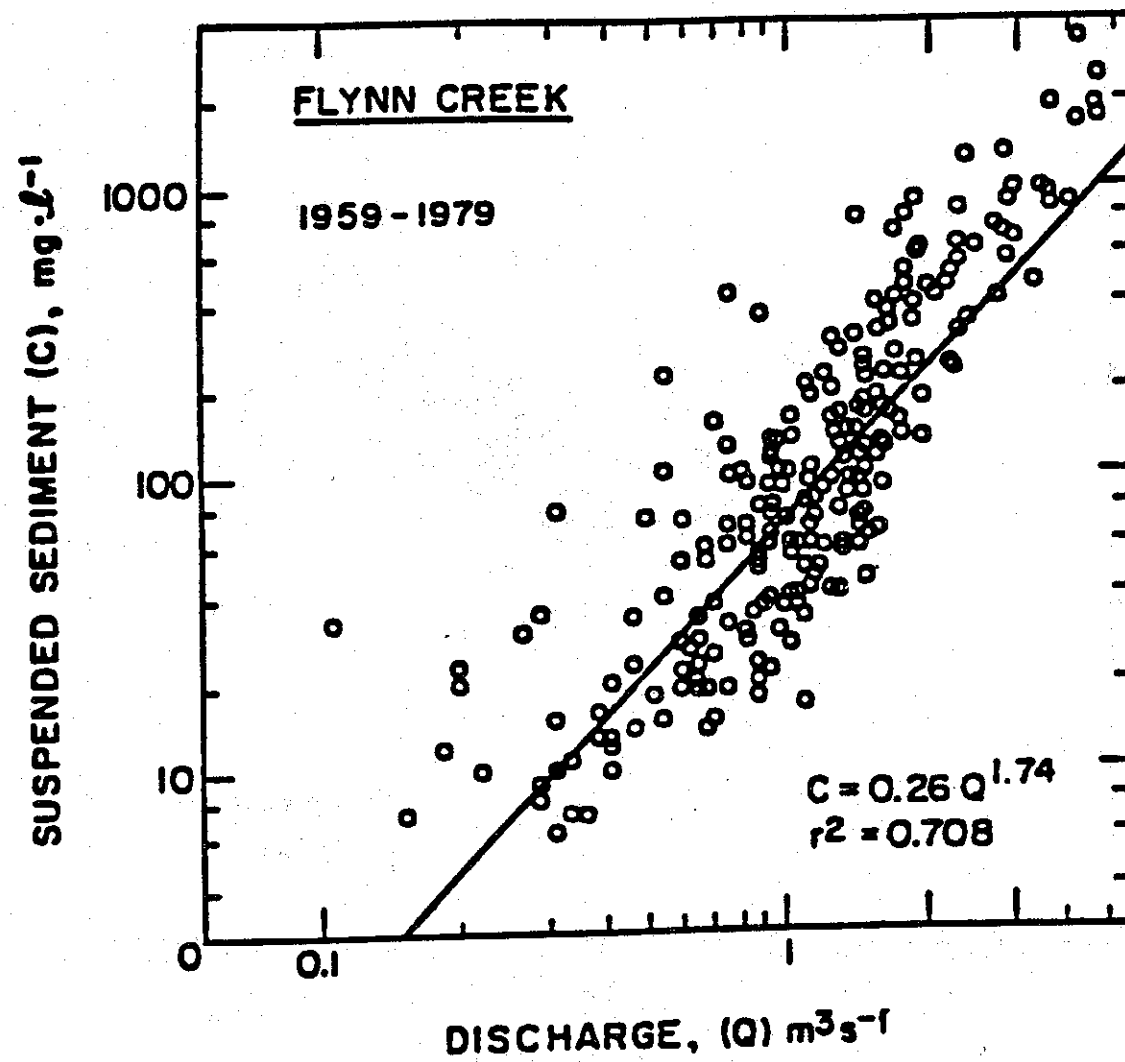


Figure 9: Sediment transport curve for Flynn Creek, based on instantaneous values from 24 storms having peak flows  $\geq 1.1 \text{ m}^3/\text{s}$  (VanSickle and Beschta, 1993).

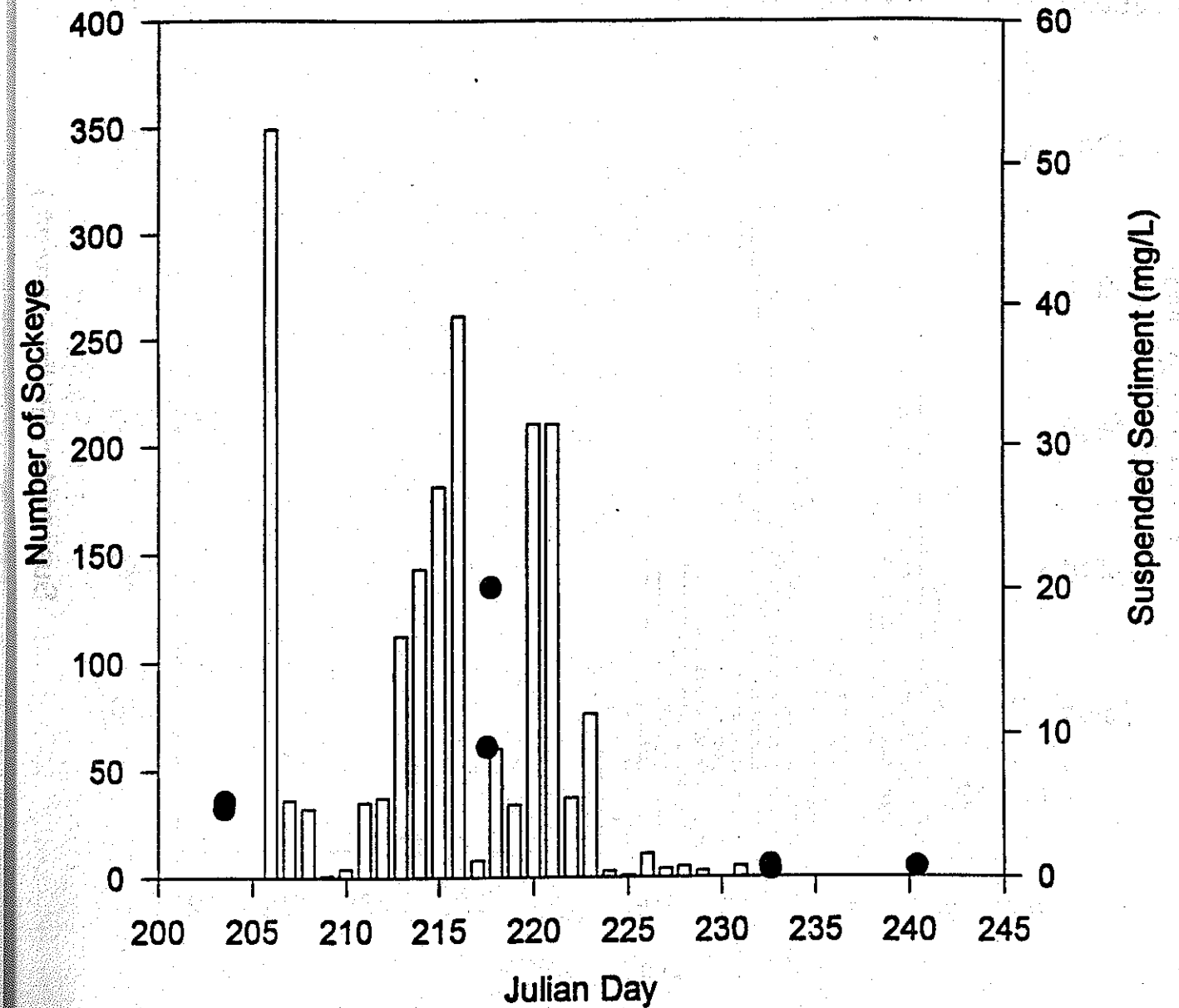


Figure 10: Counts of sockeye salmon from a fence at the mouth of Gluskie Creek and suspended sediment (1992). Suspended sediment levels predicted from sediment-discharge relations are typically below  $5 \text{ mg/L}$  for this period.

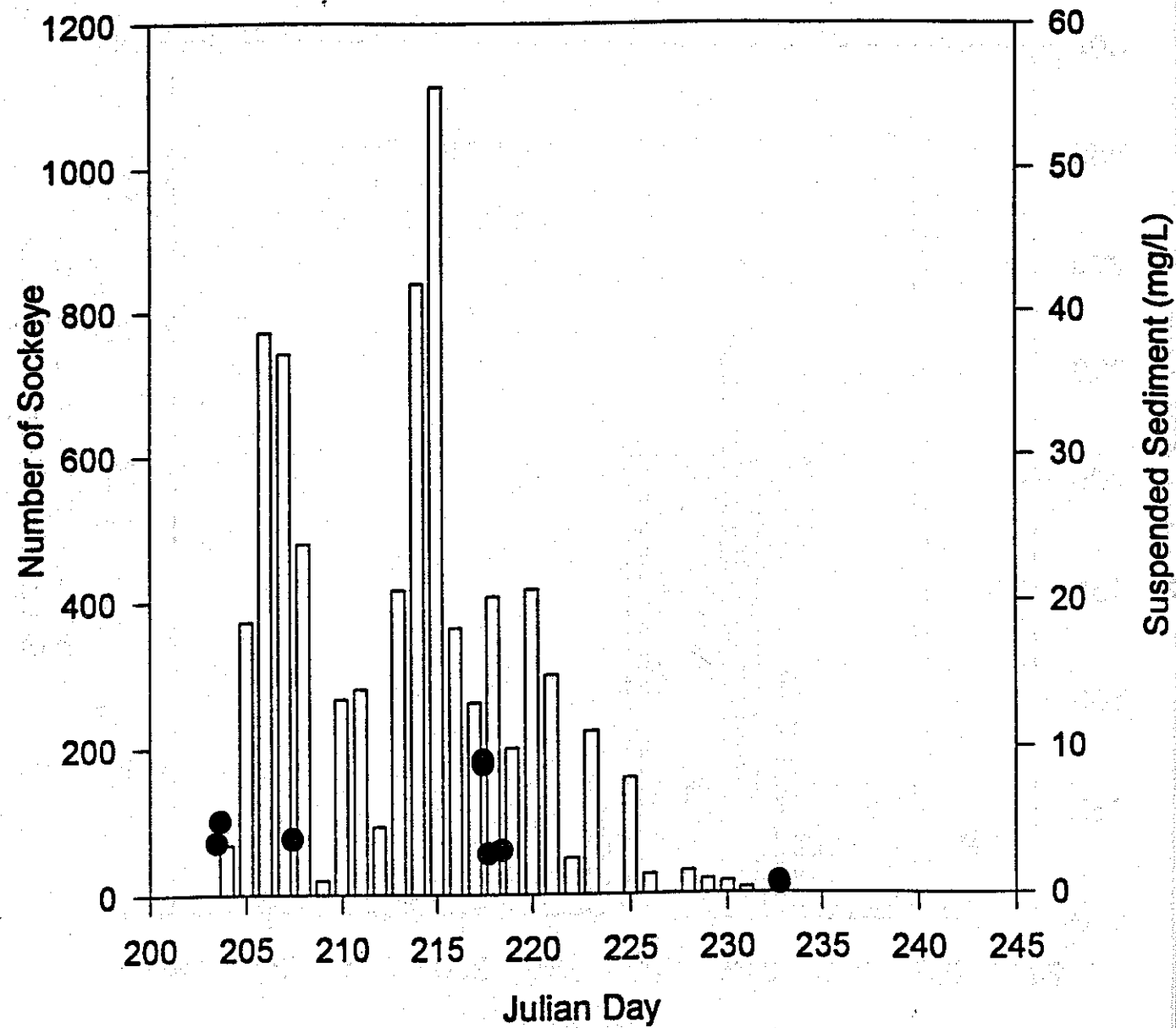


Figure 11: Counts of sockeye salmon from a fence at the mouth of Forfar Creek and suspended sediment (1992). Suspended sediment levels predicted from sediment-discharge relations are typically below 5mg/L for this period.

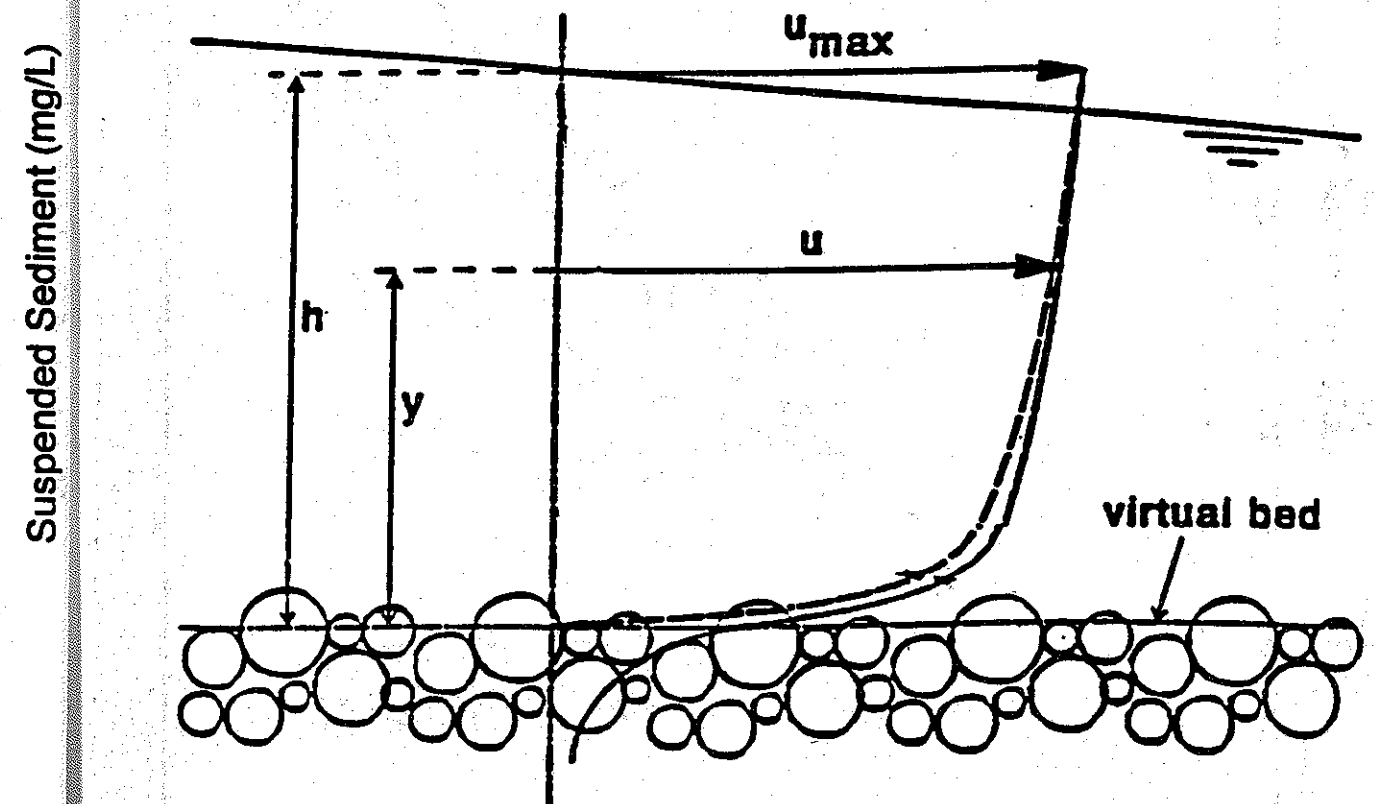


Figure 12: Definition sketch of mean velocity and suspended sediment distributions in convergent streamflow over a gravel bed (Alonso and Mendoza, 1992).

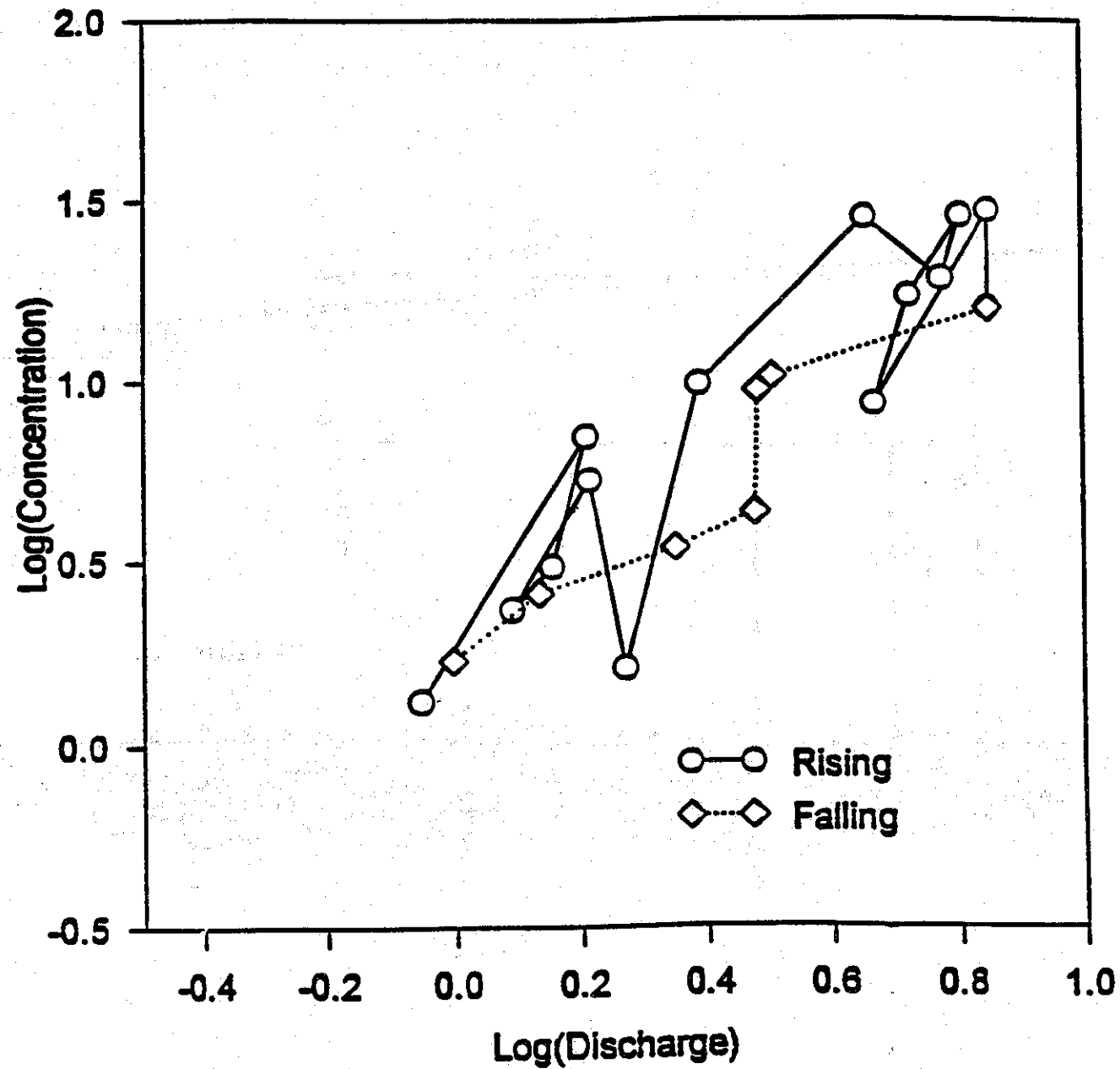


Figure 13: Forfar Creek event hysteresis (May/June, 1993). Sequential discharge levels ( $\text{m}^3/\text{s}$ ) and their respective suspended sediment concentrations ( $\text{mg/L}$ ) are presented for the rising limb (solid line) and falling limb (dashed line) for the snowmelt event, resulting in a clockwise loop.

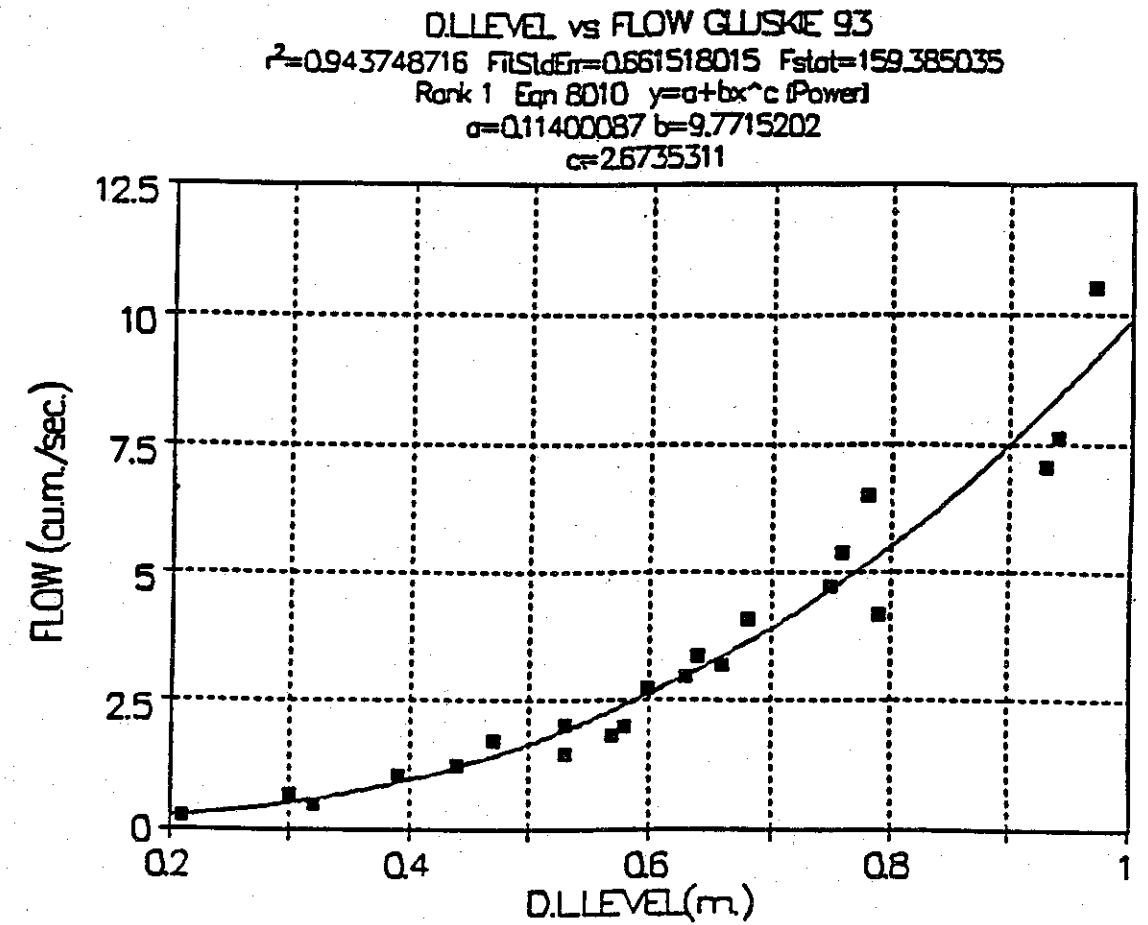


Figure 14: Gluskie Creek rating curve (1993). Flow predictions are more variable at the higher water levels. Water levels were measured using an electronic data logger.