

**HYDROLOGICAL AND RIPARIAN ASSESSMENT
NAHATLATCH RIVER,
BRITISH COLUMBIA**

Prepared for:

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Fraser River Action Plan
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1. INTRODUCTION

The Nahatlatch River Watershed is in the Fraser Timber Supply Area and contains significant quantities of mature timber, with most of the operable timber concentrated along the valley of the main river and its tributaries (Appendix B). Approximately 61 km of the Nahatlatch mainstem is Class A fish habitat which supports average escapements of 7,600 sockeye, 6,500 pink, 1,000 coho and 100 chinook salmon. Bull trout, steelhead, Dolly Varden char, Rocky Mountain Whitefish and rainbow trout are also found in the main river and its tributaries. There is concern that forest harvesting along the valley bottom, unless properly managed, may damage the main river and, ultimately, the fisheries resource.

The Department of Fisheries and Oceans is preparing a Riparian Management Plan for the Nahatlatch River watershed, whose objective is to provide specific management guidelines that ensure the protection of fish habitat in sensitive reaches of the river. The purpose of our study is to provide the hydrological, channel stability and riparian habitat analysis needed to delineate effective riparian management areas. Our specific objectives are to:

- Provide an overview of the Nahatlatch River watershed: its logging history, hydrologic regime and hydrologic stability;
- Use air photographs to assess the stability of the main channel of the Nahatlatch River. Identify unstable reaches, particularly examining the reach between Nahatlatch Lake and the Mehatl River confluence which provides prime spawning and rearing habitat for sockeye, chinook and coho salmon, and the reach upstream of the Mehatl River whose floodplain has been recently logged.
- Use air photographs to define the floodplain of the Nahatlatch River between Nahatlatch Lake and Mehatl River and identify off-channel rearing habitat on the floodplain. Verify the floodplain limits during a field visit;
- Delineate riparian habitat management zones from Nahatlatch Lake to Mehatl River and recommend guidelines for harvesting and re-forestation within this zone.

- Recommend guidelines for harvesting and reforestation, and also erosion control works if needed, in the logged reach of the Nahatlatch River upstream of Mehatl River.

1.1 Methods and Organization

The objectives were mostly addressed by analysing existing information. Watershed characteristics were evaluated from 1:50,000 NTS maps, streamflow from Water Survey of Canada records and climate from Atmospheric Environment Service records. Logging history was derived from previous reports and air photograph analysis, as well as from data on openings contained in the Ministry of Forests silvicultural files.

Aerial photographs and maps were the main source of information on channel characteristics and channel stability, though a video, filmed from helicopter by B.C. Environment personnel in October 1993, provided details on some reaches. A profile of the main channel was extracted from 1:50,000 NTS Maps and an overview of the entire channel was prepared from air photographs flown in 1993 (Appendix A).

The reaches from Nahatlatch Lake to the Mehatl Creek confluence and upstream of the Mehatl River were studied in more detail. Historic air photographs (Appendix A), covering a 30-year period, were used to assess channel stability and the most recent air-photographs were used to identify the extent of the floodplain and off-channel rearing habitat in the reach upstream of Nahatlatch Lake.

The river was visited in late August, 1995. Floodplain limits were verified during this visit and the main channel downstream of Mehatl River was inspected by boat. The reach upstream of Mehatl River was inspected from the logging road network and photographs were taken of the channel during a low-level overflight.

2. THE NAHATLATCH RIVER WATERSHED

2.1 Physiography and Geology

The Nahatlatch River is a glacially fed, fourth order stream with a drainage area of approximately 1,250 km². The headwaters are located on the eastern edge of the Pacific Ranges of the Coast Mountains at elevations above 1,800 m (Figure 1). Most of the watershed is underlain by granodiorite and quartz diorite plutonic rocks though the Nahatlatch River crosses a gneiss outcrop upstream of Mehatl Creek (Reach 5) and flows through metamorphic rocks downstream of Frances Lake. About 1% of the watershed is covered by active glaciers, mostly in the upper Nahatlatch and Mehatl rivers and Tincup Creek (Table 1). The active glaciers cover too small an area to influence the hydrology of the main river, or its larger tributaries, but they do contribute fine and coarse sediment to the stream system.

The main channel is about 79 km long and flows to the south-east in the upper watershed before turning north-east and east in the lower watershed. It flows through a series of lakes at an elevation of just over 300 m before draining into the Fraser River at an elevation of 110 m, near Boston Bar (Figure 2). Table 1 summarizes the drainage area, area of glaciers, channel slope and elevation range of the Nahatlatch watershed and its 11 main tributaries.

2.2 Climate

The Nahatlatch Watershed includes five biogeoclimatic regions, ranging from Alpine Tundra (AT), Englemann Spruce-Subalpine Fir (ESSF), and Mountain Hemlock (MH) at higher elevations, through Coastal Western Hemlock (CWH) at moderate elevations in the upper Nahatlatch and Mehatl River watersheds, into the Interior Douglas Fir (IDF) biogeoclimatic zone at low elevations near the Fraser River. Table 1 summarizes the area of each zone within the overall watershed and each of the main tributaries. The Alpine Tundra, Englemann Spruce-Subalpine Fir and Mountain Hemlock zones are thought to accumulate heavy snowpacks which provide the main contribution to the snowmelt freshet; the Coastal Western Hemlock zone accumulates a moderate snowpack which may melt and re-establish during the winter contributing to rain on snow floods, and the Interior Douglas Fir zone accumulates a minor, early-melting snowpack.

The Atmospheric Environment Service (AES) does not operate a climate station in the Nahatlatch watershed; consequently its climate must be described from nearby stations (Table 2), lying in the same ecosection or ecoregion (Demarchi 1994). The upper Nahatlatch basin is part of the Eastern Pacific Ranges Ecosection (Pacific Ranges Ecoregion; Demarchi 1994) while the lower basin lies in the Leeward Pacific Ranges Ecosection (Interior Transition Ranges Ecoregion).

Upper Nahatlatch Watershed (Eastern Pacific Ranges): Mean annual temperatures range from 9°C in the valleys to less than 2°C at moderate elevations. January is by far the coldest month with mean temperatures of -3°C and extreme minimum temperatures of around -25°C. July is the warmest month with mean temperatures of 18 to 20°C and extreme daily temperatures of around 40°C in the valley bottoms.

Annual normal precipitation ranges from 1,200 mm to at least 2,000 mm. Precipitation is greatest from October through March, and least from May through September. Snow forms roughly 30% of the total precipitation in the valley bottoms but increases to over 90% at higher elevations, with the greatest monthly snowfall totals in December and January.

The Nahatlatch River snow course (1D10; 1,520 m) has a maximum normal accumulation of 1,578 mm water equivalent on May 1. In some years snowpack continues to accumulate until June 1, but on average some melt occurs in May with the majority of the melt in June.

Lower Nahatlatch Watershed (Pacific Leeward Ranges): The Pemberton climate stations, which lie to the west of the Pacific Leeward Ranges, seem most representative of this ecosection (Table 2). Mean annual temperature at these two valley-bottom stations is similar to that at Lillooet.

Annual normal precipitation is thought to vary from around 500 mm near the Fraser River to as much as 1,100 mm further inland, with about 25% of the total precipitation falling as snow along valley bottoms. The portion falling as snow increases with elevation, as does total precipitation.

Much of the precipitation falls in the winter, partly as rain at lower elevations, and mostly as snow at moderate to high elevations. Less than 20% of the total precipitation falls from May through September, which have the highest evapotranspiration rates.

2.3 Hydrology

Table 3 describes the Water Survey of Canada gauging stations that have been established in the Nahatlatch River Watershed. Only the main river has been gauged and the only operating station is "*Nahatlatch River below Tachewana Creek, 08MF065*" which has a 21-year record of daily flows. The two older stations -- "*Nahatlatch River at the outlet of Frances Lake, 08MF007*" and "*Nahatlatch River near Keefers, 08MF008*" -- provided intermittent measurements between 1912 and 1921.

The *Nahatlatch River below Tachewana Creek* gauge records flows from the upper 715 km² of the Nahatlatch River watershed, which includes about 57% of the total watershed area. The Mehatl River is the major tributary to the Nahatlatch River upstream of the gauge and provides a little more than one-third of the drainage area upstream of the WSC gauge (Table 1).

Mean annual runoff at the Water Survey of Canada gauge is about 1,500 mm (1974 to 1989), where this is the mean annual flow expressed as an equivalent depth of water over the basin area. The lower part of the watershed (downstream of the Water Survey of Canada gauge) provides much less flow than that upstream of the gauge. A regression analysis using records from the two older gauges suggests that the lower watershed only adds about another 10 to 20% to the flow recorded at the *Nahatlatch River below Tachewana Creek* gauge, resulting in an overall mean annual runoff from the entire basin of about 1,000 mm (nhc and Mr. R. Hamilton 1994).

Figure 3 is the daily runoff distribution for the *Nahatlatch River below Tachewana Creek* gauge, showing the average, minimum, and maximum runoff for each day of the year, based on the flow record to 1992. Minimum flows typically occur in January and February, under ice cover, and flows remain consistently low throughout the winter, though small floods sometimes occur. Average daily runoff reaches its peak during snowmelt, in June, and then declines until October, when flows rise again as a result of fall rainstorms.

The maximum annual daily flow either occurs between the end of April and early July, or between October and December (Figure 3), though moderate-sized floods may also occur in late August and September. This pattern is typical of the Eastern Pacific Ranges where in most years, the annual flood results from snowmelt in the spring but the largest floods result from fall rainstorms and rain

on snow events that occur when Pacific storms spill over the Coast Mountains. Typically, the largest floods result from a period of cold weather and snow accumulation, followed by a rapid rise in freezing levels combined with intense precipitation.

Table 4 summarizes the annual maximum instantaneous and daily flows recorded at the "*Nahatlatch River below Tachewana Creek*" gauge. The greatest flood occurred following the Boxing Day storm of December 1980 and the second largest flood was in January 1984. The Boxing Day storm was particularly destructive as it washed out several bridges along the main river and its tributaries.

The instantaneous and maximum daily peak flows quoted in Table 4 were analyzed to estimate floods at various return periods. The floods at various return values quoted in Table 5 are an average of the values for that return period predicted by several frequency distributions. Note that snowmelt and rainfall peaks are not analyzed separately and maximum values for each year are selected from a January 1 to December 31 calendar.

2.4 Logging History

McCombs and Chittenden (1990) and Prism Consulting (1993) describe the early logging history in the Nahatlatch River basin. The first harvesting was near the mouth of the river in the 1880's for construction of the Canadian Pacific Railway trestle crossing. Later, in 1923, a tie mill was built at Keefers, which operated until 1930. Several companies also cut poles along the main river and hauled these out along a road constructed to Nahatlatch Lake. A shingle mill operated near Frances Lake in the 1930's and a tie mill operated near the same area in the 1940's and 1950's.

McCorkle Brothers Logging built roads and bridges through the watershed in the early 1950's and logged as far upstream as the Mehatl River confluence (Figure 5: 1961 air photographs). Their operation was mostly "cat-logging": cutting fir, hemlock and cedar larger than 18 inches diameter and floating it down the Fraser River. They logged on the north side of the floodplain of the Nahatlatch River, from Nahatlatch Lake to Mehatl River, and often removed trees to the river bank along this reach (Figure 5). Apparently, they continued logging in the watershed until a major forest fire in 1961 forced them out (McCombs and Chittenden 1990).

Several companies re-entered the watershed, starting in 1969, including Hampton Lumber Mills, Scott Paper Ltd, Cattermole Timber and B.C. Forest Products Ltd. Cattermole Timber is now the only remaining operator. Air photographs from 1973 show recent logging on the south side of the main river between Nahatlatch Lake and Mehatl River, particularly on alluvial fans of the larger tributaries. Apparently, Scott Paper Ltd logged cottonwood from this areas through the 1970's and into the 1980's.

Table 6 summarizes harvested areas in the Nahatlatch Watershed and in its tributary basins. Logging history was extracted from History Record and QMF-100 Reports provided by the Ministry of Forests and proposed logging from Five-Year Plans provided by Ministry of Forests District Office. The Ministry of Forest records show that most cut blocks have been logged since 1983 and do not include any record of the logging from the 1950's and 1960's.

Total harvest is less than 2% of the land area in the overall watershed and in most of the tributaries to the Nahatlatch River, except Log Creek, where it is about 6% of the land base. Much of the proposed cut over the five-year plan to 1998 is in the upper Nahatlatch watershed and Kookipi Creek (Table 6).

2.5 Forest Harvesting and Hydrology

The British Columbia Forest Practices Code and the Watershed Assessment Procedure propose to manage increases in flood peaks that result from logging by controlling the rate of harvest. Openings are distributed over a range of elevations and aspects and the equivalent clearcut area (ECA) within the watershed (or within the significant zone for runoff generation) is maintained below some maximum value, which may range from 20 to 35%, depending on basin type and the history of past disturbance. For equivalent clearcut areas below the typical range of maximum values, it is assumed that logging has had no significant impact on hydrologic regime. (The equivalent clearcut area is calculated from the product of the total cut area and a regeneration recovery factor.)

Only about 21% of the Nahatlatch River watershed has operable timber, which is mostly found at lower elevations along the major valleys (Appendix B). Snowmelt floods in the Nahatlatch River watershed are mostly generated from the Mountain Hemlock, Englemann Spruce-Subalpine Fir and

Alpine Tundra biogeoclimatic zones which are at high elevations where harvest has not occurred and is not expected to occur in the future. Consequently, it is thought that the existing harvest has not increased snowmelt peaks and that proposed harvest will not increase snowmelt flood peaks in the Nahatlatch Watershed or its major tributaries, such as Mehatl River, Kookipi and Log Creeks.

Forest harvesting may also increase rain on snow flood peaks. The main melt contribution is generated in the transient snow zone (often extending from a few hundred to 800 m or so elevation) and roughly corresponds with the Coastal Western Hemlock biogeoclimatic zone and part of the Interior Douglas Fir biogeoclimatic zone. Existing and proposed forest harvesting in the Nahatlatch River watershed is concentrated in the CWH zone, and in the IDF zone in the eastern part of the watershed, and consequently have the potential to increase rain on snow flood peaks, if not properly managed. (Note that a number of variables -- such as antecedent snow conditions, storm characteristics and climate -- affect potential increases in rain on snow flood peaks and few studies have successfully demonstrated increased peaks following forest harvesting.)

Areas of CWH and IDF biogeoclimatic zone in the overall watershed and in three major tributaries, as well as existing and proposed harvest, are summarized in the following table:

Watershed	CWH Zone (km ²)	IDF Zone (km ²)	Harvested Area to 1992 (km ²)	Proposed Harvest to 1998 (km ²)
Nahatlatch River ¹	328	90	24.0	16.4
Mehatl River	116	0	5.1	0
Kookipi Creek ¹	39.4	6.9	2.6	3.8
Log Creek ¹	6.7	8.8	5.0	0

1. Harvesting occurs in the CWH and IDF biogeoclimatic zone.

Total harvest, to 1992, is estimated to amount to about 5% of the area of the CWH biogeoclimatic zone in the Nahatlatch watershed and in the Mehatl River watershed which is thought to be too low to have significantly increased rain on snow flood peaks. Logging proposed to the end of the current five-year plan will bring the total cut to about 10% of the combined CWH and IDF zones in the overall watershed. This level of cut should also not produce significant increases in rain on snow floods but further review should be undertaken of any harvesting proposed after 1998.

In Kookipi Creek, the existing harvest level is about 5% of the combined CWH and IDF zones and the proposed harvest brings the total to about 14% of the combined zones. Small increases in rain on snow floods may occur by the end of the current five-year plan (to 1998) and further analysis of the distribution of cut blocks and of hydrologic recovery within this watershed is recommended. A detailed assessment is needed of any harvest proposed after 1998.

In Log Creek, the existing harvest is more than 30% of the combined CWH and IDF biogeoclimatic zones. In our opinion, this level of harvest has the potential to significantly increase rain on snow floods and no further harvesting should be undertaken without a detailed hydrologic assessment and an evaluation of hydrologic recovery.

The hydrologic regime of the mainstem Nahatlatch River, upstream of Nahatlatch Lake, may be affected by forest harvesting in the Mehatl and the upper Nahatlatch (upstream of the Mehatl) Rivers. However, harvesting in the upper watershed has not progressed to the point where increased flood peaks that may alter the river channel are expected. Consequently, channel instability to date, that may be a consequence of logging, has occurred as a result of increased coarse sediment supply from logging road or clearcut failures or as a result of bank instability induced by floodplain harvesting, rather than by changes to the hydrologic regime.

The hydrologic regime of the Nahatlatch River downstream of Nahatlatch, Hannah, and Frances Lakes is buffered by storage in the lakes and is not likely to be much affected by forest harvesting in the upper watershed (Table 1). However, Log and Kookipi Creeks discharge to the main river immediately downstream of Frances Lake and have significant levels of harvest. Forest harvesting in these two watersheds may have increased their flood discharges, though this is only expected to have produced a minor increase in peak discharges in the mainstem river. This occurs because floods on the main river are primarily generated in the upper watershed and flood peaks from the upper watershed are not synchronous with those from Kookipi and Log Creeks. Similarly, proposed harvesting is not expected to increase flood peaks on the main river.

2.6 Long-Term Harvesting in the Mehatl River Watershed

The Mehatl River is the major tributary to the upper Nahatlatch River and provides a little more than

one-third of its drainage area (Table 1). The Mehatl and upper Nahatlatch Rivers have a somewhat different distribution of elevation and biogeoclimatic zones and, as a result, the Mehatl River will have a different hydrologic regime (see following table).

	<i>Mehatl Watershed</i>	<i>Upper Nahatlatch Watershed</i>
<i>Alpine Tundra</i>	49 km ² (17%)	133 km ² (18%)
<i>ESSF</i>	55 km ² (20%)	187 km ² (25%)
<i>Mountain Hemlock</i>	64 km ² (22%)	190 km ² (25%)
<i>Coastal Western Hemlock</i>	116 km ² (41%)	241 km ² (32%)
<i>Interior Douglas Fir</i>	0 km ² (0%)	2 km ² (0%)

Overall, the Mehatl River is thought to contribute a little less than one-third of the total flow to the gauge below Tachewana Creek, or to have a mean annual flow of about 13 m³/s. The Mehatl River has a smaller portion of its basin in the Alpine Tundra, Englemann Spruce - Subalpine Fire, and Mountain Hemlock biogeoclimatic zones and should have an earlier and somewhat smaller snowmelt peak than the overall upper watershed. As in the upper Nahatlatch River watershed, the annual flood will usually occur during snowmelt but the largest floods will occur as a result of rainstorms or rain on snow. The Mehatl River is expected to have proportionately larger rain on snow floods than the upper Nahatlatch River because of its relatively greater area in the Coastal Western Hemlock biogeoclimatic zone.

Maximum daily discharges for various return periods on the Mehatl River were estimated from the analysis of floods at the Nahatlatch River below Tachewana Creek gauge (Table 5). Creager C's calculated for the flood estimates at the gauge were used in conjunction with watershed area to calculate flood peaks on the Mehatl River. This procedure estimated a mean annual instantaneous flood of 165 m³/s; the 200-year instantaneous flood was estimated as 290 m³/s. As discussed above, the mean annual flood may be over-estimated and the 200-year flood may be underestimated.

Two scenarios are evaluated for long-term harvesting in the Mehatl River, as follows:

- a 2-pass system, where 100% of the operable timber is cut over 35 years; and

- a 3-pass system, where 100% of the operable timber is cut over 50 years.

Based on Appendix B the operable land base is estimated to be 44 km², of which 5.1 km² was harvested prior to 1992. The operable land base represents about 38% of the CWH biogeoclimatic zone, or about a similar portion of the land base that contributes to rain on snow floods.

Harvesting of the operable land base over the next 35 years would imply an average cut of about 1.1 km²/year, when adjusted for the existing harvested area. At the end of the 35-year cycle, hydrologic recovery on the blocks harvested prior to 1992, and the blocks harvested early in the cycle, would reduce the equivalent clearcut area to less than 44 km². Hydrologic recovery is assumed to start at a tree height of around 3 m (Watershed Restoration Program 1994). This height is roughly equivalent to "free-to-grow", which is usually achieved by about 15 years after harvesting in the Nahatlatch watershed. A review of height-age curves for Western Hemlock indicate that 3 m is achieved at ages of 11 to 18 years for the medium to poor sites which are thought to be found in the Mehatl River. In calculating ECA, we have assumed that recovery starts at 15 years after harvesting.

Hydrologic recovery is completed (to 90%) at a tree height of 10 m, which is reached by hemlock at ages of about 25 to 30 years on medium sites and much longer on poor sites. In calculating ECA, we have assumed that recovery is completed about 30 years after harvesting. Based on the above assumptions, we estimate that at the end of the cycle the ECA will be about 27 km², or about 23% of the CWH biogeoclimatic zone area. This is about the maximum that will be reached during the 35-year cycle, depending on assumptions about growth rates and recovery.

For a 50-year cycle, the average rate of cut is about 0.78 km²/year, when adjusted for the existing harvested area. At the end of the 50-year cycle hydrologic recovery will have been completed (up to 90%) on blocks cut prior to 1992, on blocks cut early in the cycle, and partially completed on blocks more than 15 years old. The maximum ECA, at the end of the cycle, will be about 20 km², depending on assumptions about growth rates and recovery. This represents about 17% of the CWH biogeoclimatic zone.

It is our opinion that the 35-year harvest cycle would produce an equivalent clearcut area that may

increase rain on snow flood peaks, though the increase may not be observed during a particular floods. While enhancement of the peaks may not occur, and may be reasonably small if it does, some concern should be raised because 1) the ECA will exceed 20% for a considerable period of time and 2) the rain on snow peaks are the major floods that modify the channel. Enhancement of these floods has the greatest potential for channel change in the Mehatl River and delivery of coarse and fine sediment to the downstream Reach 4 of the Nahatlatch River.

The 50-year harvest cycle produces a smaller maximum ECA and consequently has less potential to increase rain on snow peaks.

2.7 Harvesting and Sediment Regime in the Mehatl Watershed

The operable forest ranges from an elevation of about 400 m at the mouth of the watershed to about 1,600 m in the headwaters, with its upper limit often extending to about 500 to 700 m above the valley floor (J.M. Ryder and Associates Terrain Analysis Inc 1995). Valley side slopes are steep, underlain by intrusive rocks of the Scuzzy Pluton (primarily granodiorite), and covered with a thin layer of surficial material, primarily till and colluvium. Surficial deposits are coarse textured, consisting of about 50% large clasts, with a matrix of medium and coarse sand. Slopes in the Mehatl drainage are relatively stable. Avalanches, debris slides and flows are the most common forms of slope failure and they mostly occur in mid- and upper-slope gullies and along steep stream-cut banks near the valley bottom (J.M. Ryder and Associates Terrain Analysis Inc 1995).

Terrain mapping identified 91 unstable polygons (i.e. those with evidence of slope failure) and 299 potentially unstable polygons (slopes over 50% but with no sign of instability) which are mostly found along the mid and upper slopes of the operable forest. The unstable and potentially unstable polygons together include about 55% of the total number of polygons and appear to cover more than half of the operable forest (J.M. Ryder and Associates Terrain Analysis Inc 1995).

Harvesting within the unstable and potentially unstable polygons has the potential to increase the rate of slope failure and, consequently, the supply of sand and coarse sediment to the Mehatl River and to Reach 4 of the Nahatlatch River. Slope failures are expected to occur as a result of loss of root mat strength following harvesting and from instability and drainage diversion associated with

road construction. Failures resulting from reduced root mat strength in clearcut blocks cannot be easily controlled or managed by harvesting techniques. Fewer failures are expected in clearcut blocks than from road construction.

J.M. Ryder and Associates Terrain Analysis Inc (1995) suggest that main haul roads can be located on stable slopes along the valley bottom where they would contribute fine sediment to the main stream but would not increase the incidence of slope failure. Slope failures from roads crossing potentially unstable or unstable polygons (which are expected to be spur roads or branches entering tributary valleys) can be reduced by careful road location and review by a slope stability specialist. Seasonal de-activation of roads crossing potentially unstable and unstable polygons would also help reduce the incidence of slope failure from road construction. However, some failures are likely to occur as a result of road building on steep slopes and the increase of the natural sediment supply rate will depend mostly on the road design and construction practices utilized in the watershed.

3. THE NAHATLATCH RIVER

3.1 Division into Reaches

The Nahatlatch River was divided into 9 reaches of approximately uniform slope, based on the long profile shown on Figure 2 (see also Figure 1). Classification by slope is convenient, since many channel characteristics are directly related to it. The reaches are described on Table 7 following the system of Kellerhals, Church and Bray (1976: see Appendix D). Bed material sizes quoted in Table 7 are from Coast River Environmental Services Ltd (1993).

Our reaches are similar to those proposed by Coast River Environmental Services Ltd (1993) though our reach breaks are often in a slightly different place. Our break between Reach 1 and Reach 2 is about 2 km further upstream than that of Coast River Environmental Services Ltd. Our reach 4 starts at Nahatlatch Lake rather than about 2 km upstream of the lake. Our reaches also extend further upstream to include the main channel upstream of Tincup Creek.

3.2 Evaluation of Channel Stability

Reach 1 extends 10 km upstream from the confluence with the Fraser River, at an average slope of 1.3% (Table 7). The channel, which is entrenched in a narrow forested valley, has diagonal and side bars, a few small islands, an irregular pattern and only a small, fragmented floodplain. The bars and channel pattern are typical of a stable channel that transports only a small bed load. (The heads of the islands trap logs and floating debris.)

A review of air photographs from 1986, 1987, 1991 and 1993 show no perceptible changes along the reach, except at its confluence with the Fraser River, where the channel is naturally unstable on its fan deposits. Video footage also shows a stable channel, with only minor lateral activity, as indicated by a few areas of bank erosion and several side channels that are wetted at high flows. The channel also appears to be vertically stable; it is not presently aggrading or degrading.

Reach 2 extends from the end of Reach 1 to Frances Lake. It is similar to Reach 1, with an irregular pattern and confinement by its valley walls, but is about twice as steep (Table 7). The flow is very

irregular with several sets of rapids in the reach. Kookipi and Log Creeks enter this reach immediately below Frances Lake but neither creek has built a fan or delta into the main river and there is no sediment storage on bars along the reach, likely as a consequence of the steep gradient and high transport capacity for coarse material.

Video footage shows a large log jam at the head of the island and side channel downstream of Kookipi and Log Creeks. The logging road on the north side of the river has been protected by riprap to prevent bank erosion. The reach appears to be vertically stable.

Reach 3, includes Frances, Hannah, and Nahatlatch Lakes. The section of river connecting Frances and Hannah Lakes has moderately fast flow, while that connecting Hannah and Nahatlatch Lakes has a low gradient and very low velocities. Both channels are very stable as they have no upstream supply of coarse sediment.

In 1963, the upper Nahatlatch River entered Nahatlatch Lake through an elongate delta that extended from the north towards the south shore of Nahatlatch Lake. Prior to 1973, the upper Nahatlatch River eroded its right bank so that it entered Nahatlatch Lake about 1 km upstream of its old mouth. Since 1973, the old channel has partly filled with sediment and most of the flow now appears to enter Nahatlatch Lake through the new opening.

Since 1973, the Nahatlatch River has constructed a new delta, filling part of a bay on the west side of the old delta. The new delta had a surface area of about 2 to 3 hectares by 1993. Surveys of the delta could be used to estimate its volume of sediment which could then be used to calculate the average annual coarse sediment load reaching the mouth of the upper Nahatlatch River.

In **Reach 4**, between Nahatlatch Lake and the confluence of Mehatl River, the Nahatlatch River has a meandering pattern and moves laterally by downstream progression of its bends and by cutoffs. Bank erosion is one source of sediment to this reach; its tributaries are also important sources, as described in Section 4.1.

Reach 5 consists of a series of rapids, chutes and falls over a distance of 3 km. The channel is laterally and vertically stable and bed material consists of large boulders and rock outcrops.

Reach 6 extends 7 km upstream of the rapids at an average slope of 0.006. Through this reach the Nahatlatch River has an irregular meandering pattern, large point bars, and a nearly-continuous floodplain. Parts of the river are laterally confined by contact with valley walls or road embankments that are protected with rip rap. The channel is laterally unstable -- irregularly eroding its existing channel and shifting to a new channel -- particularly at the upstream end of the reach. It is thought that the instability results from deposition of coarse sediment at the head of the reach. As this coarse sediment is moved downstream, the locus of channel instability will shift accordingly.

A review of 1953, 1973 and 1993 air photographs indicated irregular lateral channel activity and build-up of gravel bars. Bank and bed erosion in this reach is an important source of coarse sediment to Reach 4 as material mobilized in the lower part of Reach 6 is thought to move directly through Reach 5. Snow avalanches are common on the upper valley walls and some appear to reach the river. Several gullies on the valley wall along this reach have also failed and their sediment is carried to the main river by tributary streams.

By 1993, much of the valley flat had been logged. Part of the channel has either a narrow riparian forest, or no riparian forest, as a result of logging to stream banks, blow down, or channel erosion that removed riparian vegetation. At the downstream end of the reach, where the valley is narrow, rock protection has been constructed to protect a bridge and the north and south bank road.

Large logjams and organic debris accumulations partially block the channel in several locations. Sudden failures of complete blockages can cause surges of flow, capable of transporting large amounts of sediment and severely eroding sections of the banks.

Reach 7 is a confined reach with a sinuous pattern and large side and points bars, particularly downstream of Cougar Creek which appears to contribute large quantities of coarse sediment to the main river. Logging along the main river valley had reached Cougar Creek by 1993.

Reaches 8 and 9 are typical upper mountain reaches. Avalanche tracks and landslides enter the channel and it is entrenched, confined by valley walls, and follows an irregular pattern. The main channel is stable with only minor lateral activity and downcutting.

4. REACH 4 -- MEHATL RIVER TO NAHATLATCH LAKE

4.1 Channel Pattern and Lateral Stability

The 18 km reach from Nahatlatch Lake to the Mehatl River confluence is an important spawning area, particularly the upper half of the reach, from just below Tachewana Creek to just above Mehatl River. The overall slope of the reach is estimated at 0.0007 (0.07%); it is somewhat greater above Tachewana Creek and somewhat less below.

The channel has an irregular to tortuous meandering pattern, is sometimes confined or deflected by the valley walls and has a nearly continuous series of diagonal and point bars, with a few small islands (Figure 6). The most sinuous channel is located upstream of Tachewana Creek, whose fan constricts the main valley and reduces the upstream channel gradient. Bed material changes from sand near Nahatlatch Lake, to gravel in the middle of the reach, to coarse gravel and cobbles at the upstream end of the reach though the pattern is disrupted by tributaries which contribute coarse sediment to the main channel.

The major sources of sediment to this reach are the Mehatl River, the Nahatlatch River upstream of Mehatl River, its tributaries, and bank erosion within the reach. The Nahatlatch River upstream of Mehatl River is an important source of coarse sediment. Mehatl River also contributes coarse sediment but, based on an inspection of air photographs, it is thought to be a less important source than the upper main river.

All of the large tributaries to Reach 4 also add coarse sediment to the main river. Teapot and Grizzly Creeks, and particularly Tachewana Creek, are unstable on their fans and deposit coarse sediment in the main river downstream of their mouths. A review of historic air photographs indicates that these channels were not as unstable in 1951 -- prior to forest harvesting -- as they are today. This may result from logging to the banks along their lower reaches or a combination of logging and increased natural sediment supply from their upper watersheds.

The fans of both Tachewana Creek and another small tributary lying immediately west were logged prior to 1961 (Figure 5). Tachewana Creek became unstable following logging and has remained

so. Channel erosion and shifting, in conjunction with upstream, natural sediment supply, provide coarse sediment to the Nahatlatch River. The fan of Grizzly Creek was logged prior to 1973 apparently initiating channel instability and increased sediment delivery to the main river. The fan of Teapot Creek does not appear to have been logged and its channel instability results from increased upstream sediment supply.

Bank erosion and channel migration on the Nahatlatch River results from cut-offs and meander loop expansion and downstream progression. Abandoned ox-bows are visible on the most recent air photographs though these have occurred over many years (Figure 6). Comparing the 1961, 1973, 1983 and 1993 air photographs demonstrates that the overall channel pattern has remained fairly stable but that banks have eroded as meander loops have migrated and the channel has cut-off some of its meander loops.

Figure 5 show major sites of erosion and deposition that were identified by comparing air photographs of different dates. (The eroding sites recorded from about 20 to 60 m of bank retreat between the two dates of photographs, or rates of retreat of about 2 to 6 m/year.) The sites were divided into those that occurred between 1961 and 1973 and those that occurred between 1973 and 1983 and were all marked on the 1961 air photographs. Figure 5 show that nearly all of the bank erosion and cut-off sites have occurred downstream of Grizzly Creek. As well, most of the bank erosion sites resulted from downstream progression of meanders and occurred on the north bank, along the section that was harvested in the late 1950's. It is our opinion that removal of riparian vegetation lead to increased rates of bank erosion and lateral instability through part of Reach 4.

Major changes along the reach are summarized below. Between 1961 and 1973, the major changes in Reach 4 were as follows:

- a new channel was cut through to Nahatlatch Lake,
- a large log jam accumulated and blocked the channel about 1.8 km upstream of Nahatlatch Lake. Some of this debris resulted from logging,
- an oxbow or meander scar on the south bank, about 3.5 km upstream of the lake, filled in with sediment,
- a landslide from the road entered the stream about 6.5 km from the lake,

- increased large organic debris was observed on bars and along the channel.

Between 1973 and 1983, the following changes occurred:

- the "short-cut" channel at the inlet to Nahatlatch Lake became more prominent,
- a meander was cut through 1.8 km upstream of the original lake inlet as a result of the log jam blocking the main channel,
- a meander was cut through a clearcut patch at 12.5 km from the lake.

The lateral changes between 1983 and 1993 were mostly minor though the channel appears to be wider than previously with more trees overhanging the channel as a result of minor local bank erosion. Continued bank erosion, within a previously cut area, has led to a potential cut-off site about 10.8 km from the lake. The 1993 photographs also show the 1961 delta channel as almost abandoned, with nearly all the flow passing through the "short-cut", resulting in build-up along the new delta front in the lake.

Based on the air photograph analysis described above, logging of the riparian forest in the 1950's, 1960's and 1970's affected the lateral stability of Reach 4 of the Nahatlatch River in three ways:

- Increased rates of bank erosion and downstream migration of meanders along banks where riparian vegetation had been removed to the streamside. Channel widening may also have occurred;
- Increased numbers of meander cut-offs through logged-over areas that likely resulted from high velocities of overbank flow across cutblocks or channelization along skid trails; and
- Increased sediment supply from tributary streams that were de-stabilized by logging of vegetation to their stream banks, on their fans.

There are few published results on the effect of clearcut logging on floodplains on the morphology of the adjacent channel which can be used to confirm these observations. Studies and incidental observations in British Columbia suggest that channels can become much wider and less stable,

though it is difficult to separate the results of floodplain logging from those of increased sediment supply resulting from logging on upstream, unstable slopes or other watershed changes. Kellerhals Engineering Services Ltd (1993) summarized a number of case histories of floodplain logging on Vancouver Island rivers and concluded that floodplain logging (often to the channel banks) leads to increased channel width though rates of increase are highly variable, and the reasons for the variable rates are not known.

Karanka (1993) looked at channel stability on the Kitimat River, following floodplain and island logging that was completed without significant leave strips. He found that the active channel had not increased in size but that the overall active riparian zone (active channel plus secondary channels or parts of the floodplain that may support vegetation but carry flow during floods) had increased in size by about 25%. Part of this increase resulted from destruction of log jams that controlled access to secondary channels (attributed to reduced supply of new debris) as well as logging disturbance at the head of the channels. These secondary channels then rapidly widened in response to increased flows because bank vegetation had been removed.

Most previous studies of floodplain logging have addressed channels that are harvested to their banks. Where a leave strip remains, the least stable channel type with respect to floodplain logging is thought to be one with a low, frequently inundated floodplain and multiple secondary channels, that shifts laterally by channel avulsion. With this channel type, disturbance of riparian vegetation for linear features such as roads, skid trails, or long clearcuts parallel to the main channel can lead preferentially to flow along these paths and, eventually, to avulsion of the main channel.

4.2 Vertical Stability

The 1993 photographs show much larger gravel and sand bars than were visible on earlier photographs, particularly downstream of Grizzly and Tachewana Creeks. It is difficult to assess whether the bars are larger as a result of sediment deposition or if they appear larger because of differences in water levels on the various air photographs. The flow in the 1993 photographs was unusually low (stage of 1.25 m) when compared to that in 1983 (stage of 1.74 m) or 1973 (stage of 2.14 m) and the apparent differences in the size of bars partly result from the overall one metre differences in water level. (Note that the October 1993 video shows that near the downstream end

of Reach 4 some log-jams and organic debris were well embedded in gravel bars, suggesting that they have been buried by recent sediment deposits.)

The Water Survey of Canada gauge is located in a long, straight reach about one-half kilometre downstream of Tachewana Creek. Its stage-discharge rating curves were investigated to determine if aggradation is taking place in this part of the channel. According to the Water Survey of Canada the gauge is reliable and its operation is fairly trouble-free, except for the accumulation of floating debris. Eleven different rating tables have been used over the 21-year history of the gauge (Figure 4 shows the gauge section).

Table 8 provides a specific gauge analysis, listing the stage for a range of flows for each of the different rating tables. Some minor shifts have occurred in the stage-discharge relationship over time but there is no trend to aggradation or degradation, suggesting that this section of channel has been fairly stable.

The Water Survey of Canada specific gauge data does not support aggradation in the channel but it is possible that evidence of the accumulation of sediment is masked by increases in channel width. A review of the station history revealed a note from 1985 suggesting that the gauging section appeared to be aggrading and that additional tubing for the gauging mechanism might be required in the future though there is no record of additional tubing subsequently being installed. Further analysis would be required to assess whether the gauge is actually aggrading or not.

Our preliminary conclusion is that increases in bar size near Tachewana Creek mostly result from differences in water level on the various historic air photographs. Aggradation may be occurring further downstream, closer to Nahatlatch Lake.

4.3 Sediment Supply and Transport

Bed load transport rates were computed for Reach 4 using a number of different formulae (Meyer-Peter, Schoklitsch, DuBoys-Straub, Bagnold, Ackers-White and Einstein), a range of flows, and the cross-section and bed-material properties at the WSC gauging section below Tachewana Creek. The different equations gave large variations in transport rates, but consistently showed that no

transport takes place at flows less than the 2-year flood (213 m³/s), and that at least a 5-year flood (258 m³/s) is required for significant volumes of transport. In effect, the bed material appears to be "over-sized" for the low channel gradient, which may partly explain the limited channel shifting evident from the review of historic air photographs.

One implication of the low transport rates is that Reach 4 is sensitive to upstream coarse sediment supply, arriving from the upper Nahatlatch River or Mehatl Creek, or from tributaries within the reach. If forest harvesting increases the supply of coarse sediment, then its accumulation or aggradation will reduce channel capacity, leading to overbank flow at lesser discharges, and a decrease in the overall stability of the reach.

5. REACH 4 RIPARIAN MANAGEMENT AREA

The riparian management area is intended to maintain water quality, stream channel function and the diversity of the aquatic ecosystem and sustain the diversity and productivity of wildlife and vegetation. It may also provide forest and range use, if these are compatible with the first two objectives. The Forest Practices Code defines the riparian management area as extending from the stream banks to the greater of; 1) the top of the inner gorge, 2) the outer edges of the floodplain, or 3) a distance specified in the standards. Along Reach 4 of the Nahatlatch River the appropriate boundary is the edge of the floodplain.

The floodplain is defined as extending to the highest elevation contour where there is evidence of moving water, such as active or inactive flood channels, recent fluvial soils, sediment on the ground surface or in tree bark, rafted debris or tree scarring and it includes all off-channel rearing habitat. We have assumed that this definition is roughly equivalent to that used by the Ministry of Environment, Lands and Parks, which defines the floodplain as a low-lying area, susceptible to flooding from a nearby watercourse, whose area is that inundated by the 200-year flood, plus a free-board allowance.

The Nahatlatch Lake to Mehatl Creek reach has a history of overbank flooding. Stream gauging notes from 1912 to 1921 indicate that a homesteader settled above Nahatlatch Lake but his house was washed away when a log-jam formed in the river. More recently, the 1980 Boxing Day flood destroyed two log bridges and a number of culverts.

The approximate floodplain boundaries shown on Figure 6 were interpreted from aerial photographs and adjusted with channel and floodplain surveys (Appendix C) and field visits. The valley floor in Reach 4 is quite flat, resulting in a wide floodplain, and it is difficult to exactly define its boundaries without detailed topographic maps or extensive cross section surveys. As a verification of the air photograph mapping, the floodplain width was established at three cross sections based on water levels computed for the 200-year instantaneous flood at the WSC gauging station. Floodplain boundaries were also verified along the left, or north, side of the valley by measuring distances from the road to the apparent start of the floodplain, as identified by the presence of standing water, recent sediment deposits or other evidence of overbank flooding.

The riparian management area is divided into a reserve zone closest to the stream where harvesting is not permitted and a management zone where some harvesting may be permitted, if ecologically suitable. Reach 4 of the Nahatlatch River has an "S1" riparian classification and its minimum reserve zone is 50 m along each bank. The management zone is a minimum of 20 m wide though along Reach 4 it extends from the edge of the reserve zone to the edge of the floodplain on each bank, as discussed below.

We have drawn the reserve zone to include all visible off-channel habitat (meander scars, oxbows, small secondary channels, wetlands) and to provide sufficient riparian forest to assuredly maintain channel function. We interpret maintenance of channel function to mean that bank erosion and meander migration rates are not increased by logging, that the incidence of meander cut-offs are not increased, and sediment supply from tributary channels, by further de-stabilization of channels on their fans, is not increased. This is achieved by establishing a reserve that extends 50 m from the concave or actively-eroding bank of meanders along the main river (this provides from 10 to 50 years before the channel erodes through the reserve zone) and will maintain natural rates of erosion. Maintaining natural rates of coarse sediment supply to Reach 4, both from upstream and from within the reach, is also important in maintaining natural rates of bank erosion.

The reserve is much broader within meander loops, often including all the forest contained between the limbs, in order to minimize the risk of cut-offs occurring. Increases in the number of cut offs will lead to a steeper, straighter channel which may not provide as good aquatic habitat. Further de-stabilization of tributary streams is prevented by establishing a reserve to cover the active parts of their fans. Figure 6 shows the boundaries of the reserve zone.

Some harvesting may be acceptable within the management zone that extends from the reserve to the limits of the floodplain. Specific prescriptions will need to be developed by a riparian ecologist or specialist to address wildlife and vegetation concerns.

If harvesting does proceed within the management zone, it will need to be planned to minimize the risk of channel modification. We recommend the following:

1. Avoid building roads or trails that run parallel to the channel. These provide alternative pathways for flow and may lead to a channel diversion or avulsion.
2. Use small harvested areas and avoid developing a long series of harvested areas that run parallel to the river and may attract flow leading to a channel diversion or avulsion.
3. Avoid harvesting in old channels or depressions, particularly those that are connected to the main river or to major tributaries, and may concentrate flow during major floods.
4. Minimize the size of harvested areas near the reserve at the apices of tight bends or near other reserve areas where significant channel erosion is occurring.

There are no studies or other information that provide specific guidelines on the maximum acceptable level of harvest within the management zone that will still maintain channel integrity within the reserve zone. Previous harvesting on the floodplain suggests that the risk of severe channel modification from harvesting in the management zone is low and it is not unreasonable to assume that 20% or more of the management zone could be harvested without affecting channel stability, assuming that harvested areas are distributed as described above. Ecological criteria may reduce the acceptable level of harvest.

6. REACH 6 -- NAHATLATCH RIVER UPSTREAM OF MEHATL RIVER

6.1 Channel Pattern and Lateral Stability

The 7-km long Reach 6 is a relatively low gradient section of the upper Nahatlatch River, with a much steeper reach downstream and a steeper reach leading to its head (Figure 2). The gradient of Reach 6 is estimated at around 0.006, which is about one-quarter of that estimated for the upstream Reach 7 and, as a result, coarse sediment carried through Reach 7 is deposited near the head of Reach 6. The coarsest sediment remains there though finer materials are carried downstream, through Reach 5, and to Reach 4. As a result, bed and particularly bar material tends to become finer downstream in Reach 6 though coarse sediment delivered from tributaries and valley walls disrupts this pattern. Reach 6 is aggrading over long time periods.

Reach 6 has an irregularly sinuous pattern, flows on a broad floodplain and exhibits irregular lateral activity consisting of bank erosion, meander development and channel avulsion. It is frequently in contact with its valley walls (particularly near the downstream end of the reach), and has a continuous series of diagonal and point bars. Bed material ranges from cobbles and boulders at the upstream end of the reach to gravel near the downstream end.

The major sources of coarse and fine sediment to this reach are the upstream Nahatlatch River, tributaries entering the reach, and bank erosion within the reach. Tincup and Pygmy Creeks are the major tributaries to Reach 6 and they both enter from the south side of the Nahatlatch valley. Tincup Creek is unstable on its fan. Photo 1 shows its current position on the extreme south of its fan, what is apparently a new active channel, as well its previous channel position. Tincup Creek shifted into its present channel sometime after 1983. Pygmy Creek has remained in roughly the same channel position since 1961. It is difficult to assess the sediment contribution from these two creeks but is thought to be less than that arriving from the upper Nahatlatch River. Photo 1 suggests that quantities of large woody debris arrive from Tincup Creek as well as from the upstream main river.

Despite the width of the floodplain through Reach 6 the channel is affected by processes on the valley wall. Near the downstream end of the reach a talus cone has built out to the margins of the channel and, prior to 1961, occasionally supplied quantities of coarse sediment to the main river:

it is now substantially vegetated and stable (Figure 7). Also prior to 1961, a large avalanche or slide deposited sediment in the river between Tincup and Pygmy Creeks and pushed the main channel to the north side of its valley (Figure 7). Several small tributaries and gullies also contribute sediment to the main channel and snow avalanches commonly reach the valley bottom.

Prior to 1983, the valley bottom of Reach 6 had not been logged. Inspection of air photographs from 1961, 1973 and 1983 indicated that the main channel was unstable prior to harvesting, as indicated by abandoned channels on the floodplain, particularly in the middle and lower sections of the reach. Figure 7 summarizes major areas of deposition and erosion that were identified by comparing the older air photographs. They are discussed below:

- Sediment from the upstream river is deposited at the head of Reach 6, where the gradient decreases from Reach 7. These deposits filled a meander bend on the left, or north, side of the river as the channel migrated southward. The channel has continued to migrate south and is now attacking its right bank. The main river appeared full of sediment at this site on all air photographs.
- A bar was deposited downstream of the mouth of Tincup Creek, probably incorporating sediment carried by the tributary.
- The main channel between between Tincup and Pygmy Creeks avulsed, or shifted from the south side of the valley to the north. The avulsion is thought to result from sediment deposited by a landslide that entered the main valley prior to 1961.
- The main channel downstream of Pygmy Creek avulsed, or shifted, from the north side of the valley to the south. Vegetation patterns on the air photographs suggest previous shifting of the main channel in this section of Reach 6 though the most recent shift may have resulted from sediment and organic debris introduced into the main channel by the upstream landslide.
- Three bends downstream of Pygmy Creek have enlarged through erosion on their outside, or concave, banks.

6.2 Forest Harvesting and Channel Stability

The 1993 air photographs show six cut-blocks lying wholly or partly on the valley bottom of Reach 6 (Figure 8). Reserve or leave strips were left along the river at all sites; however, in some instances, the leave strips have been eliminated or narrowed by blowdown or river bank erosion. Measurements from the 1993 air photographs and photographs taken during the 1995 field visits, indicate that about 2.1 km of river bank have either no leave strip or a negligible one. Also, about 1.2 km of channel bank are protected by rock revetments and have no riparian vegetation.

Figure 8 shows sites of channel erosion along Reach 6 between 1983 and 1993, as identified by comparing air photographs from those dates. These are discussed below:

- Continued erosion and deposition at the head of Reach 6. The main river is continuing its southward shift and is eroding its right bank along the clearcut. Erosion appears to result from the deposition of coarse sediment from the upstream main river though the pace of erosion is expected to increase when the channel removes the remaining riparian vegetation.
- The main river is eroding its right bank at the next downstream bend. Vegetation on the right bank has re-established on the avalanche deposit.
- The main channel avulsed, or shifted its course, just upstream of Tincup Creek. The shift appears to be associated with deposition of a large log jam at the head of the old channel (Photo 1).
- Minor erosion and deposition occurred in the river adjacent to the next downstream cut block that were not related to forest harvesting.
- The bends upstream of the most downstream bridge crossing eroded between 1983 and 1993 and were stabilized with rock rip rap. The bank is eroding between its protected sections by outflanking the existing rip rap.

Harvesting on the floodplain of Reach 6 is now only having a very minor effect on bank erosion and channel instability because leave strip of riparian vegetation remains along most of the banks. However, where erosion or blowdown removes this fringe of tree there is a potential for accelerated bank erosion and de-stabilization of the channel as described in the previous section. The main concern for channel instability in Reach 6 is accelerated sediment supply to Reach 4.

6.3 Reach 6 Riparian Management Area

The riparian management area is intended to maintain water quality, stream channel function and the diversity of the aquatic ecosystem and sustain the diversity and productivity of wildlife and vegetation. It may also provide forest and range use, if these are compatible with the first two objectives. The Forest Practices Code defines the riparian management area as extending from the stream banks to the greater of; 1) the top of the inner gorge, 2) the outer edges of the floodplain, or 3) a distance specified in the standards. Along Reach 6, which has an "S1" riparian class, the minimum reserve extends 50 m from the stream bank.

The reserve zone is intended to provide sufficient riparian forest to assuredly maintain channel function. We interpret maintenance of channel function to mean that bank erosion and meander migration rates are not increased by logging, and that sediment supply from tributary channels, by de-stabilization of channels on their fans, is not increased. Increased bank erosion or sediment supply can both lead to de-stabilization of the main channel and greatly increased sediment supply to downstream reaches.

Natural channel migration or bank erosion rates have not been measured for Reach 6 but may average from 1 to 5 m/year, where banks are under attack, such as at the outside of bends. Consequently, a 50 m reserve may be eroded through in ten to fifty years, or before the vegetation in the management zone or cut block has regenerated sufficiently to maintain natural rates of bank erosion. Our recommendations then for planning for future harvesting along the valley bottom are:

1. Establish a riparian management area including a 50 m reserve from the channel bank and a management zone extending across the floodplain or a minimum of 20 m.

2. Determine if the channel bank is actively eroding or is expected to be under attack in the near future, based on inspection of the bank and analysis of river channel behavior on air photographs.
3. Where bank erosion is expected or likely to take place, we recommend that no harvesting take place within the first 20 m of riparian management zone, providing a 70 m wide buffer between the eroding bank and clearcut boundary. We also recommend that the clearcut boundary be appropriately treated to prevent blowdown within the 70 m buffer zone. This width should be sufficient to maintain bank erosion within the reserve, under light to moderate bank attack.
4. Where bank erosion is not expected or is unlikely within the riparian management area, forest harvesting may be undertaken within the management zone, depending on whether or not this meets other objectives.
5. Section 5 of this report provides recommendations for harvesting within the management zone that minimize the risk of channel shifting.
6. Review bank erosion and loss of riparian vegetation along the cut block on a regular basis and prepare a bank stabilization program, if required. The purpose of the stabilization program would be to slow the rate of erosion to permit re-establishment of riparian vegetation.

6.4 Recommendations for Remedial Works

The purpose of remedial works along Reach 6 would be to maintain natural rates of bank erosion and prevent accelerated supply of coarse sediment to the downstream Reach 4. We recommend two types of works:

1. River training works: Works intended to slow the rate of bank erosion until riparian vegetation can re-establish. Some of these structures can be built with large organic debris or other similar material rather than large rock in order to avoid long stretches of protected

bank.

2. Riparian Planting: Silviculture or other forestry activities to re-establish riparian vegetation as quickly as possible.

The first priority for work in Reach 6 is at its upstream end (Photo 1) where the channel is attacking its right bank. The most upstream site is along the upper 100 m or so of the cut block where most of the riparian vegetation has been eroded away, banks are about 2 m high, and the channel may potentially avulse into the cut block.

We recommend bank protection along this section of the Nahatlatch River. Because of the severe angle of attack on the bank by the main river we feel that the protection should be constructed from blast rock placed on the bank and extending below typical scour depth. Alternatively, the protection could be constructed as a wall consisting of organic debris supported by driven piles. Debris deposited on the next downstream bar could be used to construct the wall. It is important to extend the protection far enough upstream that it is not outflanked during the next large flood.

A site about about 200 m, or so, downstream is also eroding though some riparian vegetation remains along the bank. Erosion rates can be reduced at this site by re-arranging the organic debris deposited on the bar in the main channel. This debris can be placed along the right channel bank, and held in place by cabling to the bank or to a deadman or by partial burial. Placing the debris along the bank should reduce erosion. We recommend monitoring this site and placing bank protection if the riparian vegetation continues to erode.

The log jam immediately upstream of Tincup Creek is also a potential contributor to bank erosion. Part of this jam may derive from riparian trees eroded from the upstream banks though much of it likely was carried down from Reach 7. Removal of some of the debris blocking the main channel would reduce the potential for bank erosion and channel shifting through this section. The removal should be supervised by a biologist and the material stockpiled for construction of bank protection or instream works along this reach. Debris removal the mouth of Tincup Creek would also benefit channel stability.

7. SUMMARY AND CONCLUSIONS

Floods on the Nahatlatch River are generated both by snowmelt and by rain on snow, with snowmelt freshets generally occurring between May and July and rain on snow floods from October to January. Generally, the largest floods -- and those that move bed material and alter the morphology of the main river in Reach 4 -- result from rain on snow events. Forest harvesting is not thought to have any effect on discharges during snowmelt freshets as the biogeoclimatic zones where heavy snowpacks accumulate have not been logged and the overall harvest level is likely to remain much less than 20% because of the limited operable area.

Rain on snow floods may potentially be increased by forest harvesting. Harvesting has concentrated in those biogeoclimatic zones that accumulate the transient snowpacks that contribute to these floods. Harvesting now amounts to about 5% of this zone in the Nahatlatch and Mehatl River watersheds and will reach 10% of this zone in the overall watershed at the end of the current five-year plan. In Kookipi Creek, harvest levels in this zone will reach about 14% by 1998 and we recommend analysis of the distribution of cut blocks and of hydrologic recovery. In Log Creek, the existing harvest is more than 30% of the CWH and IDF zones. No further harvesting should occur in this watershed without a detailed hydrologic assessment and an evaluation of recovery.

Analysis of a thirty-five and fifty year harvest cycle for the Mehatl River indicated that maximum equivalent clearcut areas would be about 27 km² and 20 km². These are equivalent to about 23% and 17% of the CWH biogeoclimatic zone or about an equivalent amount of the transitional snow zone. These values are near the lower end of the range where increases in rain on snow floods are expected. However, ECA will remain elevated for a number of years for both harvest cycles and there is a potential for downstream channel change because of increased peak flows during rain on snow floods. The potential is obviously greater for the shorter harvest cycle.

More than half of the terrain polygons in the operable harvest area in the Mehatl watershed are either unstable or potentially unstable. Harvesting of these polygons can potentially increase coarse sediment supply to the Mehatl River and the downstream Nahatlatch through slope instability resulting from root mat deterioration or road construction. Road construction is thought to be the more important source of debris slides and debris flows. Construction needs to be carefully planned

and reviewed in these unstable areas and seasonal de-activation of roads should be practiced. Even with good practices we expect some landslides to result from harvesting which will increase sediment supply to the Mehatl River.

The Nahatlatch River is reasonably stable for most of its length with many of its reaches confined by valley walls. The least laterally stable reach, and one that is sensitive to harvesting on the floodplain, is Reach 6, upstream of Mehatl River. Here, large gravel bars, bank erosion and channel shifting provide an important source of coarse sediment which may be deposited in Reach 4.

The major spawning reach (Reach 4 – Nahatlatch Lake to Mehatl Creek) has an irregular to tortuous channel pattern and shifts laterally by meander cut-offs and downstream meander migration. It is moderately sensitive to forest harvesting. Reach #4 has a low gradient, overbank flooding and limited transport capacity for its bed material. Calculations indicate that bed materials are only moved in significant quantities during floods with about a five-year return period, i.e. primarily during rain on snow floods.

The north bank of this reach was harvested in the 1950's and 1960's while the south bank was harvested in the 1970's and 1980's with trees removed to the channel banks in some sections. The harvesting seems to have affected channel stability by 1) increasing rates of bank erosion (and channel widening) where the riparian forest has been removed, 2) increasing the number of meander cut offs through harvested areas by concentrating flow, and 3) increasing sediment supply by destabilizing tributaries on logged alluvial fans.

Inspection of air photographs indicated that channel bars are larger in 1993 than in 1973. This may have occurred because of lower water levels in the most recent air photographs or because coarse sediment has accumulated along the main channel. Specific gauge records from the Water Survey of Canada gauge "*Nahatlatch River below Tachewana Creek, 08MF065*" do not show any trend to aggradation but the gauge is in a long, straight reach which may be slow to show the effects of sediment deposition and channel widening may have partly compensated for the aggradation. We feel that some aggradation has occurred, particularly near the downstream end of the reach, but that further analysis would be required to determine if coarse sediment is accumulating upstream of Tachewana Creek.

Accumulation of coarse sediment is an important issue for Reach 4 because its low transport rates mean that it is sensitive to increased supply. Sediment from upstream reaches or from tributaries within the reach that deposits on the bed increases the frequency of overbank flooding, the potential for channel shifting or avulsion, and rates of bank erosion. Consequently, control of coarse sediment supply from upstream harvesting activities is a very important issue for channel stability. This is particularly important along Reach 6 where the Nahatlatch River is laterally unstable and may be an important source of coarse sediment to Reach 4.

A riparian management area (RMA) was defined along Reach 4 of the Nahatlatch River that extends to the boundaries of its floodplain. The floodplain was defined from analysis of air photographs and maps and requires field confirmation of boundaries. Within the RMA, the reserve zone was drawn to include off-channel habitat (primarily meander scars, ox-bows and small secondary channels) and to provide a 50 m wide riparian reserve at the apices of meander bends where the channel is eroding fastest. It will take from 10 to 50 years for the channel to erode through the reserve zone.

The reserve zone also includes the riparian forest within the meander loops. This forest is left because channel shifting by loop cut-off and harvesting the floodplain is thought to be aggravated by removal of vegetation and construction of trails or roads within the zone. The harvesting and trails or roads concentrate flow and potentially increase the number of cut offs. An increased frequency of cut offs lead to a somewhat straighter, steeper channel which may not provide as suitable fish habitat.

A reserve zone is also needed along the alluvial fans of the major tributaries -- Tachewana, Grizzly and Teapot Creeks -- to the Nahatlatch River in Reach 4. The reserve is intended to prevent further de-stabilization of these creeks on their fans and prevent accelerated supply of coarse sediment.

Harvesting in the management zone of the Reach 4 floodplain is seen as providing a low risk to channel modification, assuming that roads and harvested areas are laid out so that they do not encourage concentration of flow and channel diversion or avulsion.

Reach 6 is a relatively low-gradient reach where upstream sediment is deposited and sorted. Sediment from the upper watershed is deposited at the head of the reach and this section is

particularly unstable though major channel avulsions occur as far downstream as Pygmy Creek. The river was unstable prior to harvesting of the valley bottom after 1983 and has continued to be unstable at roughly the same locations.

Forest harvesting has only had a small impact on channel erosion to this date. However, about 2.1 km of river bank have either no leave strip or a negligible one and it is these areas that may experience accelerated erosion after the riparian vegetation has been eroded. For future harvesting, we recommend that the first 20 m of the management zone not be harvested where channel banks are either unstable or may be under attack by the main river in the near future so that a 70 m buffer is left between the buffer and any harvested block. At more stable sites, the reserve zone can decrease to 50 m recommended in the Forest Practices Code but a bank stabilization plan should be prepared to address unusual or unexpected erosion at these sites.

The most unstable part of the reach and the site where accelerated erosion of harvested land may occur is at the upstream end. We recommend several mitigative works to reduce the potential for accelerated bank erosion through this reach.

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Table 1: Characteristics of Tributaries to the Nahatlatch River

Stream Name	Distance from Mouth (km)	Bank Side	Area (km ²)	Area Controlled by Lakes		Mainstem Length (km)	Channel		Basin		Snowpack Accumulation						
				>1km (km ²)	250m - 1km (km ²)		Elevation Minimum (ft)	Elevation Maximum (ft)	Average Slope	Elevation Minimum (ft)	Elevation Maximum (ft)	Alpine	Area of ESSF	Heavy	Moderate	Light	
											AT	ESSF	MH	CWH	IDF		
Nahatlatch Watershed	0	-	1256	299.7	5.16	11.91	79.3	350	5950	0.022	350	9000	160.6	450.3	227.7	327.8	89.6
- Log Ck.	11.8	LB	82	0.0	1.49	0.19	17.4	950	5750	0.084	950	8600	9.1	57.5	0.0	6.7	8.8
- Kookiji Ck.	12.5	RB	159	0.0	5.16	0.00	24.3	1025	5050	0.050	1025	7400	8.5	91.1	12.9	39.4	6.9
- 3.2	-	RB	25	0.0	1.39	0.00	9.3	1650	5650	0.131	1650	7400	2.9	16.3	0.0	0.3	5.3
- Squakum Ck.	20.2	LB	43	0.0	1.23	0.00	10.6	1050	6450	0.155	1050	8200	5.1	32.5	0.0	0.0	5.5
- Teapot Creek	28.0	RB	56	8.2	0.00	0.00	14.1	1075	4850	0.082	1075	6700	0.2	15.3	20.9	19.4	0.0
Upper Nahatlatch Watershed	32.8	-	751	0.0	41.79	-	49.0	1080	5900	0.030	1080	9000	132	187	190	241	2
- Tachewana Ck.	32.9	LB	34	0.0	0.00	0.00	11.8	1080	5750	0.121	1080	8300	3.3	26.5	0.0	3.6	1.0
- Grizzly Creek	36.0	RB	31	0.0	0.55	0.00	8.9	1085	4850	0.129	1085	6600	0.0	19.0	0.2	11.3	0.0
- Mehall Ck.	42.5	LB	289	0.0	22.16	3.01	36.2	1090	6050	0.042	1090	9000	49.0	55.4	63.5	116.0	0.0
- 12.0 (N. Mehall Ck.)	-	LB	46	0.0	1.34	0.26	12.3	2250	6875	0.110	2250	9000	10.8	25.7	0.0	5.6	0.0
- Pygmy Creek	47.9	RB	39	0.0	5.73	0.30	9.9	1750	5950	0.117	1750	7500	9.6	0.0	21.3	8.3	0.0
- Tincup Creek	49.1	RB	54	0.0	10.30	2.03	11.2	1760	5075	0.090	1760	7600	13.9	0.0	30.6	9.9	0.0
- Cougar Creek	59.2	RB	44	0.0	1.71	1.91	11.6	2550	6050	0.092	2550	8000	14.8	0.0	24.0	5.1	0.0

* Biogeoclimatic zones are Alpine Tundra (AT), Mountain Hemlock (MH), Englemann Spruce - Subalpine Fir (ESSF), Coastal Western Hemlock (CWH) and Interior Douglas Fir (IDF).

* The positions of biogeoclimatic zones are derived from a 1:50,000 overlay provided by the Chilliwack Forest District.

Table 2: Climate Stations near the Nahatlatch River

Climate Station	Ecosection (1)	Physiographic Region (2)	Latitude	Longitude	Elevation (m)	Precipitation (mm) (3)				Mean Annual Temperature
						Annual	May to Sept	Annual Snowfall	Greatest Daily	
Interior Transition Ranges Ecoregion										
Lillooet Seton BCPA	SCR	PR	50.40	121.55	198	286.5	93.6	48	29.5	8.7
Lillooet	SCR	PR	50.42	121.56	290	391.4	139.7	73.2	114.3	-
Lillooet Cedar Falls	SCR	PR	50.36	121.52	555	405.0	127.6	118.5	51.1	-
Lillooet Russell St	SCR	PR	50.42	121.56	244	341.5	118.7	81.4	47.2	-
Shalath	SCR	PR	50.44	122.13	244	514.2	118.3	110.5	55.1	9.6
Bralome	SCR	PR	50.47	122.49	1015	636.3	156.6	271.3	55.9	4.1
Lytton	SCR	PR	50.14	121.34	175	467.3	92.3	162.5	76.7	10
Pemberton BCFS	EPR/LPR	PR	50.19	122.49	218	1186.9	223.9	310.5	92.2	7.2
Pemberton Meadows	EPR/LPR	PR	50.27	122.56	223	990.2	197.1	283.4	101.6	7.0
Pacific Ranges Ecoregion										
Hells Gate	EPR	PR/CM	49.47	121.27	122	1198.9	176.5	188.5	96.5	9.2
Hope A	EPR	CM	49.22	121.29	39	1715.8	326.5	192.6	142.0	9.7
Hope Kawkawa Lake	EPR	CM	49.23	121.24	152	1556.0	301.6	197.2	111.0	9.3
Allison Pass	EPR	CM	49.08	120.5	1341	1524.5	288.2	1431.5	81.3	1.8

1. SCR, the Southern Chilcotin Ranges; EPR, Eastern Pacific Ranges; LPR, the Leeward Pacific Ranges Ecosection.
2. PR is the Pacific Ranges; CM, the Cascade Mountains;
3. Climate data from the 1951-1980 Canadian Climate Normals.

Table 3: Water Survey Canada Stream Gauges

Station Name	Station Number	Drainage Area (km ²)	Period of Record
Nahatlatch River at outlet of Frances Lake	08MF007	777	1912-1921
Nahatlatch River near Keepers	08MF008	1040	1912-1921
Nahatlatch River below Tachewana Creek	08MF065	715	1973-1993

**Table 4: Nahatlatch River below Tachewana Creek (08MF065)
Summary of Historic Maximum Flows**

Year	Date	Max. Inst. Flow (m3/s)	Max. Daily Flow (m3/s)	Inst./Daily Flow Ratio
1973	Oct 28	309	211	1.46
1974	Jun 18	282	258	1.09
1975	Nov 04	300	271	1.11
1976	Jul 08	201	170	1.18
1977	Jun 07	174	147	1.18
1978	Jun 04	222	186	1.19
1979	Sep 08	169	125	1.35
1980	Dec 27	422	323	1.31
1981	Oct 31	298	207	1.44
1982	Jun 20	291	234	1.24
1983	-	-	-	-
1984	-	362	232e	-
1985	Jun 02	167	145	1.15
1986	May 26	317	262	1.21
1987	May 12	238	193	1.23
1988	-	-	-	-
1989	Nov 10	310	218	1.42
1990	-	-	-	-
1991	-	-	-	-
1992	Apr 30	289e	226	-
1993	May 13	265	230	1.15

**Table 5: Nahatlatch River below Tachewana Creek (08MF065)
Flood Estimates**

Return Period (years)	Instantaneous Maximum Discharge (cms)	Maximum Daily Discharge (cms)
2	269	213
5	331	258
10	364	282
20	391	302
50	422	324
100	442	338
200	459	351

Table 6: Logging History: Nahatlatch River Watershed

Stream Name	Basin Area (mouth) (km ²)	Logged Area (1)					% Logged Area		
		Oldest (pre-63) (km ²)	Older (63-72) (km ²)	Old (73-82) (km ²)	Recent (83-92) (km ²)	Proposed (1993-98) (km ²)	Total/ Basin	Recent/ Basin	Recent & Proposed/ Basin
NAHATLATCH RIVER									
Nahatlatch R.	1256	0.2	0.4	4.0	19.4	16.4	2%	2%	3%
- Lower Nahatlatch R.	946	0.2	0.4	4.0	16.5	8.2	2%	2%	3%
- Upper Nahatlatch R.	310	0	0	0	3.0	8.2	1%	1%	4%
- Log Ck.	82	0	0	0	5.0	0	6%	6%	6%
- Kookipi Ck.	159	0	0	0	2.6	3.8	2%	2%	4%
- Unnamed Ck.	53	0	0	0	0	0	0%	0%	0%
- Mehatl Ck.	293	0.2	0.4	3.7	0.8	0	2%	0%	0%

1. Logged areas are from Ministry of Forests records and may not be complete for the period before 1963

Table 7: Nahatlatch River -- Overview of Reach Characteristics

Reach No.	Reach Description	each Character			Description of River Valley			Channel/Valley Relation	Channel Stability	
		Length (km)	D/S Station (km)	Average Slope	Width (m)	Wall Stability	Vegetation		Lateral Activity	Vertical Activity
9	Headwater reach above elev. 1494 m	1.45	81.25	0.400	No distinct valley flat	Avalanche activity	Sparse, mainly low brush	Partly entrenched. Glacial lake outflow.	Limited irregular activity	Minor downcutting
8	Upper mountain reach above elev. 1006 m	11.25	70.00	0.043	No distinct valley flat	Large slide on RB, u/s end. Avalanches	Alpine forests	Entrenched	Limited irregular activity	Minor downcutting
7	Middle mountain reach above elev. 549 m	16.90	53.10	0.027	150	Avalanches Some slides	Forested Some logging	Entrenched	Limited irregular activity	Minor downcutting
6	Lower mountain reach above elev. 507 m	7.00	46.10	0.006	up to 400	Large areas of clear cutting	Forested, but extensively logged.	Partly entrenched, sometimes confined by valley walls	Single channel with bank erosion and irregular activity	Bar build-up and aggradation.
5	Rapids reach above elev. 335 m	2.90	43.20	0.060	No distinct valley flat	Stable	Heavily forested	Entrenched	Relatively stable	Stable
4	Mehatl Creek to Nahatlatch Lake W inlet, above elev. 322 m	18.40	24.80	0.0007	400-1200	Stable	Forested (historically logged)	Sometimes confined by valley walls	Cut-offs/some progression. Bank erosion.	Bar build-up and aggradation.
3	Nahatlatch Lake W inlet to Frances Lake outlet, above elev. 322 m	12.05	12.75	0.0002	300-800	Stable, slide area on north shore Hannah I.	Forested	Confined by valley walls	Relatively stable	Stable
2	Frances Lake outlet to d/s of rapids, above elev. 244 m	2.75	10.00	0.028	200	Stable	Forested	Frequently confined by valley walls	Minor bank erosion	Relatively stable
1	Rapids to Fraser River confluence, above elev. 110 m	10.00	0.00	0.013	150	Slide area on RB	Forested	Entrenched	Minor irregular channel activity	No obvious aggradation/ degradation

Table 7: Nahatlatch River -- Overview of Reach Characteristics

Reach No.	Reach Description	Description of Channel						Bed Material					
		Pattern	Islands	Bars	Type of Flow	Obstructions	Bank Vegetation	% 0-2mm	% 2-100mm	% 100+ mm	% Bedrock	D90 (mm)	
9	Headwater reach above elev. 1494 m	Irregular	None	-	Tumbling	Boulders/rock outcrops	Sparse			Mainly coarse gravel & boulders			
8	Upper mountain reach above elev. 1006 m	Irregular	None	-	Tumbling/irregular	Boulders	Sparse			Mainly coarse gravel & boulders			
7	Middle mountain reach above elev. 549 m	Irregular	None	Frequent small diagonal and side bars.	Irregular/some falls	Logs	Light			Mainly coarse gravel			
6	Lower mountain reach above elev. 507 m	Irregular meanders	Some (small)	Diagonal and point bars.	Uniform	Large log jams & organic debris.	Light	10	60	30	0	600	
5	Rapids reach above elev. 335 m	Series of rapids, chutes and falls	None	None	Tumbling	Rock outcrops	-	10	20	60	10	600	
4	Mehall Creek to Nahatlatch Lake W inlet, above elev. 322 m	Tortuous meanders	Some (small)	Diagonal and point bars.	Uniform	Log jams	Vegetated	u/s 10 mid 10 d/s 70	60 80 30	20 10 0	10 0 0	300 200 100	
3	Nahatlatch Lake W inlet to Frances Lake outlet, above elev. 322 m	Series of lakes	None	None	Uniform between lakes	None	Vegetated	N.L. 10 F.L. 10	50 30	40 60	0 0	300 400	
2	Frances Lake outlet to d/s of rapids, above elev. 244 m	Irregular	Some (small)	Diagonal bars	Irregular	Log jams	Vegetated	10	20	60	10	800	
1	Rapids to Fraser River confluence, above elev. 110 m	Irregular	Some (small)	Diagonal/side bars	Irregular	Log jams	Vegetated	u/s 10 mid 10 d/s 10	20 20 50	60 30 30	10 40 10	800 600 300	

**Table 8: Nahatlatch River below Tachewana Creek (08MF065)
Specific Gauge Rating**

Year	Table No.	Gauge Elevation (m)							
		Q=10 cms	Q=50 cms	Q=100 cms	Q=150 cms	Q=200 cms	Q=250 cms	Q=300 cms	
1973	2	1.20	1.85	2.45	2.98	3.47	3.94	4.35	
1974	3	1.20	1.85	2.45	3.02	3.53	4.02	4.35	
1975	4	1.23	1.91	2.51	3.04	3.53	4.02	4.51	
1976	4	1.23	1.91	2.51	3.04	3.53	4.02	4.51	
1977	5	1.20	1.84	2.45	3.04	3.53	4.02	4.51	
1978	6	1.23	1.86	2.43	2.97	3.51	4.02	4.51	
1979	7	1.16	1.86	2.43	2.97	3.51	4.02	4.51	
1980	8	1.16	1.82	2.36	2.90	3.43	3.97	4.51	
1981	8	1.16	1.82	2.36	2.90	3.43	3.97	4.51	
1982	8	1.16	1.82	2.36	2.90	3.43	3.97	4.51	
1983	9	1.14	1.82	2.35	2.89	3.42	3.96	4.49	
1984	9	1.14	1.82	2.35	2.89	3.42	3.96	4.49	
1985	9	1.14	1.82	2.35	2.89	3.42	3.96	4.49	
1986	10	1.11	1.82	2.35	2.86	3.36	3.86	4.36	
1987	10	1.11	1.82	2.35	2.86	3.36	3.86	4.36	
1988	10	1.08	1.80	2.35	2.86	3.36	3.86	4.36	
1989	11	1.08	1.80	2.35	2.86	3.36	3.86	4.36	
1990	11	1.08	1.80	2.35	2.86	3.36	3.86	4.36	
1991	11	1.08	1.80	2.35	2.86	3.36	3.86	4.36	