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SUSPENDED SEDIMENT IN THE LITTLE QUALICUM WATERSHED 1986-2001.

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ABSTRACT

The Little Qualicum River spawning channel operated by the Department of Fisheries and Oceans is sensitive to suspended sediment. Accumulation of fines in the spawning beds eventually degrades gravel quality and only routine cleaning will maintain egg survival. Increased suspended sediment is also detrimental to juvenile salmon that rear in the channel. We used egg-to-fry measurements to assess the impact on eggs deposited in the gravel and a model developed by Newcombe and Jensen (1996) to assess the impact on juvenile salmonids.

A program initiated in 1986 identified and removed some sources of sediment in the watershed. Also new strategies for operating the spawning channel mitigated the impact of sediment. Between 1986 and 2001 a large number of suspended sediment measurements were made to assess this program -- samples were taken throughout the watershed and over the length of the spawning channel.

Results showed that sediment was generated from a variety of land use activities and from natural landslides. The settling basin at the inlet of the channel removed most of the sand and reduced suspended sediment concentrations by approximately 50%. In spite of this, between 12 tonnes (winter 1999/00) and 237 tonnes (winter 1990/91) of the lighter silt and clay escaped the settling basin and entered the channel. We estimated that between 50 and 75% of this material was deposited in the spawning channel.

RÉSUMÉ

Le chenal de ponte de la rivière Little Qualicum exploité par le ministère des Pêches et des Océans est sensible aux sédiments en suspension. L’accumulation de fines dans les frayères mène éventuellement à la dégradation de la qualité du gravier et seul un nettoyage régulier permet d’assurer la survie des œufs. Une charge accrue de sédiments en suspension nuit aussi aux saumons juvéniles qui utilisent le chenal comme aire de grossissement. Nous avons utilisé des rapports entre la taille des œufs et la longueur des alevins pour évaluer l’impact sur les œufs pondus dans le gravier et un modèle élaboré par Newcombe et Jensen (1996) pour évaluer l’impact sur les salmonidés juvéniles.

Un programme lancé en 1986 a permis d’identifier et d’éliminer quelques sources de sédiments dans le bassin versant tandis que de nouvelles stratégies d’exploitation du chenal de ponte ont permis d’atténuer l’impact des sédiments. Entre 1986 et 2001, un grand nombre de mesures des sédiments en suspension ont été effectuées en vue d’évaluer ce programme. À cette fin, des échantillons ont été prélevés à l’échelle du bassin versant et du chenal de ponte.

Les résultats ont révélé qu’une gamme d’activités d’utilisation des sols et des glissements de terrain naturels étaient à l’origine des sédiments. Le bassin de sédimentation situé à l’entrée du chenal a permis d’éliminer la plus grande partie du sable et de réduire les charges de sédiments en suspension par environ 50 %. Malgré cela, de 12 tonnes (hiver 1999-2000) à 237 tonnes (hiver 1990-1991) de particules légères de limon et d’argile ont été déchargées dans le chenal de ponte, où nous estimons que de 50 à 75 % de celles-ci ont été déposées.

1.0. INTRODUCTION

The Little Qualicum River flows northeast from Cameron Lake and enters the Strait of Georgia near the town of Qualicum Beach (Fig. 1). The river downstream of Cameron Lake is approximately 20 km long. The entire watershed (including Cameron River and Lake) has an area of 237 km^2 and is 54 km in length. Cameron Lake has a surface area of 4.22 km^2.

About 14 km downstream of the Lake, water is diverted from the river to supply the Little Qualicum Spawning Channel. A settling basin at the head of the channel is designed to protect the spawning gravel from high levels of sediment that often occur during the fall and winter. Although the settling basin removes the sand much of the silt and clay remains suspended and enters the channel. A high proportion of this finer material settles out as the water meanders down the shallow 4171 meter channel. This occurs as the silt and clay infiltrate the interstices of the porous spawning gravel and accumulate (Fletcher et al. 1995). Thus the channel becomes a long horizontal filter which absorbs fine sediment. Eventually permeability drops and the productivity of the channel decreases.

Yearly gravel cleaning after the spring smolt migration restores permeability. A bulldozer is used to dislodge sediment by scarification. During this operation, high water flow is maintained so that silt is swept downstream. To prevent this silt from re-entering the Little Qualicum River, cleaning effluent is intercepted and pumped to land for treatment. The cleaning operation takes about two weeks of intensive work (McLean et al. 1996).

Reducing the inflow of sediment to the channel has many benefits. The egg-to-fry survival rate and production of aquatic insects is increased (Mundie and Crabtree 1997) while the stress on juvenile fish in the channel and cost of the yearly gravel cleaning operation is reduced. In 1986 a program was initiated to reduce the inflow of sediment. The program involved: a) identifying and stabilizing sediment sources in the watershed b) improving the performance of the settling basin and c) reducing water inflow rates during sediment events. Reducing flow improves settling basin performance and decreases the sediment load to the channel.

Monitoring suspended sediment (NFR or Non-Filterable Residue) in the channel and watershed was an important component of this program. NFR measurements were used to assess the removal efficiency of the settling basin and to quantify the amount of sediment entering the channel. This gave an estimate of the sediment that must be removed during gravel cleaning.

NFR sampling in the watershed was used to pinpoint sediment sources. Sampling upstream and downstream of a suspected site quantified the visual impression of increased turbidity. This allowed ranking sediment sources in the watershed for remediation. NFR data was also used to predict the biological impact of siltation. If duration and concentration are known the impact on various life stages of fishes and invertebrates can be predicted (Newcombe and Jensen 1996).

Routine monitoring of suspended sediment was initiated in 1986. This report only includes values measured in the channel and in the watershed between 1986 and 2001. It does not include NFR values associated with gravel cleaning operations.

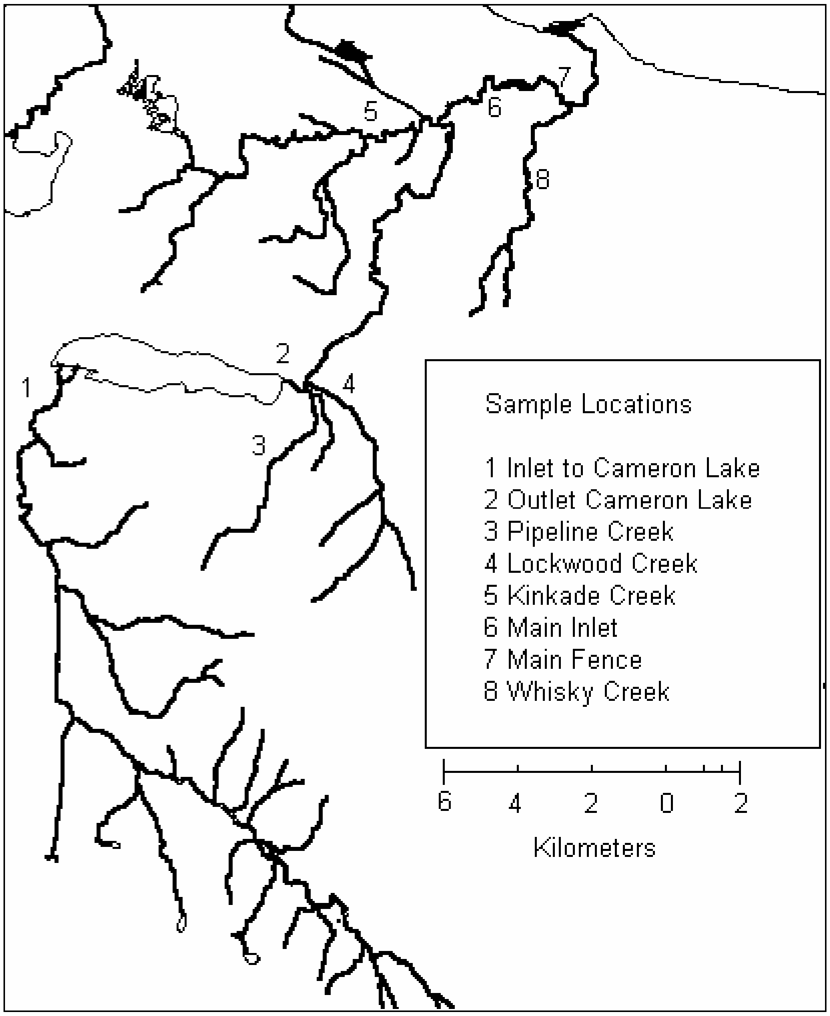


Figure 1. Map showing sample sites in the LQ watershed.

2.0. MATERIALS AND METHODS

2.1. SPAWNING CHANNEL AND SETTLING BASIN.

Figure 2 shows a schematic of the LQ spawning channel. The channel is divided into five sections by diffuser structures (labelled Dif 1, Dif 2 ...). Diffuser 6 marks the downstream end of the channel. Grab samples for NFR were taken at the inflow to the settling basin and at the diffusers. An automatic composite sampler was located at diffuser 1. This consisted of a submersible pump that delivered a 250-ml sample to a composite storage bucket when activated for 10 s. To obtain a representative sample the pump was held in an area of upwelling and was activated every hour during normal operation or every 30 minutes during periods of heavy sediment influx or transients. After a time interval the composite storage bucket was thoroughly mixed and subsampled to get the average NFR for the period. The sample period was as short as 8 hours when inflow conditions were variable and up to 2 weeks if conditions were stable.

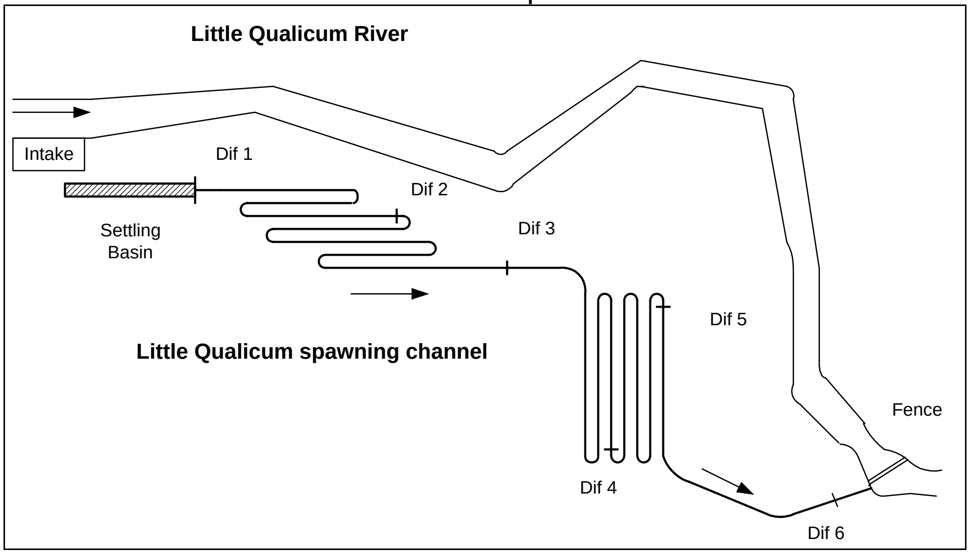


Figure 2. Schematic diagram showing sample sites on Little Qualicum Spawning Channel.

Dimensions and typical operating characteristics for the settling basin and spawning channel are as follows.

The settling basin is 400 ft (122 m) long, 50 ft (15 m) wide, and 5 ft (1.5 m) deep. The volume (V) is 100,000 ft^3 (2832 m^3) and the surface area (A) is 20,000 ft^2 (1858 m^2). The operating flow (Q) is typically 45 cfs (1.27 m^3/s), with a mean residence time (V/Q) of 37 minutes. The overflow rate (Q/A) is 0.07 cm/sec.

The spawning channel is 13,684 ft (4171 m) long; 25 ft (7.6 m) wide; and 1.3 ft (40 cm) deep. The slope is 1.5 in 1,000. The mean residence time (passage time from Dif 1 to Dif 6) is 2.8 hr.

2.2. SUSPENDED SEDIMENT ANALYSIS.

Non-filterable residue (NFR) was determined by passing a volume of water (1 to 2 liters) through a tared glass filter disk (9 cm diameter Whatman 934-AH). The amount of sediment retained on the disk is defined as NFR in mg/L. Weight was measured on oven dried (105 ^oC) disks using a Mettler model AE240 analytical balance (readability 0.01 mg). These filters retain all particles greater than 1.5 microns.

The detection limit (level that is just significantly different from a blank) was determined by performing 39 independent measurements on distilled water. The detection limit should be at least 3 standard deviations (SD) from the blank value (Strickland and Parsons, 1968). The SD of these blank measurements was 0.2 mg/L. To be conservative a detection limit of 1 mg/L (5 SDs) was used in this study.

2.3. CALCULATION OF SEDIMENT INPUT.

The amount of sediment entering the channel at diffuser 1 in one day was calculated from: kg/d = 0.101941*Q*NFR*24, where Q = flow in cubic ft per sec (cfs) and NFR = average daily suspended sediment concentration (mg/L). Days where the average NFR was less than 1 mg/L were not included. Accumulated sediment was expressed in metric tons (1 tonne = 1000 kg).

Particle Size. Sediment samples were taken from 1 foot beneath the gravel surface in each section of the spawning channel. Samples were pumped from standpipes used for measuring gravel permeability (Mason et al. 1992). Only particles that can pass through 3175 micon holes are collected using this method. Particle size was determined at the MacMillan Bloedel Ltd. Woodlands Laboratory (Gammel 1988). Particles were divided into: > 62 microns (sand); < 62 (silt); < 31; < 16 and < 4 microns (clay).

2.4. PREDICTION OF EFFECTS.

The Newcombe and Jensen (1996) model predicts the impact of suspended sediment on juvenile salmonids. Severity of ill-effect (SEV) is related to NFR (mg/L) and duration of exposure (hr). The SEV scale covers the following responses: nil effect (0); behavioral (1 to 3); sublethal (4 to 8) and lethal (9 to 14). SEV was predicted from their equation for juvenile salmonids SEV= 0.7262 + 0.7034logex + 0.7144logey where: x= duration of exposure (hr) and y= NFR (mg/L) at Diffuser 1. Days where the average NFR was < 1 mg/L were not included in the calculation of SEV.

3.0. RESULTS AND DISCUSSION

3.1. SEDIMENT TIMING.

High sediment loads at diffuser 1 coincide with floods in the Little Qualicum River (Fletcher et al. 1995). Figure 3 shows the average daily NFR value for 13 years of data.

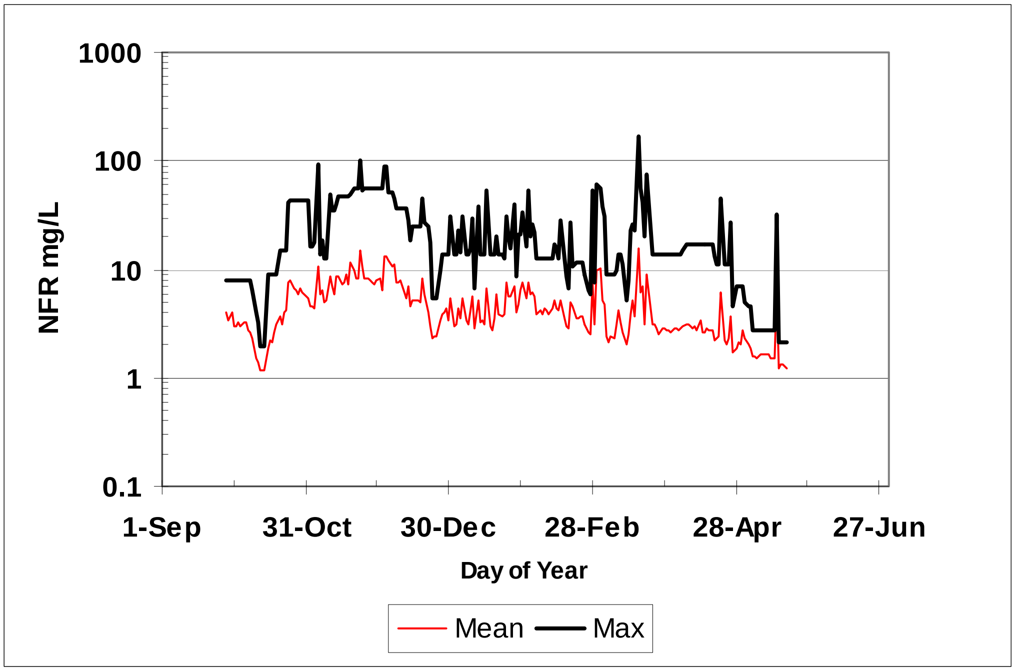


Figure 3. Mean NFR concentration at diffuser 1 over 13 years of monitoring.

3.2. SEDIMENT ENTERING THE SPAWNING CHANNEL PER YEAR

The amount of sediment entering the spawning channel varies from year to year. Appendix 1 shows the NFR of composite and grab samples and also the cumulative sediment passing diffuser 1 between 1986 and 2001. Table 1 summarizes the amount of sediment entering the spawning channel (at diffuser 1) per year and severity of ill effect is also shown. Much of this sediment is trapped by the spawning gravel and accumulates in the channel.

Table 1. Amount of sediment passing diffuser 1 over the fall and winter and the predicted severity of ill effect (SEV) on juvenile salmonids in the channel.

Year	Tonnes	SEV
1986/87	Insufficient Data	
1987/88	Insufficient Data	
1988/89	88	7.48
1989/90	36	7.08
1990/91	237	8.41
1991/92	121	7.90
1992/93	195	8.25
1993/94	109	7.83
1994/95	93	7.72
1995/96	88	7.68
1996/97	68	7.50

1997/98	59	7.40
1998/99	119	7.90
1999/00	12	6.55
2000/01	26	6.96

3.3. DEPOSITION OF SUSPENDED SEDIMENT IN LQ SPAWNING CHANNEL.

Suspended sediment is deposited in the voids of the spawning gravel as water flows down the length of the channel. Thus there is a reduction in NFR between channel inflow and outflow. Examples of sediment removal are shown in Figure 4. On March 18/97 the NFR at diffuser 1 was high (165 mg./L) and the outflow (diffuser 6) was 12.6 mg/L -- 92 % was removed between the inflow and outflow of the channel. On March 9/92 the NFR was 5.2 mg/L (diffuser 1) and 80 % of the sediment was removed. In both cases most of the sediment was removed in the upper 2 sections of the channel (80% in March 18/97 and 71% March 9/92) while the remainder was removed in the downstream three sections (12% in March 18/97 and 9% in March 9/92).

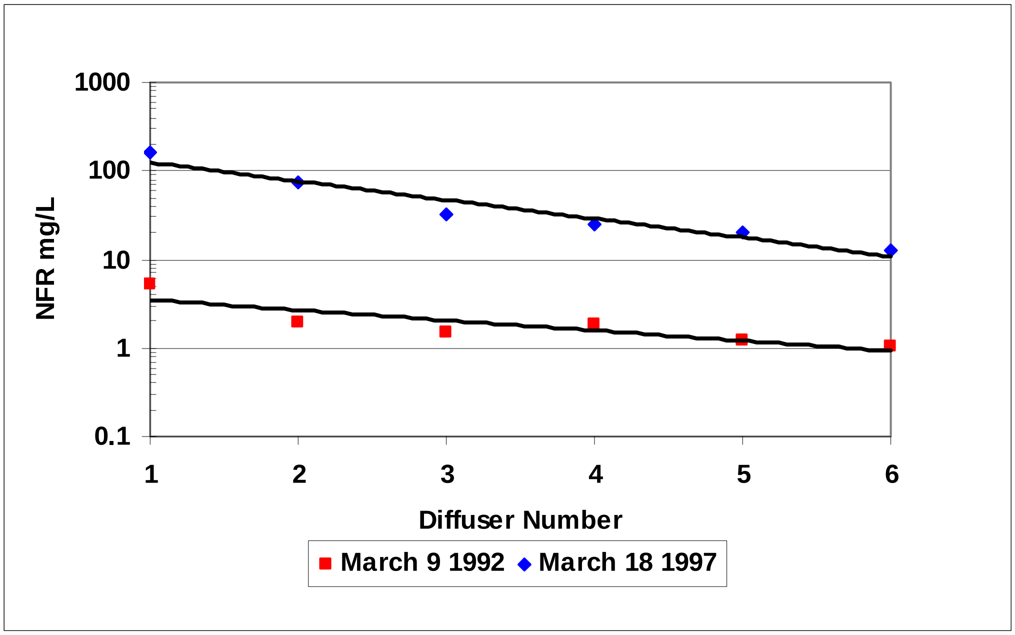


Figure 4. Decrease in suspended sediment (NFR) as water flows down the length of the channel (Diffuser Number). Data is shown for March 18/97 and March 9/92.

Deposition of suspended sediment depends on the size of the suspended particle, concentration, state of the stream bed and channel flow. It also depends on activity in the channel -- sediment is dislodged when fish spawn or when the gravel is disturbed. At these times the channel actually produced NFR.

Over the past 15 years a number of paired grab samples were taken at the channel inflow (diffuser 1) and outflow (diffuser 6). Paired samples were taken within 15 minutes of one another. These results were pooled to derive a relationship between percent deposition (A%) of suspended sediment by the spawning channel (A% = (D_1 - D_6)*100/D1) and the inflow NFR concentration D_1 (mg/L). Figure 5 shows A% vs D_1 -- only samples where either D_1 or D_6 were greater than the detection limit of 1 mg/L were used in this derivation. If one of the paired values was less than 1 mg/L it was set equal to 1 mg/L so that A% could be calculated. This procedure results in a conservative A% value. For example if D_1 = 5 mg/L and D_6 < 1 mg/L the A% value is reported as 80%. Negative A% values in Figure 5 show that sediment was produced (i.e. $D_6 > D_1$). The trend line shown in Figure 5 is the least square relationship between A% and D_1: A% = 95.8 – 143.6/D_1, $r^2 = 0.59$, N = 239. As the inflow NFR (D1) increases the second term in the equation shrinks and the predicted deposition approaches 95.8%. At inflow values of 50 and 5 mg/L the predicted A% drops to 93% and 67% respectively.

Figure 6 provides an alternate view of this data set. The difference, D1-D6, expresses the deposition of NFR by the channel (instead of A%). Positive values show deposition of sediment while negative values show sediment production. This difference is linearly related to D1 – the least square relationship is: (D1-D6) = 0.93645*D1 – 1.4498, r2 = 0.993, N = 239. Residual values show the deviation of measured values from the least square line. Figures 5 and 6 show that high inflow values always result in deposition of sediment while production of sediment sometimes occurs when inflow values are low.

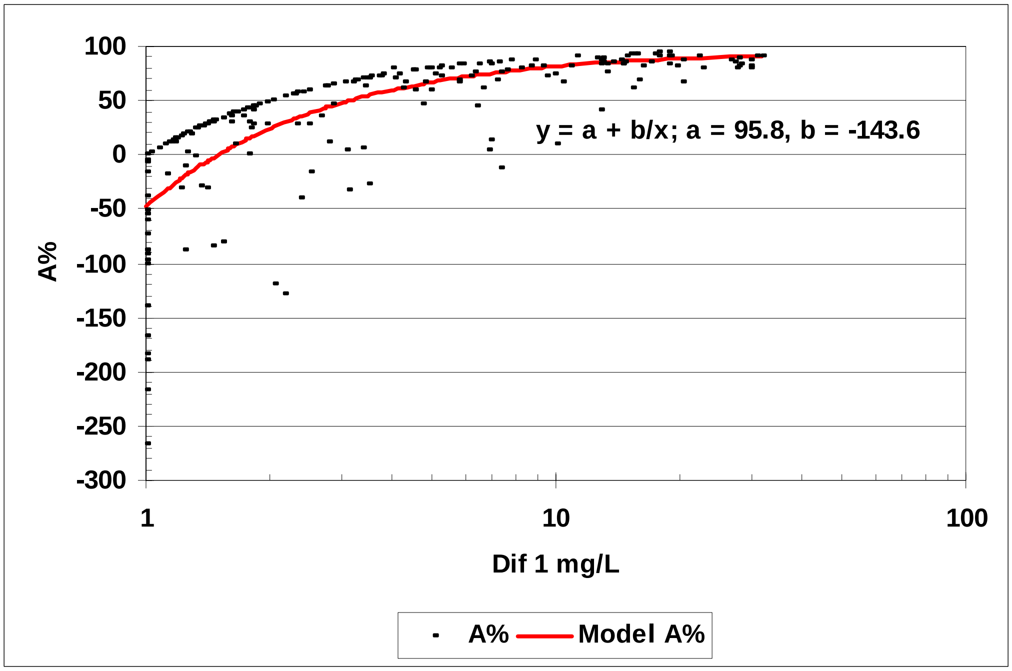


Figure 5. Deposition (A%) of suspended sediment down length of the channel vs concentration at the inflow (diffuser 1).

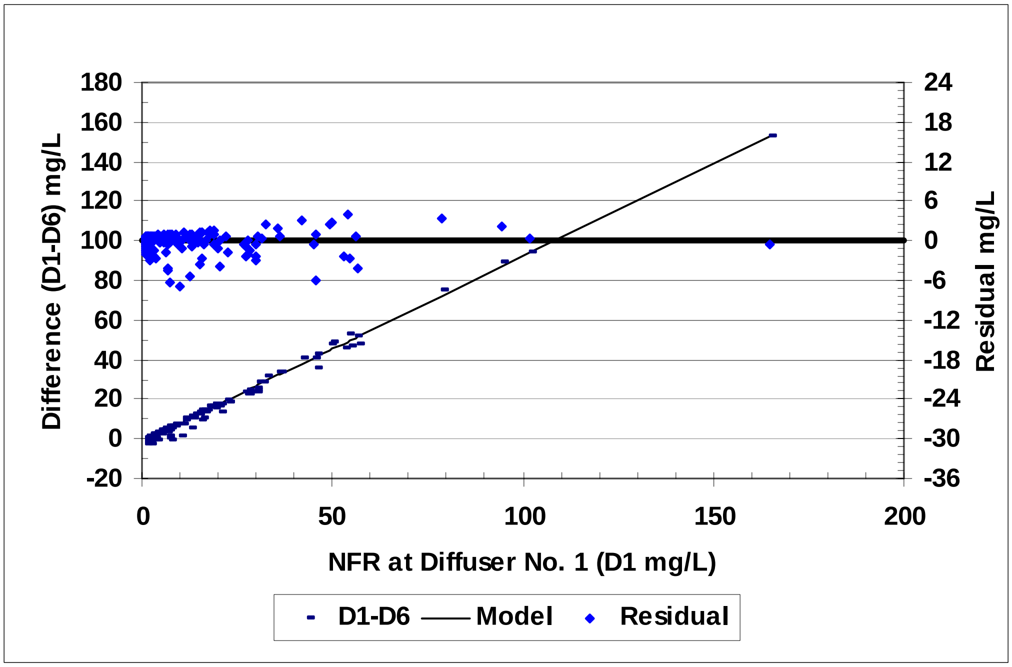


Figure 6. Difference in NFR between inflow and outflow of channel (D1-D6) vs NFR at inflow (D1).

As D_1 drops below 7 mg/L the scatter in measured values around the curve becomes extreme. This is because data has been pooled over 15 years and reflects a wide range of operating flows and conditions. Some measurements were taken when there was spawning activity in the channel. Also data in Figure 5 is based on paired samples --This type of sampling is inadequate when sediment transients enter the channel. It takes over 2 hours for a slug of sediment to traverse the channel and paired samples necessarily give inaccurate A% values. To deal with transients, automatic composite samplers are required at inflow and outflow.

Because of these limitations in the data, it was not possible to predict the accumulation of sediment in the spawning gravel for a particular year. It can be conservatively stated that of the total amount of sediment entering the channel at diffuser 1, between 50 and 75% is deposited in the gravel

Algal blooms within the channel can also contribute to sediment accumulation. In the spring of 1998 mats of Didymosphenia (Gomphonema) covered the surface of the gravel. It is estimated that this bloom contributed an additional 10 tonnes (dry weight) of fine diatomaceous material to the gravel.

3.4. REMOVAL OF SUSPENDED SEDIMENT BY THE SETTLING BASIN.

For discrete settling, the effectiveness of a settling basin is determined by the overflow rate (ratio of flow to surface area, Q/A). This is the minimum settling velocity for 100 % removal of a class of particles. Ideally the LQ settling basin (over flow rate = 0.07 cm/s) should remove all the sand fractions and a proportion of the silts and clays. In the spring of 1992 the particle size distribution of sediment that had accumulated over the winter was measured -- it was 68 % sand, 26% silt and 6 % clay.

Between 1986 and 2001, 49 paired samples at the inlet (In) and at diffuser 1 (D_1) were taken to evaluate the performance of the settling basin. Percent removal (R%) was calculated from: R% = (In-D_1)*100/In. As with the channel, NFR values below the detection limit (1 mg/L) were set equal to 1 mg/L to give a conservative estimate of R%

Figure 7 shows a plot of R% vs the inlet concentration. The trend line is the least square relationship between R% and In: R% = 59.9 – 123.2/In, (r^2 = 0.54, N = 49). Approximately 50% of the suspended sediment is removed when the inlet NFR is above 13 mg/L. As the inlet NFR approaches 350 mg/L ,the predicted removal is 60%.

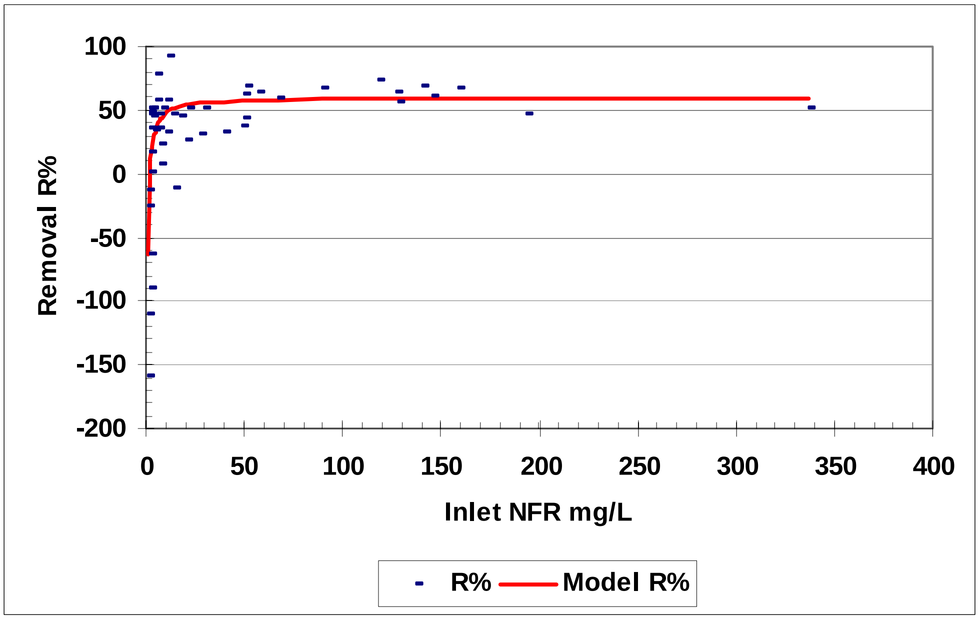


Figure 7. Removal of suspended sediment by the settling basin.

Points are widely scattered around the trend line because the data covers 15 years and reflects a wide range of operating conditions. Some of the events in Figure 7 involved silt and clay which are difficult to settle. Also, sediment was re-suspended on some occasions (negative R%) because of disturbances or flow surges.

3.5. SOURCES OF SEDIMENT IN THE LQ WATERSHED.

Over the past 15 years a number of sediment events were triggered by a variety of manmade and natural disturbances. These include: residential development, land clearing, laying of the Natural Gas Pipeline, construction of the Inland Island Highway, logging, wet land drainage, farming and river bank failure. DFO and MELP staff have worked together to identify important sediment sources and take remedial action. For example, recommendations to mitigate logging damage in the Cameron valley (Lamb 1986) and subsequent remedial work by MacMillan Bloedel Ltd has substantially reduced the flow of sediment to Cameron Lake. A joint DFO/MELP Habitat Conservation Fund Project with assistance from MacMillan Bloedel has lead to stabilization of several very damaging slides on Kinkade Creek. Also MELP has set guidelines to reduce the impact of farm drainage on Kinkade Creek (Rimmer 1993)

The Cameron valley is the headwaters of the Little Qualicum River. Most of the heavier sediment generated in this area settles in Cameron Lake. Therefore suspended sediment in the LQ River at the lake outlet consists of low concentrations of fine clay. Figure 8 shows NFRs of samples collected at the inlet and outlet of Cameron Lake during sediment events in the Cameron valley. NFR at the inlet and outlet averaged 71 mg/L and 3.0 mg/L (range < 1 to 5.6 mg/L) respectively.

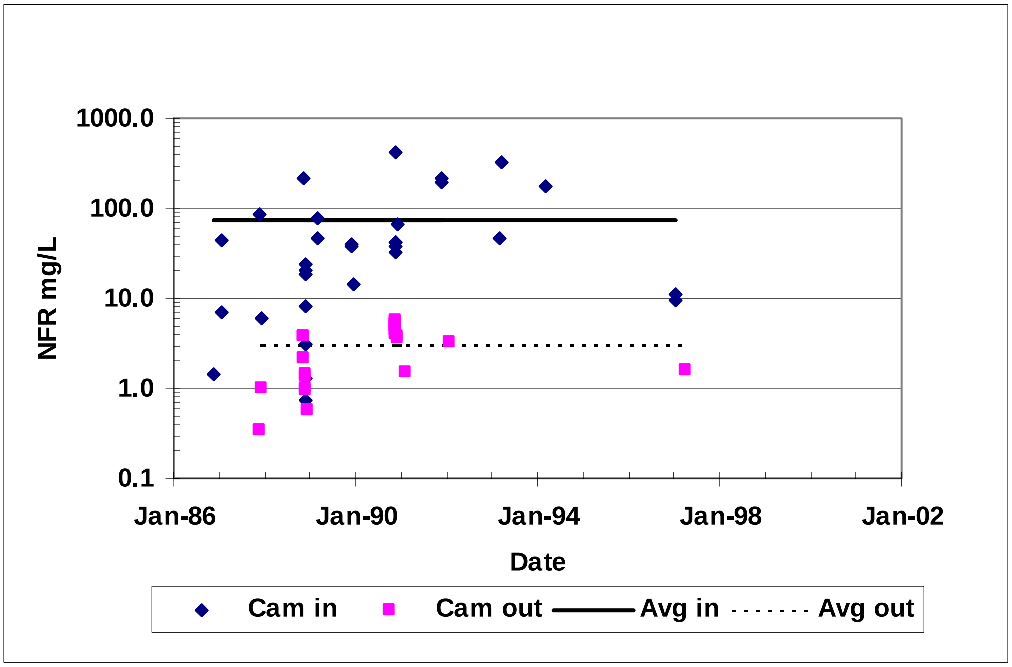


Figure 8. NFR at the inlet and outlet of Cameron Lake during sediment events in Cameron valley.

Although NFR at the outlet of Cameron Lake is low, this material has special significance to the spawning channel because it consists entirely of fine clay. This material is not removed by the settling basin but is readily removed by the spawning gravel. Furthermore sediment events in Cameron valley often leave the lake turbid for long periods so that the channel is exposed for weeks at a time. If the channel absorbs 1.5 mg/L of clay for 10 weeks, then 11.6 tonnes of sediment accumulate in the gravel. Thus even low concentrations of clay have an impact on the channel if there is a long exposure period. Such an event occurred in January and February of 1986. Prolonged exposure to clay had a significant impact on the channel. This event initiated the watershed monitoring program in the fall of 1986.

As the distance from Cameron Lake increases, NFR in the mainstem of the LQ River also tends to increase (Fig. 9). This results from natural erosion and from land use activities in the lower watershed. NFR values above 200 mg/L are common on the lower river (main fence and main intake of the LQ facility). Values would have been higher below Whisky Creek.

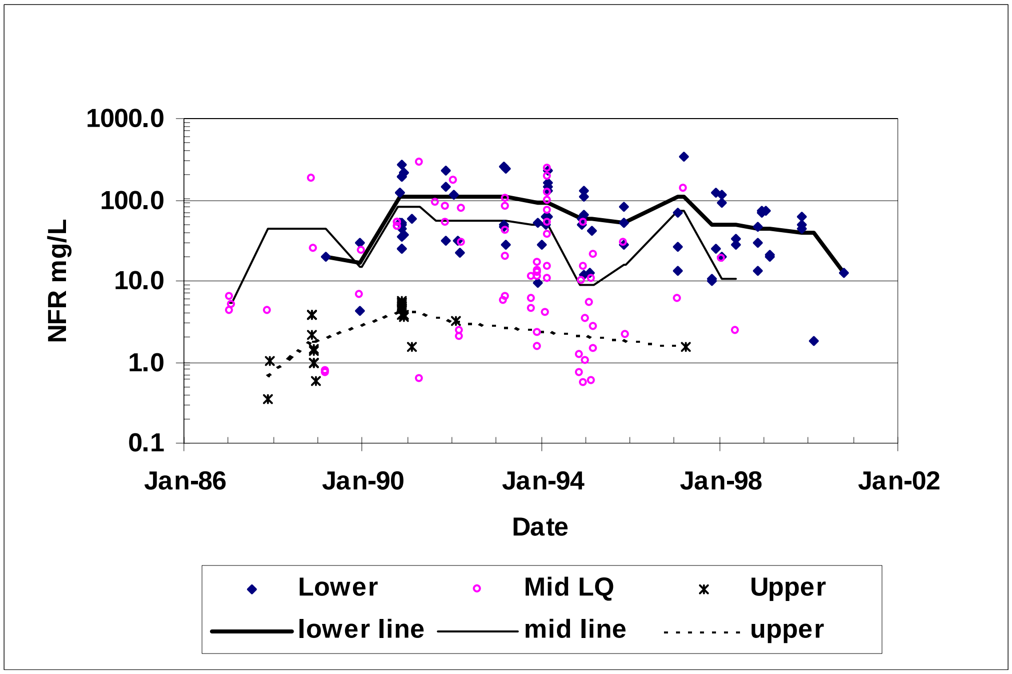


Figure 9. NFR at the outlet of Cameron Lake (crosses), at mid river (above Kinkade Creek, open circles) and in the lower river (near the LQ facility, diamonds). Lines show average values.

NFR in the lower reaches of Lockwood/Pipeline, Kinkade and Whisky Creeks were also monitored during sediment events (Figs. 10, 11 and 12). Pipeline and Lockwood are the first tributary streams to enter the LQ downsteam of Cameron Lake. These are high gradient streams and NFR spikes are associated with high rainfall and snow melt. NFR levels were also affected by logging in the watershed.

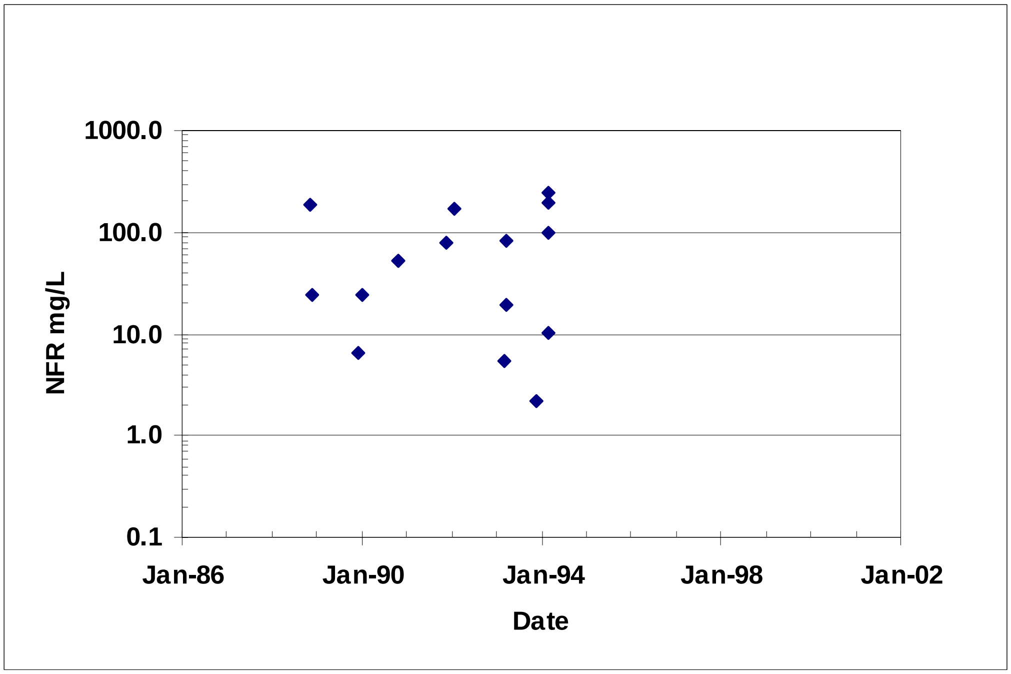


Figure 10. NFR Lockwood and Pipeline Creeks.

Suspended sediment values in Kinkade Creek are shown in Figure 11. Peaks in 1990/91 were due to erosion of several clay banks. This was the biggest contributor to the 237 tonnes of sediment that entered the channel in 1990/91 (see Table 1). Kinkade Creek is also affected by urbanization and by a number of construction waste piles that wash into the creek during heavy rains. The high values in 1994 and 95 were associated with the construction of the Inland Island Highway.

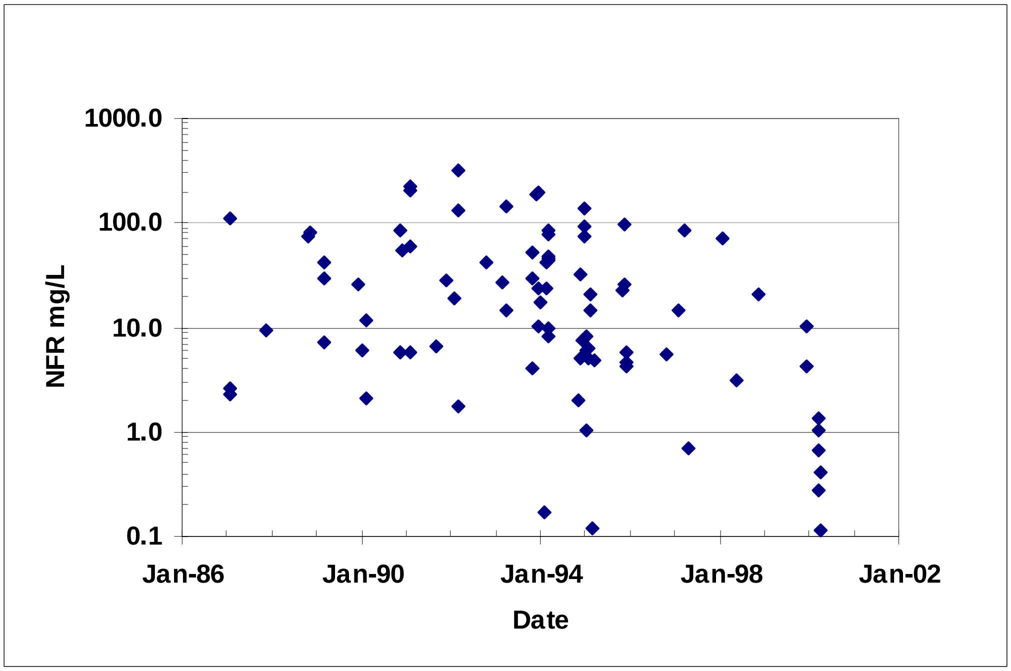


Figure 11. NFR Kinkade Creek.

Kinkade Creek is also affected by Tom Creek. Tom Creek is a small tributary that drains a large flooded area designed for over wintering waterfowl. This area is discharged into Tom Creek in late winter or early spring and the field is then used for farming. Suspended sediment levels in Tom Creek are shown in Figure 12.

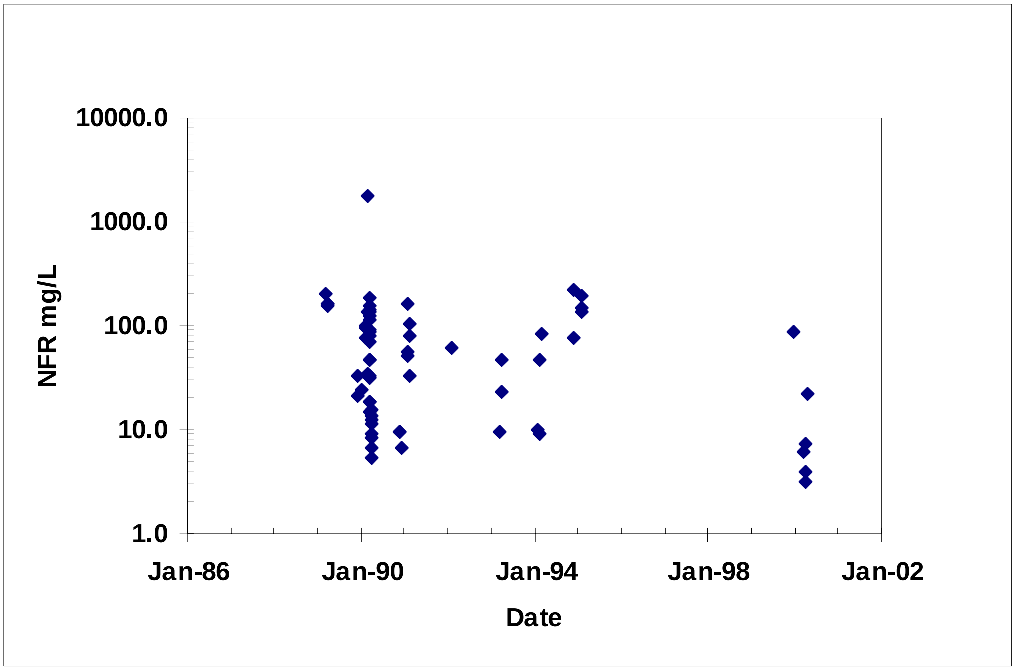


Figure 12. NFR Tom Creek.

Suspended sediment levels in Whisky Creek were affected by the gas pipeline, land clearing and by the Inland Island Highway (Fig. 13).

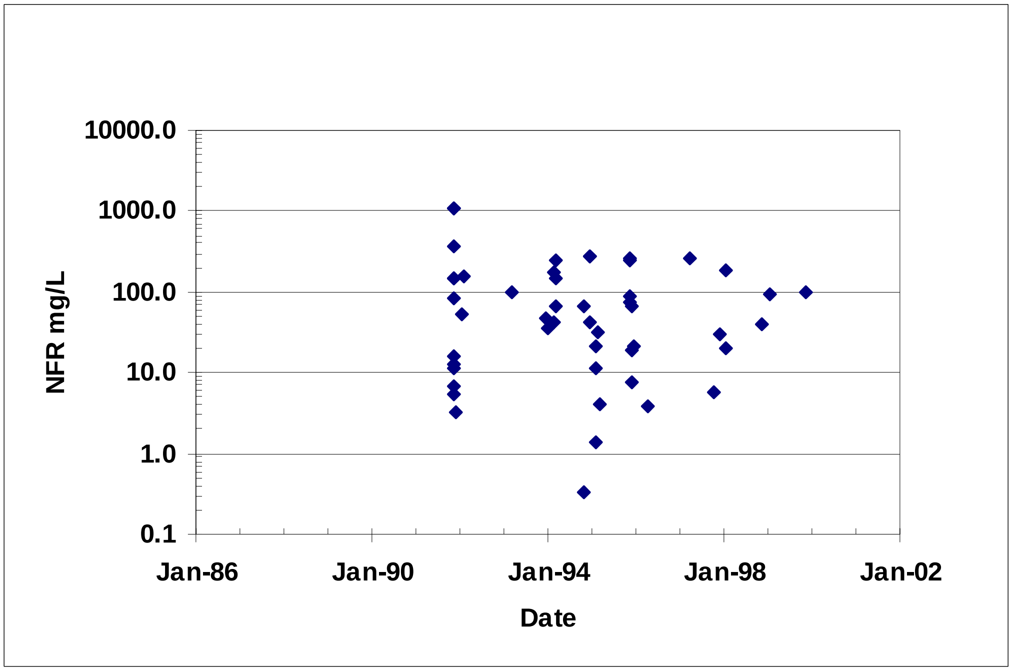


Figure 13. NFR Whisky Creek.

3.6. IMPACT OF SUSPENDED SEDIMENT ON LQ FACILITY

3.61. Egg to Fry Survival Rate.

Survival rates decrease as sediment accumulates in the spawning gravel (Fig. 14). Between 1980 and 1986 sediment accumulated and survival rates steadily dropped (trend line in Fig. 14). Sedimentation lowers permeability and ultimately lowers the intragravel oxygen supply and egg survival. The severe drop in brood 85 was due to extreme low temperatures at the time of spawning and clay deposition during the winter of 1985/86. Unfortunately the yearly input during this period was not measured. From 1986 on, the spawning gravel was cleaned yearly -- sediment did not build up and egg survival was restored.

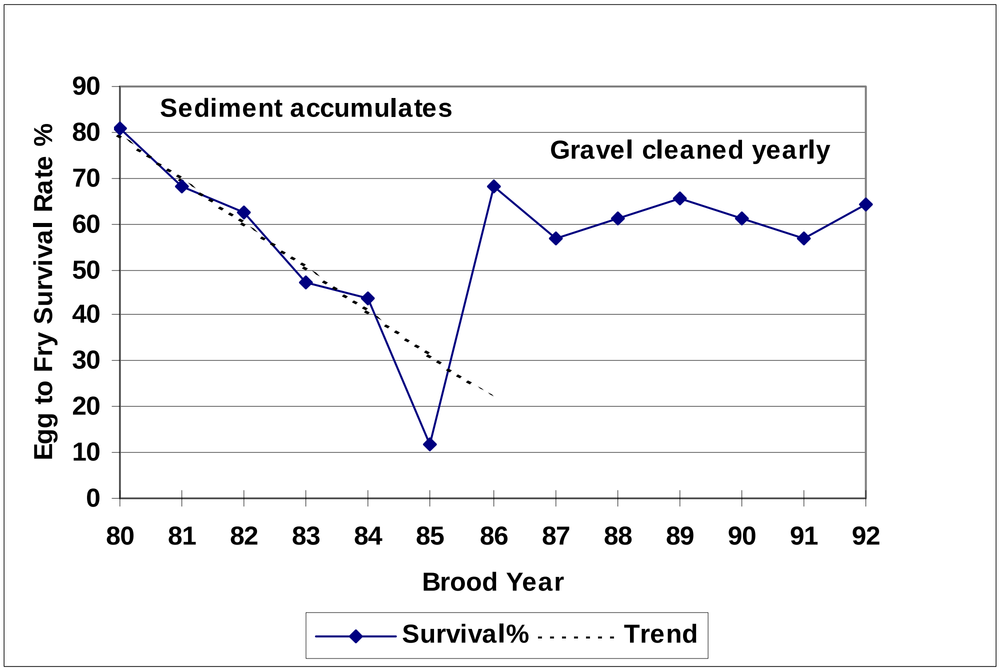


Figure 14. Egg to fry survival rates for chum salmon at LQ spawning channel.

3.62. Juveniles Rearing.

There are large numbers of coho, chinook and trout juveniles at the LQ facility. Some fish are reared in hatchery ponds while others spend their entire fresh water phase in the spawning channel (Mundie and Crabtree 1997).

Fine sediment is particularly harmful to newly emerged fry. Feeding response is suppressed and gill irritation can lead to bacterial gill disease. Gills of young fry are more sensitive to fine sediment because the interlamellar space is very small. Particles equal to or larger than this gap are more irritating than smaller particles that tend to sweep through the gill structure. Thus suspended solids consisting of very small particles are more irritating to young fry than to older fish.

Predicted SEV for juveniles rearing over the winter in the spawning channel ranged from 6.55 in 1999/2000 to 8.41 in 1990/91 (Table 1). These values represent sublethal stress. The model predicts that there was major physiological stress in 1990/91 with a reduction in feed rate. These values were calculated from NFR measurements at diffuser 1, only when NFR was greater than 1 mg/L.

The decision to calculate SEV for the entire spawning, incubation, and early rearing period (i.e. from September to May inclusively) was made assuming that there is no recovery period after a sediment event (i.e. a period of days when NFR was greater than 1 mg/L).

To illustrate the various approaches to calculating SEVs we have used the 1996-1997 spawning and incubation season. The measured NFRs and calculated SEVs for the entire season, from October 3 to May 16, for discrete sediment events, as well daily SEVs are presented in Figure 15. Daily SEVs ranged from 2.98 to 5.85, while average SEVs for the six sediment events ranged from 4.57 (from Feb. 23 Mar. 2), to 7.07 (from Mar. 14 to Apr. 30). Notice that these SEVs are all lower than the calculated SEV for the entire season of 7.50. Hence, the SEVs reported herein (Table 1) are a worst case estimate.

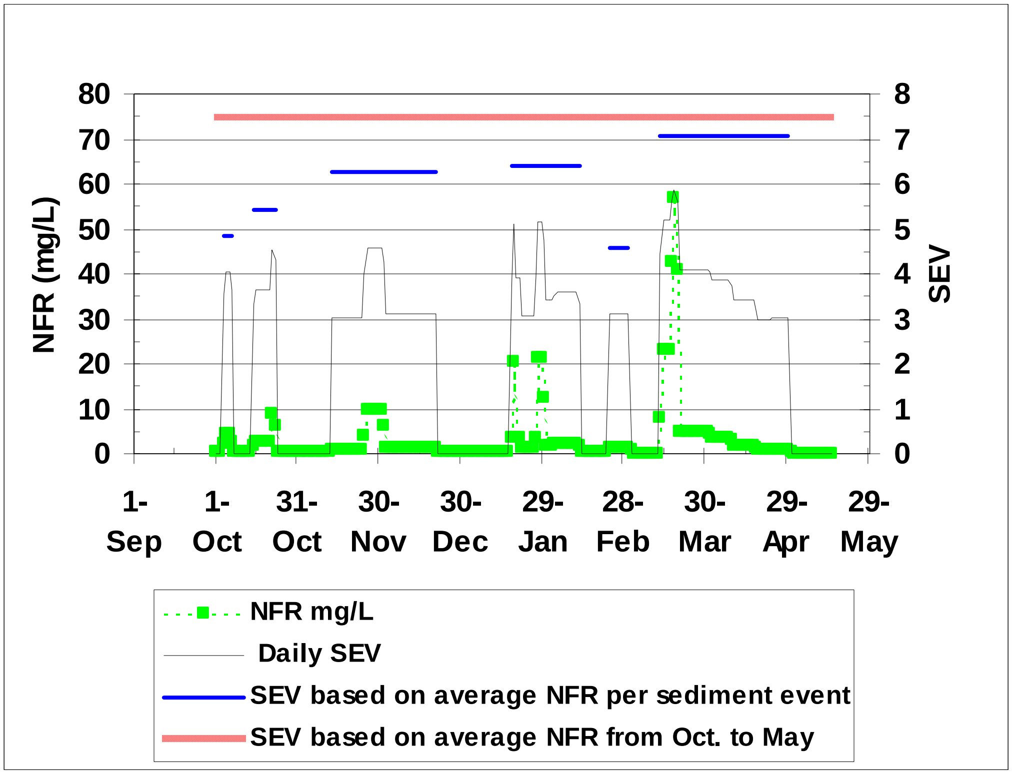


Figure 15. NFRs and SEVs for the 1996-1997 spawning, incubation, and early rearing season.

Furthermore Mundie and Crabtree (1997) found that buildup of sediment reduced the rearing capacity of the channel for coho. It prevents fry from entering the porous gravel for cover and also reduces the production of aquatic insects. Emerging insects are the main food source for coho fry in the channel.

3.7. GRAVEL CLEANING.

Spawning gravel at the LQ facility is cleaned every year in late June. Cleaning effluent is intercepted and pumped to a large settling field for treatment (McLean et al. 1996). The technical difficulties and costs of carrying out this operation are a function of the amount of fine sediment entering the channel over the previous winter. Reducing suspended sediment in the watershed not only increases the productivity of the channel but also reduce cleaning costs.

4.0. ACKNOWLEDGMENTS

Impetus for this program came out of discussions with John Hargrove, Grant Ladouceur and Bill Pollard (Weyerhaeuser Ltd) in 1986. John’s experience with the Little Qualicum watershed, his ongoing support for this program and his persistence in tracking down sediment sources have been critical to the success of this work. The authors also thank Harold Mundie, W.K. Fletcher, Charles Newcombe, John Mason and John Lamb for their interest in this problem – many useful suggestions for monitoring and controlling sediment have been proposed. We also acknowledge Joan Bennett for painstaking analysis of water samples, Jennifer Watt for work on precision and accuracy as it pertains to NFR, Quinsam Hatchery for providing Laboratory facilities, staff at Little Qualicum facility and Brian Pearce for ongoing financial support.

5.0. REFERENCES

Fletcher, W. K., W. E. McLean and T. Sweeten. 1995. An instrument to monitor infiltration of fine sediment into stable gravel stream beds. Aquacultural Engineering. Vol. 14. No.4 pp. 289-296.

Gammell, A.C. 1988. Particle size analysis: Little Qualicum Spawning Channel. MacMillian Bloedel Ltd., Woodlands Serivices Division. Draft Report to Dept. of Fisheries and Oceans. 16p.

Lamb J. 1986. Cameron River – Erosion Stream Survey and Sediment Mitigation Proposal. Unpublished Report, Dept. of Fisheries and Oceans, South Coast Division, Nanaimo B.C. 5p.

Mason, J. C., T. Sweeten and W. E. McLean. 1992. Modifications to improve the standpipe method of determining the permeability of spawning gravels for stream salmonids. Can. Tech. Rep. Fish. Aquat. Sci. 1877: 11p.

McLean, W. E., T. Sweeten, J. Hargrove and G. Ladouceur. 1996. Treatment of effluent generated during gravel cleaning operations at a spawning channel. p 77-82. In Proceedings of the 47th Annual Northwest Fish Culture Conference, Victoria B.C.

Mundie, J. H. and D. G. Crabtree. 1997. Effects on sediment and biota of cleaning a salmonid spawning channel. Fisheries Management and Ecology. **4**, 111-126.

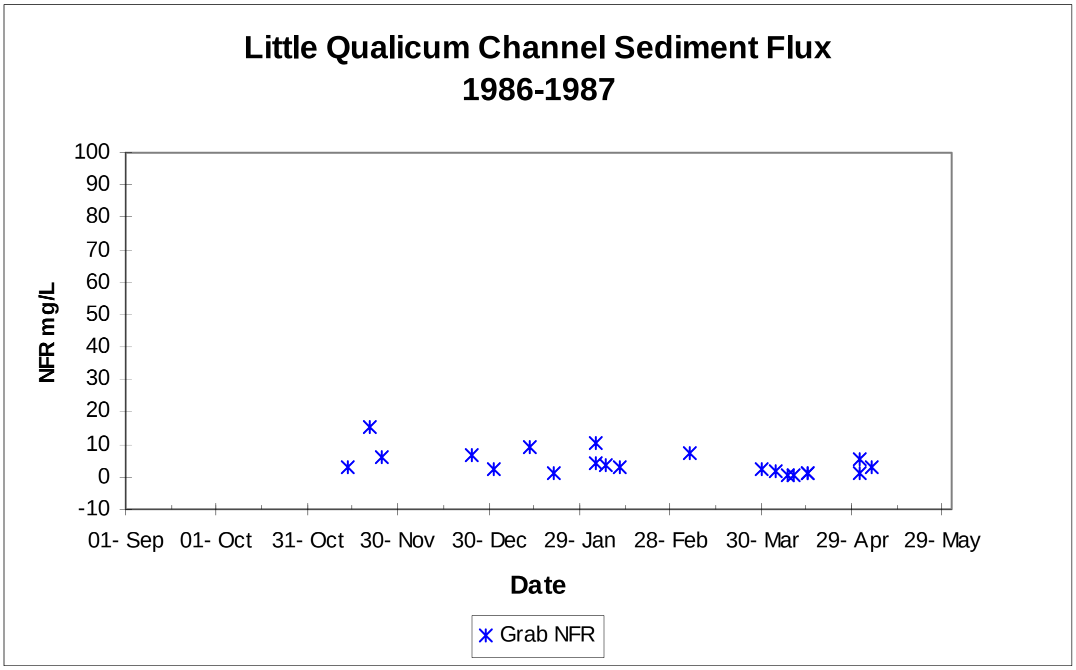
Newcombe, C. P. and J. O. T. Jensen. 1996. Channel suspended Sediment and fisheries: a systhesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management. 16:693-727.

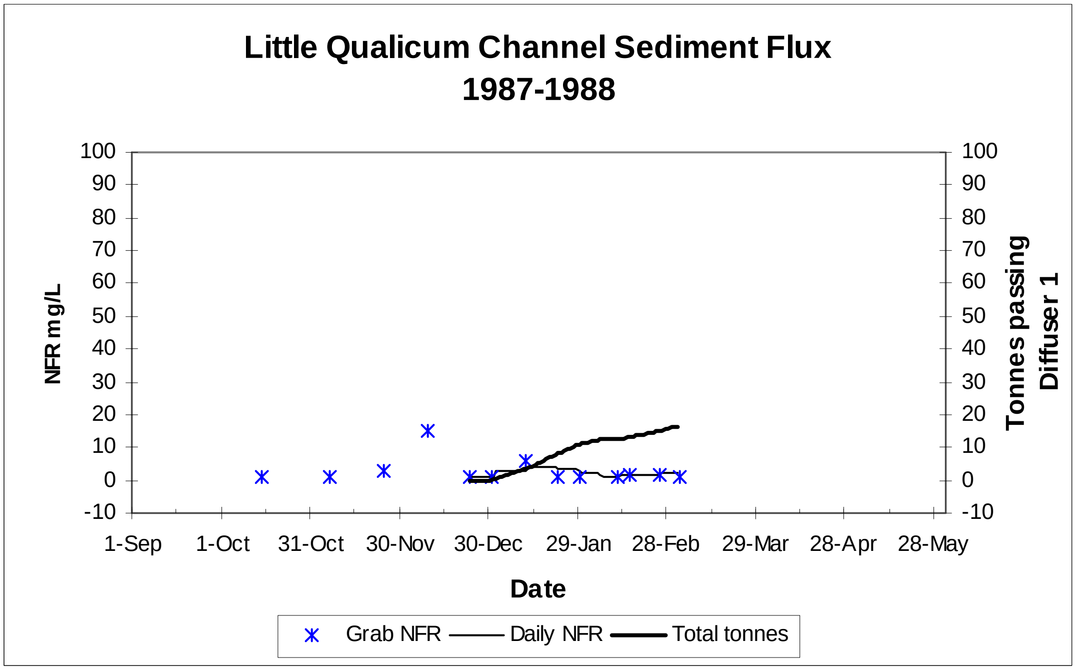
Rimmer D. W, 1993. File Note Re: Walsh’s Farm drainage to Kinkade Creek (April 22, 1993, no. 39000-01). Fisheries Section, Ministry of Environment Lands and Parks. Nanaimo B.C. 3p.

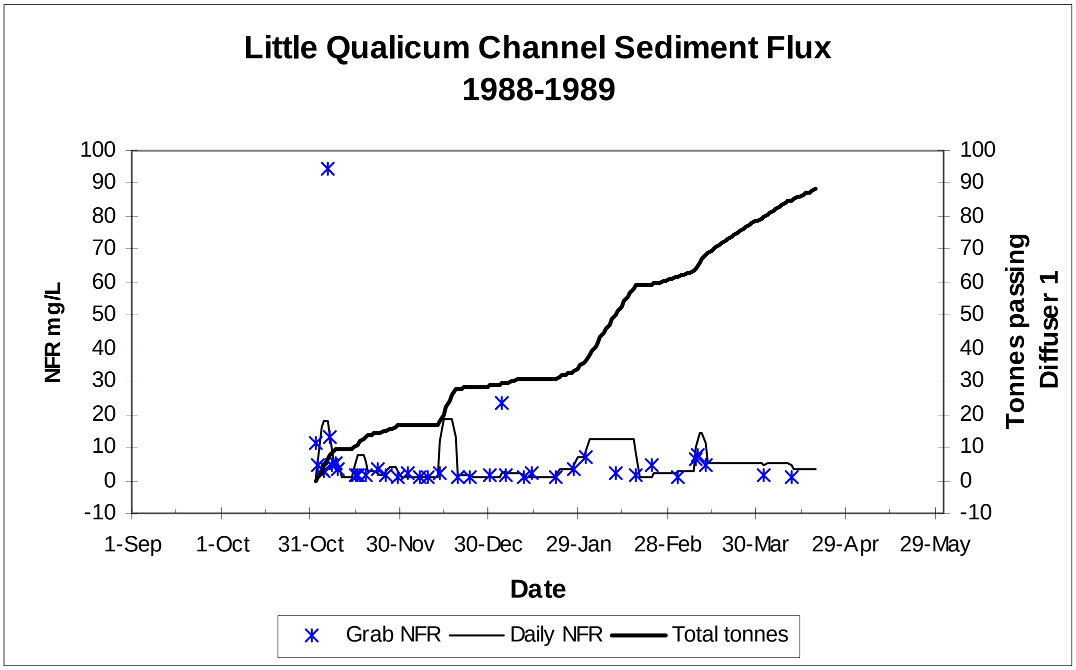
Strickland J.D.H. and T. R. Parsons. 1968. A Practical Handbook of Seawater Analysis. Bulletin 167. Fisheries Research Board of Canada, Ottawa ,311p.

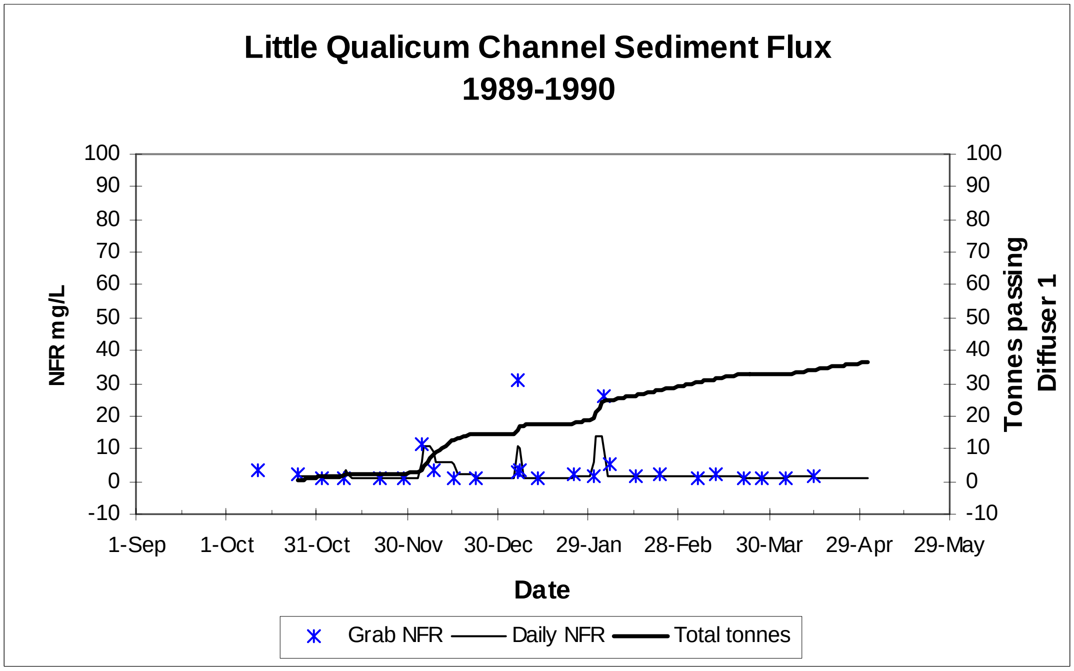
6.0. APPENDIX 1

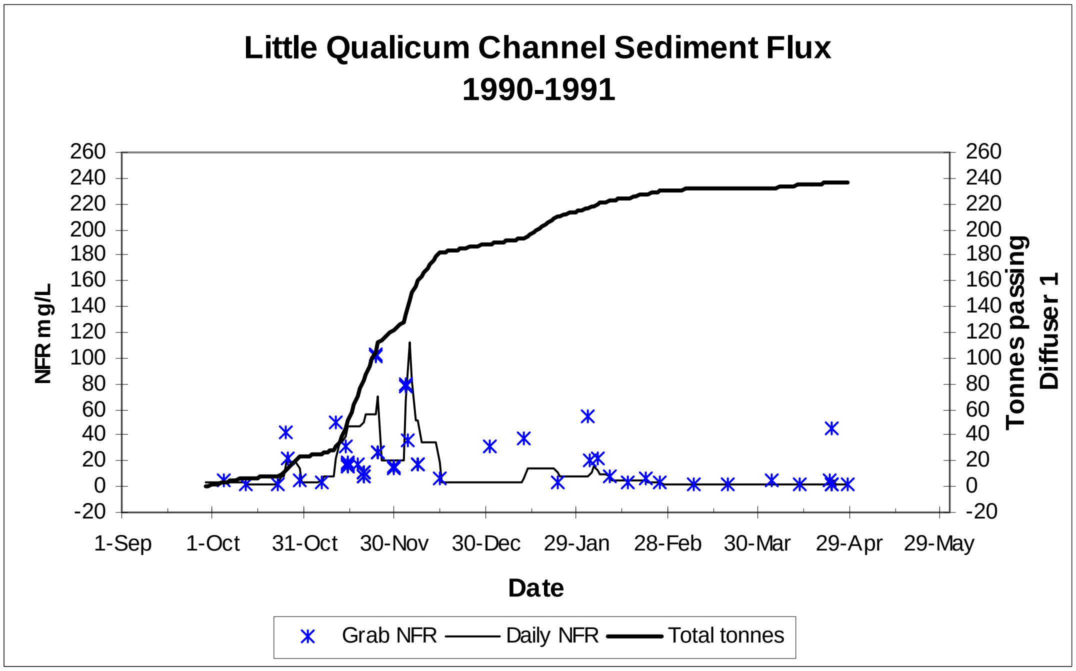
The following graphs show suspended sediment concentrations (NFR, mg/L) of grab and daily composite samples at diffuser 1 from 1986 to 2001. The cumulative sediment (Tonnes) entering the channel (i.e. passing Diffuser 1) is also displayed from 1987 on.

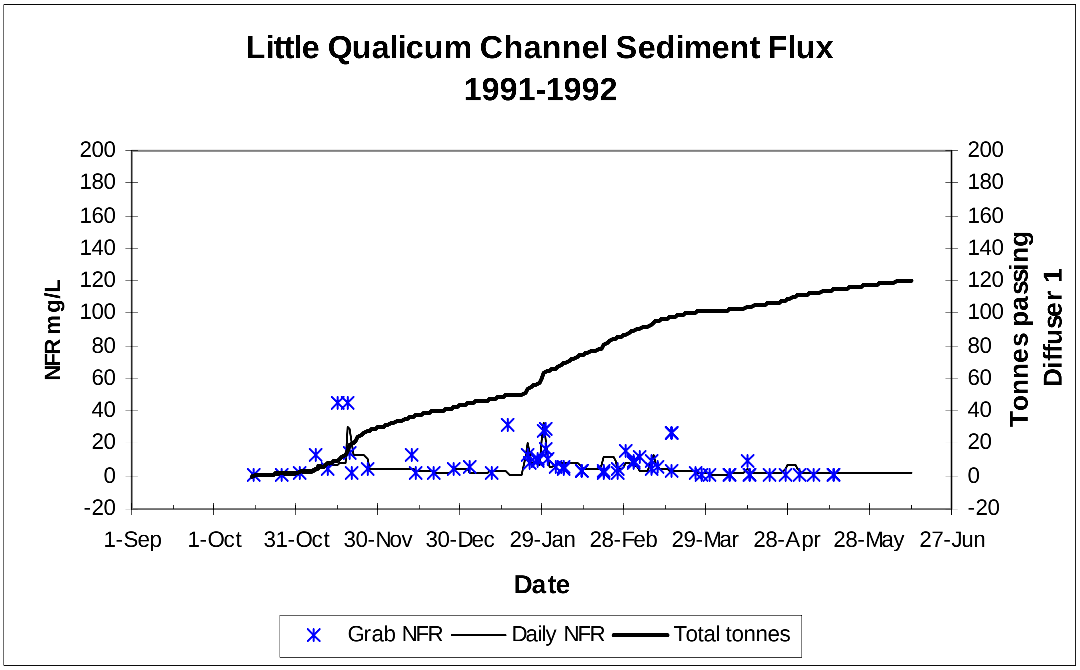


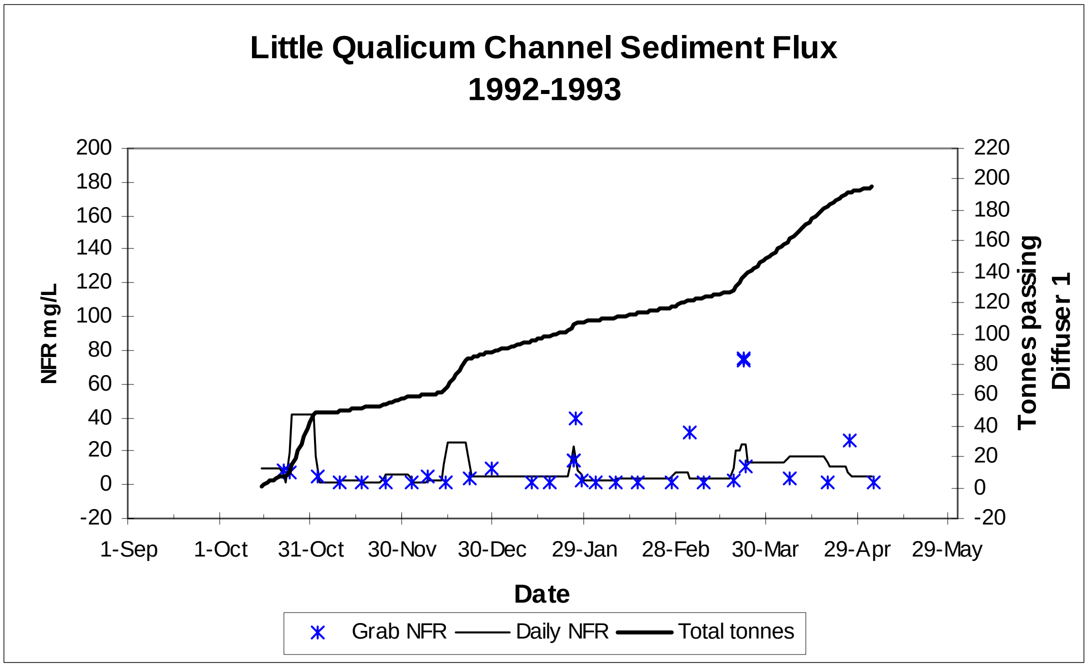


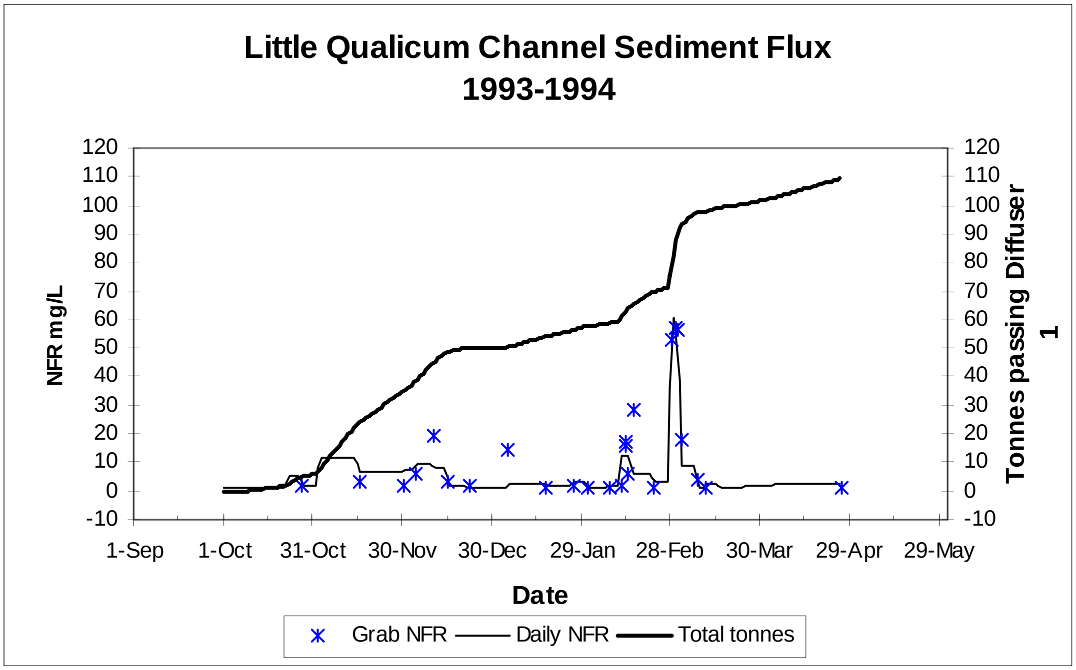

Little Qualicum Channel Sediment Flux
1988-1989
NFR mg/L
Tonnes passing Diffuser 1
100
90
80
70
60
50
40
30
20
10
0
-10
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
Date
Grab NFR
Daily NFR
Total tonnes

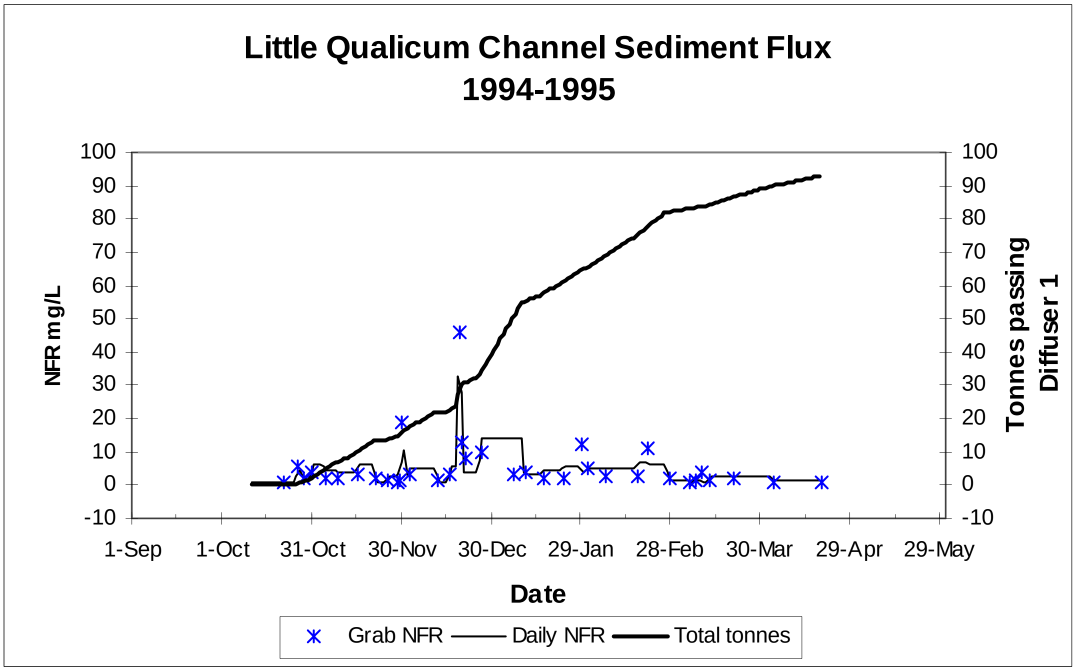

Little Qualicum Channel Sediment Flux
1989-1990
NFR mg/L
Tonnes passing Diffuser 1
100
90
80
70
60
50
40
30
20
10
0
-10
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
Date
Grab NFR
Daily NFR
Total tonnes

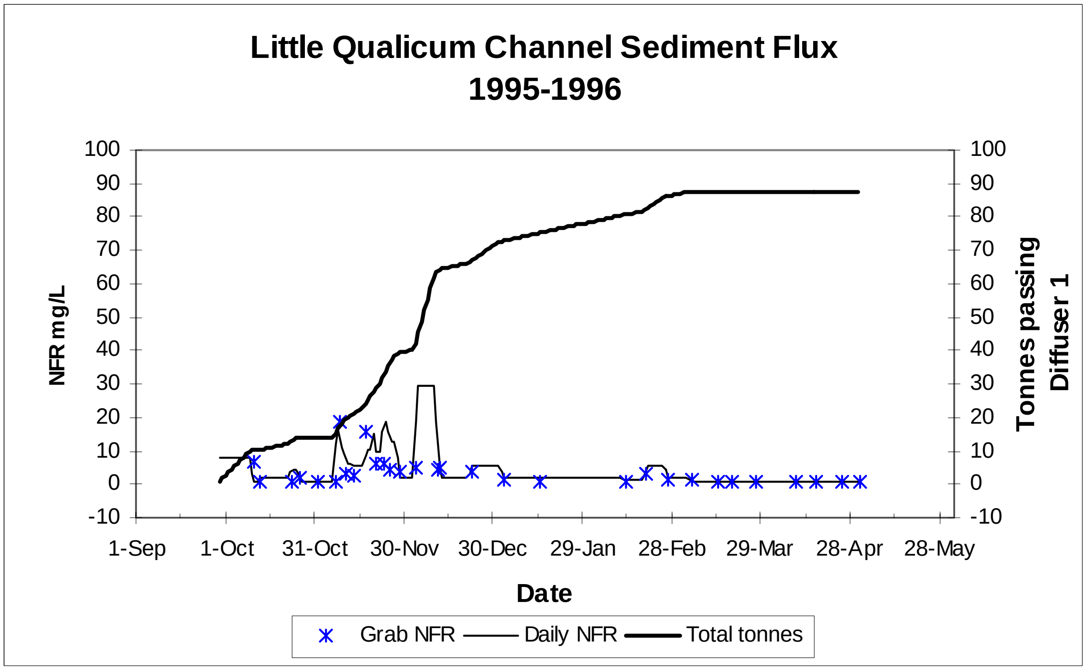

Little Qualicum Channel Sediment Flux
1990-1991
NFR mg/L
Tonnes passing Diffuser 1
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
Date
Grab NFR
Daily NFR
Total tonnes

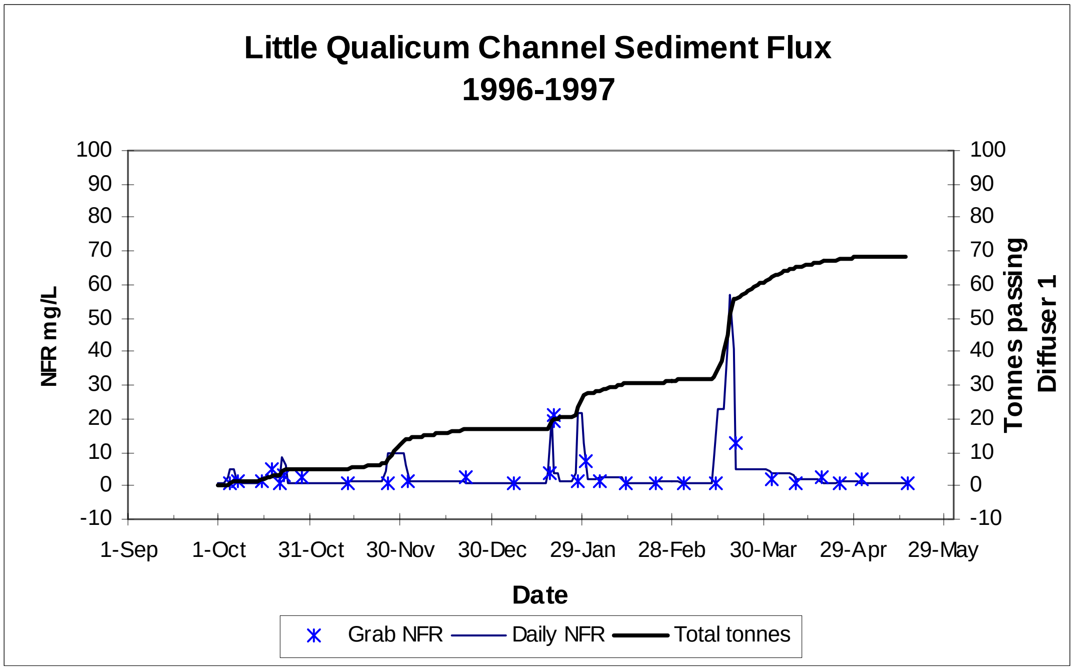

Little Qualicum Channel Sediment Flux
1991-1992
NFR mg/L
Tonnes passing Diffuser 1
200
180
160
140
120
100
80
60
40
20
0
-20
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
27-Jun
Date
Grab NFR
Daily NFR
Total tonnes

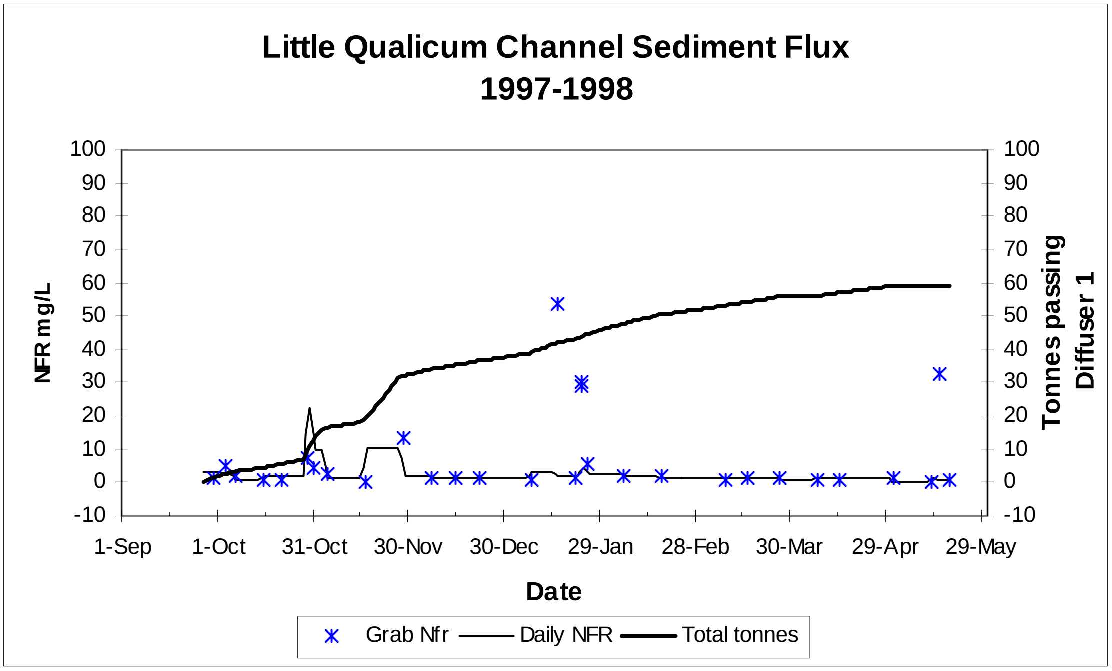

Little Qualicum Channel Sediment Flux
1992-1993
NFR mg/L
200
180
160
140
120
100
80
60
40
20
0
-20
Tonnes passing Diffuser 1
220
200
180
160
140
120
100
80
60
40
20
0
-20
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
Date
Grab NFR
Daily NFR
Total tonnes

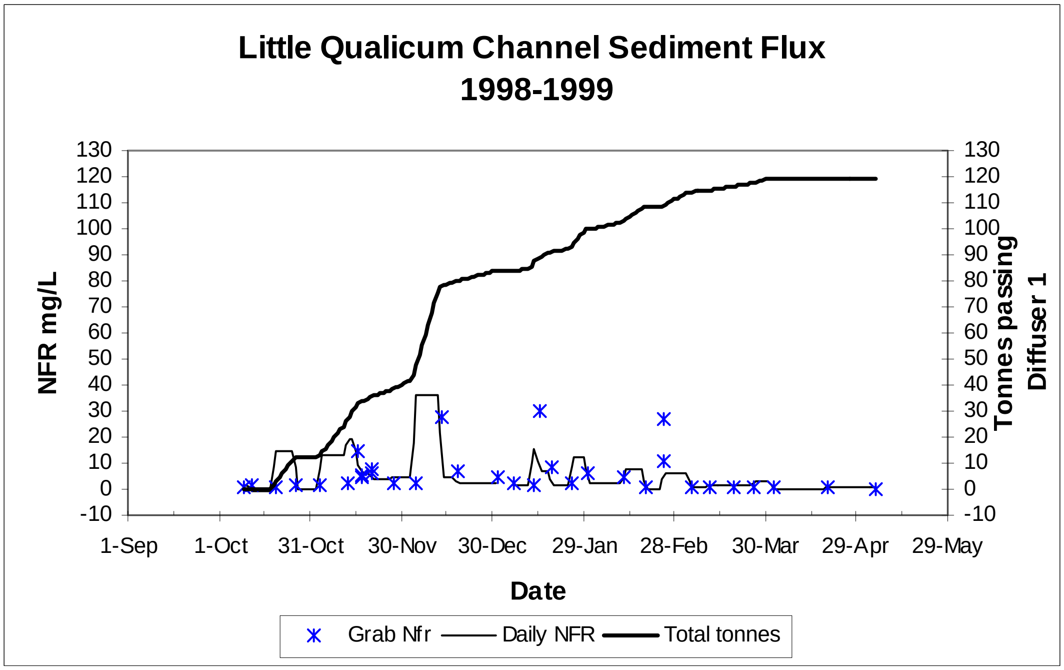

Little Qualicum Channel Sediment Flux
1993-1994
NFR mg/L
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
Tonnes passing Diffuser 1
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
Date
Grab NFR
Daily NFR
Total tonnes


Little Qualicum Channel Sediment Flux
1994-1995
NFR mg/L
100
90
80
70
60
50
40
30
20
10
0
-10
Tonnes passing Diffuser 1
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
Date
Grab NFR
Daily NFR
Total tonnes

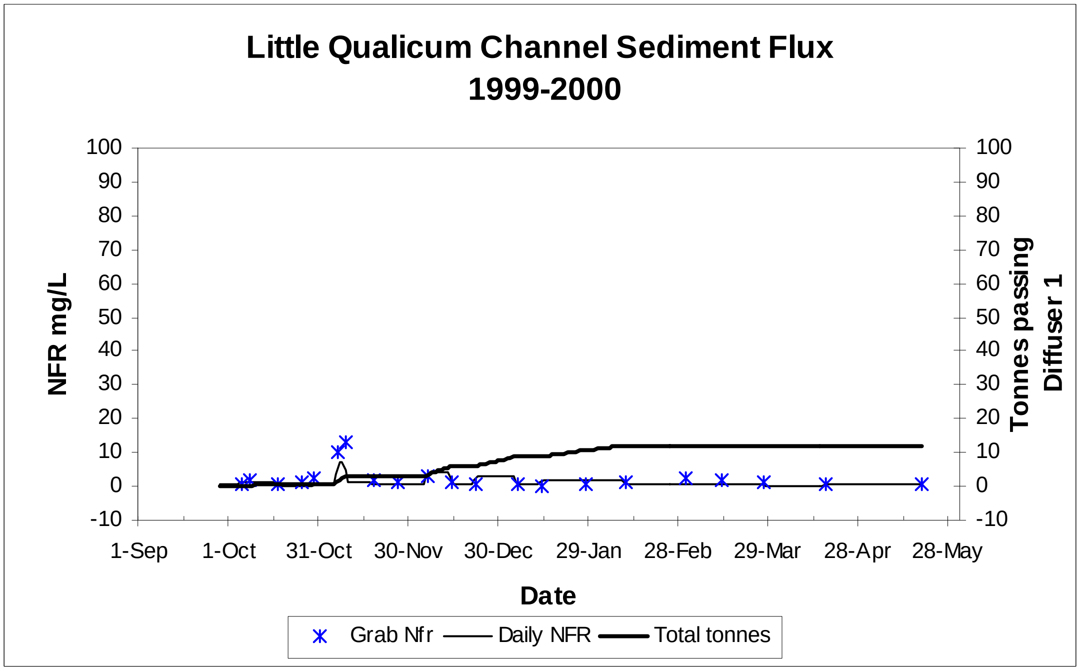

Little Qualicum Channel Sediment Flux
1995-1996
NFR mg/L
100
90
80
70
60
50
40
30
20
10
0
-10
Tonnes passing Diffuser 1
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
29-Mar
28-Apr
28-May
Date
Grab NFR
Daily NFR
Total tonnes


Little Qualicum Channel Sediment Flux
1996-1997
NFR mg/L
Tonnes passing Diffuser 1
100
90
80
70
60
50
40
30
20
10
0
-10
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
Date
Grab NFR
Daily NFR
Total tonnes

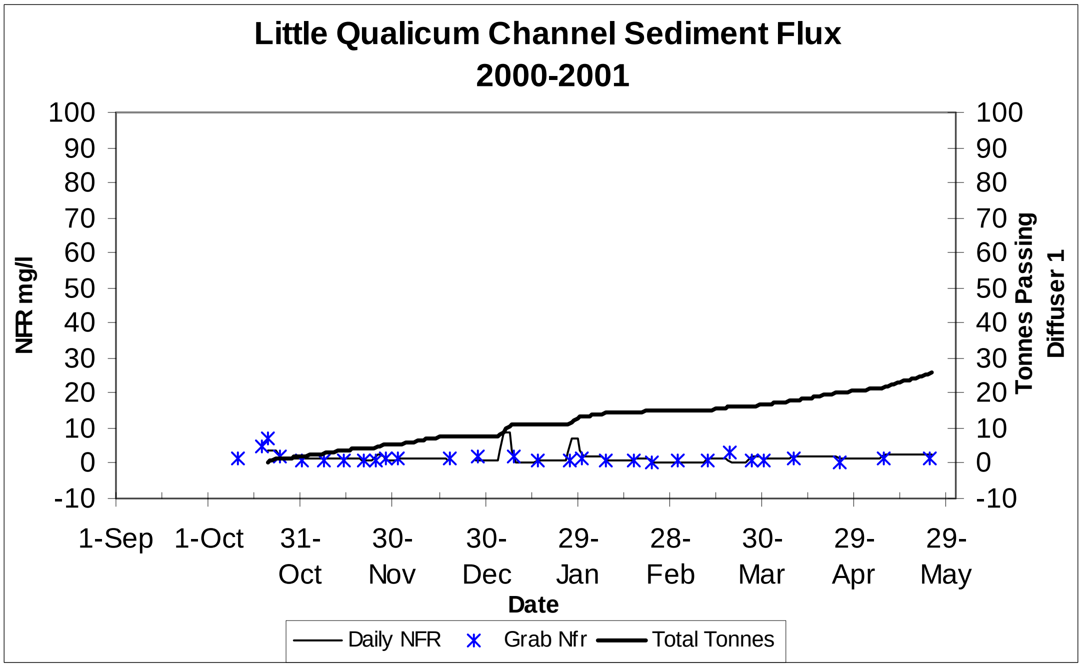

Little Qualicum Channel Sediment Flux
1997-1998
NFR mg/L
Tonnes passing Diffuser 1
100
90
80
70
60
50
40
30
20
10
0
-10
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
Date
Grab Nfr
Daily NFR
Total tonnes



Little Qualicum Channel Sediment Flux
1998-1999



Little Qualicum Channel Sediment Flux
1999-2000


Little Qualicum Channel Sediment Flux
2000-2001
NFR mg/l
Tonnes Passing Diffuser 1
100
90
80
70
60
50
40
30
20
10
0
-10
1-Sep
1-Oct
31-Oct
30-Nov
30-Dec
29-Jan
28-Feb
30-Mar
29-Apr
29-May
Date
Daily NFR
Grab Nfr
Total Tonnes