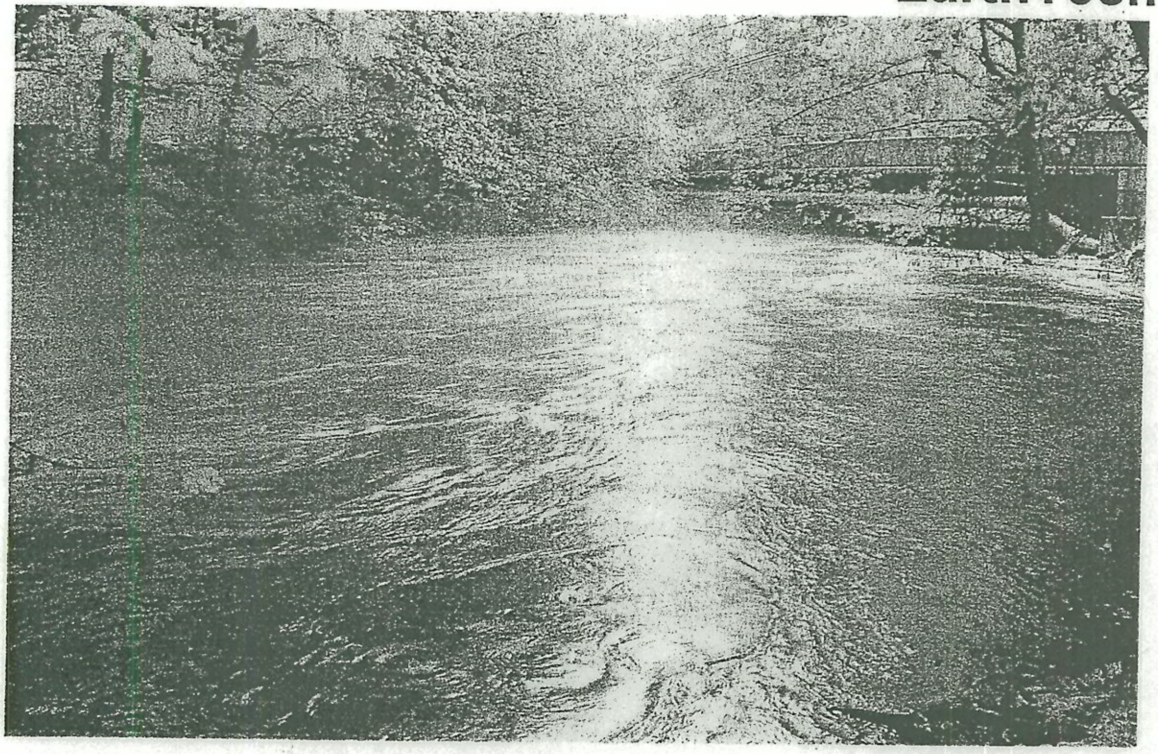
EarthTech



North Alouette River

Assessment of Channel Behaviour and Hydraulics

Final Report

January 2004

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hydraulic
consultants

North Alouette River
Assessment of Channel Behaviour and Hydraulics

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Introduction

Study Objective and Scope

Northwest Hydraulic Consultants (**nhc**) were retained by Earth Tech, on behalf of the District of Maple Ridge (The District), to conduct a study of the North Alouette River (the River) near the Town of Haney, B.C. The District requested the study following a complaint by the property owner on the right bank upstream of the132nd Avenue Bridge (the Subject Property), who maintains that bank erosion alongside her property has increased in recent years due to the hydraulic effect of the Bridge. The existing 132nd Avenue Bridge was built in 1995 to replace an older timber bridge.

The objective of the study has been to assess the condition and behaviour of the River, and identify the potential causes of bank erosion at the Subject Property. The scope of work included an analysis of flood hydrology; onsite inspection of the river channel; analysis of historical airphotos and surveys; assessment of the River's response to high flow events; and assessment of the hydraulic effects of the 132nd Avenue Bridge on the Subject Property.

The following report summarizes **nhc's** findings.

Site Visits

nhc personnel have made three separate visits to the site, including:

- **September 4th, 2003**, in order to document the erosion at the Subject Property and meet with the property owner. Bruce Walsh and Des Goold of **nhc** were accompanied on this visit by Mr. Henry Leung of Earth Tech.

- **October 17th, 2003,** to observe and document the River's behaviour during high flow. The peak discharge for this flood event had occurred late at night on October 16th.

- **October 31st, 2003**, in order to conduct a cross-section survey of the channel at the 132nd Avenue Bridge, and inspect the River upstream of the 132nd Avenue Bridge, documenting the condition of the channel and its banks.

Watershed Description

The North Alouette watershed encompasses an area roughly 69 km^2 in size, draining the majority of UBC's Malcolm Knapp Research Forest and a portion of Golden Ears Provincial Park (Figure 1). Numerous small lakes in the upper watershed account for approximately three percent of the total area. Elevations range from a maximum of 1,575 m at Edge Peak in the Golden Ears Mountains, down to sea level at the North Alouette confluence with the South Alouette River, 5 km northwest of Haney, BC.

The forest cover in the North Alouette watershed consists of mostly coniferous trees, with stands ranging in age from 1-year to more than 400-years. Logging operations date back to the late nineteenth century, with the most intense activity occurring between the years 1920 and 1931, when nearly half of the current Research Forest area was harvested. UBC took over management of the Research Forest in 1949, initiating an era of carefully regulated, low-impact logging practices.

Hydrology

As is typical with coastal watersheds, rainfall accounts for the majority of annual precipitation in the watershed and is the main contributor to peak flood events. Average annual precipitation ranges from about 2,200 mm per year in the southern lowlands, to more than 3000 mm per year in higher elevations to the north. Snowfall accounts for only three percent of the annual precipitation in the southern lowlands, while in the north there is snow cover for up to four months of the year (Environment Canada, 2003).

A Water Survey of Canada (WSC) gauging station, *North Alouette River at 232nd Street, Maple Ridge* (08MH006), is located just downstream of the 232nd Street Bridge (Figure 1). The drainage area above the gauge is approximately 35.5 km^2 measured at a scale of 1:50,000. The gauge has a record of mean daily discharge dating back to 1960 and a record of instantaneous peak discharge beginning in 1969.

The mean annual hydrograph for the North Alouette River is shown in Figure 2 and is derived from the mean daily discharge record at gauge 08MH006. The mean annual discharge at the gauge is approximately 2.8 m^3/s, which is equivalent to 2,500 mm of annual runoff.

The magnitude and timing of annual maximum discharges at Gauge 08MH006 is summarized in Table 1 (WSC, 2000). The discharge magnitudes are also presented graphically in Figure 3. As indicated in each of the aforementioned figures and tables, the annual snowpack in the north part of the watershed is not substantial enough to produce a consistent snowmelt freshet in the spring months. Instead, most large flows in the River occur as result of frontal rainstorms in the fall or rain-on-snow events in the winter months, and occasionally due to intense summer storms.

Table 1. **Magnitude and Month of Occcurence for Annual Maximum Discharges**
North Alouette River at 232nd Street, Maple Ridge **(08MH006)**

Year	Daily Avg.	Date	Instantaneous	Date
1960	20.4	Dec	--	--
1961	56.6	Jan	--	--
1962	23.2	Jan	--	--
1963	76.2	Dec	--	--
1964	58.6	Nov	--	--
1965	29.4	Feb	--	--
1966	64.3	Oct	--	--
1967	29.7	Feb	--	--
1968	55.2	Jan	--	--
1969	34.8	Jan	60.6	Jan
1970	23.3	Apr	36.8	Apr
1971	--	--	62.9	Oct
1972	58.3	Jul	103	Jul
1973	--	--	64.3	Oct
1974	--	--	53.8	Dec
1975	--	--	92	Nov
1976	--	--	51	Nov
1977	39.4	Jan	71.4	Jan
1978	31.1	Nov	77	Nov
1979	--	--	107	Dec
1980	64.6	Dec	118	Dec
1981	73.1	Oct	107	Oct
1982	40	Dec	80.4	Dec
1983	--	--	124	Jul
1984	66.9	Jan	126	Jan
1985	29.8	Nov	70.6	Nov
1986	86	Feb	162	Feb
1987	23.7	Mar	31.2	Mar
1988	26.2	Nov	--	--
1989	--	--	--	--
1990	61.5	Nov	140	Nov
1991	--	--	70.3	Nov
1992	31.4	Jan	--	--
1993	26.7	Jan	50.8	Jan
1994	--	--	63.6	Feb
1995	51	Nov	94.9	Nov
1996	26.3	Jan	41.5	Jan
1997	--	--	106	Jul
1998	62	Nov	132	Nov
1999	35.4	Dec	69.6	Dec
2000	--	--	26.3	Sept

Flood Frequency Analysis

A flood frequency analysis has been carried out on the 29 year instantaneous flow record at 08MH006. Gumbel Extreme Value I and Log Pearson III distributions provided equally good fits to the data and resulted in relatively low standard errors, averaging approximately 11 percent for the 200-year discharge estimate. The Gumbel and Log-Pearson III results have been averaged to obtain the discharge estimates shown below in Table 2.

Table 2. Flood Frequency Analysis Results
North Alouette River at 232nd Street, Maple Ridge **(08MH006)**

Return Period yrs	Instantaneous Discharge m^3/s
1	17
2	79
5	111
10	130
20	147
50	168
100	183
200	197

The results of the flood frequency analysis have been superimposed on Figure 3. The gauged flood of record, 162 m^3/s, occurred in 1986 and has an approximate return period of 40 years. Other recent floods of note include a 15-year event in 1990, and successive 5- and 10-year events in 1997 and 1998, soon after the 132nd Avenue Bridge was replaced.

WSC has been contacted to provide an estimate of discharge for October 16th, 2003 flood event, which appeared to be of significant magnitude; however, this information had not been received at the time of writing.

Physical Description of the Study Reach

The Study Reach encompasses approximately 1.8 km of the River, from 224th Street upstream to 232nd Street. The 132nd Avenue Bridge is located about one fifth of the way along the Study Reach.

Channel Gradient

Figure 4 is a longitudinal profile of the Study Reach, based on a 1989 cross-section survey conducted by the former Ministry of Environment, Lands and Parks (MOE or MELP, 1989).

According to Figure 4, the channel slope between 132nd Avenue and 232nd Street varied between 0.4 and 0.7 percent (4 to 7 m/ km) in 1989. The steepest portion of the channel had been near 132nd Avenue, between Section 114 and Section 111[1].

Existing bed levels were surveyed by **nhc** in October 2003 in the vicinity of the 132nd Avenue Bridge; these levels are shown in red on Figure 4. The bed levels surveyed by **nhc** show that gravel deposition through the 132nd Avenue crossing has decreased the slope between Section 114 and Section 110 to a value of about 0.4 percent, which, for the purpose of this study is regarded as the average slope for the reach.

Cross-Section Geometry

Cross-section widths in the Study Reach vary between about 12- and 25 m. The River is obviously wider where gravel bars are present, but the majority of flow at these locations is nevertheless confined within a 12- to 15 m wide channel.

MOE estimates that the bankfull discharge for the Study Reach is about 40 m^3/s (MOE, 1989). By assuming a range of 12- to 15 m for bankfull width; an average gradient of 0.4 percent; and a Manning's 'n' of 0.04, the bankfull depth through the Study Reach is in the range of 1- to 1.3 m, which agrees with observations made during **nhc's** site visits.

Channel Pattern

The term channel pattern refers to the characteristic shape of a stream in the horizontal plane; types of patterns include straight, meandering, braided and wandering, but they are not mutually exclusive. Straight channels are considered by many to be a particular form of meandering channel with a very low sinuosity (or 'curviness'). A braided pattern consists of two or more channels separated by gravel bars, with one channel usually being dominant. Wandering describes a braided pattern in which the bars have been stabilized by vegetation, thus becoming islands.

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[1] The gradient between Section 111 and Section 109 is probably not adverse (increasing in elevation) to the extent indicated in Figure 4. Scour through the contracted bridge opening would have lowered bed levels locally, but the influence of scour would not have extended much further downstream than Section 110.

Figure 5 (A, B) shows that while the Study Reach has a meandering pattern in general, there are several areas in which braiding or wandering behaviour also occurs (e.g. Station 0+200; Station 0+325; Station 1+000; and Station 1+320). Leopold and Wolman (1957); found that meandering behaviour gives way to braided behaviour as the channel slope increases as shown by the plot in Figure 7. MOE estimates of slope and bankfull discharge (MOE, 1989; Figure 4) have been plotted against Leopold and Wolman's curve and the result indicates that the Study Reach lies close to the threshold of meandering and braided behaviour.

Millar and Church (1993) and Millar (2000) have introduced the concept that bank stability, in addition to channel slope, is a key factor in determining whether a stream will meander or braid. According to the authors, streams that have dense, mature vegetation exhibit a stable, meandering behaviour even when the channel slope plots above the threshold line proposed by Leopold and Wolman (Figure 7). Conversely, streams have sparse bank vegetation and non-cohesive bank material show a tendency to widen and braid even a moderate slopes.

Streambanks

The condition and make-up of the streambanks is presented in Figure 5 (A, B). The total length of bankline in the study reach is approximately 2.8 km. Of this total, 1.1 kms (39 %) has some form of rock protection; 700 m (25%) are naturally protected by an adjacent gravel bar; another 700 m (25 %) are experiencing various rates of erosion; and the remaining 300 m (16 %) have no protection, but otherwise appear to be stable.

The summary table on Figure 5A provides details on the type of rock protection used at specific locations; riprap dimensions in the table were estimated by sight and no direct measurements were made.

Right Bank

The right bank of the channel contains a loosely packed matrix of non-cohesive alluvial materials including sand, gravel and some cobble size stones. In most places the alluvium is overlain by a 0.3 m thick layer of fine sand, silt and organic materials.

The vegetation along the right bank is a mixture of coniferous and deciduous trees, and several varieties of brush. Most of the deciduous trees located near the banks edge are immature. Since most areas are residential, much of the ground is covered with short grass.

The right bank is being eroded at several locations as shown in Figure 5. In every case, the affected section of bank is unprotected and fully exposed to the flow in the River. The mechanisms causing this erosion include one or more of the following:

(i) Eddying developed at the interface of poorly keyed-in or poorly blended riprap. The eddies chew into the leading or trailing edge of the unprotected bank, eroding away deep pockets of material (Photos 2 and 12);

(ii) direct hydraulic action of flow running parallel to the bank (Photo18);

(iii)deposition of gravel at mid-channel, which then deflects flow against the right bank at acute angles (Photo 2); and,

(iv)scouring action of secondary or cross-stream currents emanating from an upstream meander bend (Photos 12 and 28)

Right Bank at the Subject Property

The erosion occurring along the Subject Property is an example of mechanism 'iv'. Secondary currents develop as flow emerges from the meander bend opposite Bar #2 at Station 0+100 and impinge upon the exposed bank at the Subject Property. As a result, material is scooped from the toe of the bank and thrown streamward where it is deposited along the outside edge of Bar #1 opposite the Subject Property. The flow pattern described here is illustrated in Figure 7 (after Thorne et al; Bathurst et al).

Left Bank

The left bank of the channel is composed of similar alluvial materials as the right bank, though there is a great deal more cohesion in the mixture. The vegetation tends to be more mature and denser, which leads to the higher volume of organic material and better binding of the soil. Most of the left floodplain is used for pasture and grazing purposes, so it has not been landscaped, or otherwise disturbed, to the same extent as the right bank.

The left bank is affected by erosion as well (Figure 5), but the additional strength afforded by more mature vegetation leads to an undercut, vertical bank profile (Photos 6 and 23) rather than the lateral erosion seen on the right bank

Bed Material

The surficial geology of the North Alouette watershed consists of relatively unconsolidated, glaciofluvial till belonging to the Fort Langley Formation (Armstrong, 1984). Since the River and its tributaries carve their way through this erodible material, a potentially large volume of coarse sediment is delivered to the Study Reach annually.

Bed material sizes in the Study Reach have been analyzed at several of the gravel bars shown in Figure 5. Photographic samples were collected at each location and all particles lying within a specified grid on the photograph were measured and ranked to produce the bed material gradations shown in Figure 8.

The photo-sampling method permitted a number of sites to be sampled quickly, but has the following limitations:

- the diameter of individual grains may be distorted when measured in a two-dimensional plane;
- particles less than about 2 mm in diameter (coarse sand) cannot be measured accurately;
- the sample volume is small.

The samples collected on Bars #2, #6, #7 and #8 contain a significant fraction of finer sized particles, which appeared to have been deposited during the recent October flood. As such, their gradation curves should represent the full range of sizes for bedload material in the Study Reach. For the purpose of this study, however, the goal is to identify the mean diameter of the particles comprising the *armour* layer on the surface of the riverbed, since it is this size particle that must first be mobilized before significant sediment transport can take place. The gradation curves for Bars #4, 9 and #10 are considered most representative of the armour bed material. The median D_{50} value from these three samples is about 30 mm, which is adopted as an average D_{50} for the Study Reach.

Note, the gradation curve for Bar #15 curve is not considered representative of average sediment sizes within the Study Reach because the channel slope at this location is comparatively steep relative to the rest of the channel (1.6%; Figure 4), which naturally results in coarser bed material.

Fluvial Processes in the Study Reach

Bed Material Erosion

The potential for bed material erosion in the Study Reach is assessed in terms of the critical shear stress required to dislodge and entrain particles from the armoured streambed. Shields (1936) determined that the critical shear stress, τ_{cr}, required for entrainment of particles on hydraulically rough beds (i.e. gravel beds) can be determined from the following formula:

$$\tau_{cr} = 0.06\ g\ (\rho s - \rho)\ D / 1000 \qquad (1)$$

Where:

τ_{cr} = the critical shear stress in kN
g = gravitational constant of acceleration, 9.81 m/s^2
ρs = density of the bed material, taken as 2,650 kg/m^3
ρ = density of water, 1,000 kg/m^3; and,
D = sediment diameter (expressed as the D_{50}) in m

The use of Equation 1 is a simplified approach that does not account for effect of variations in the flow or variations in bed material characteristics (Knighton, 1984). Generally speaking, variable flow conditions, including flow surges and turbulence, increase the potential for bed erosion while variations in the size and shape of individual sediment particles will tend to decrease erosion

Bearing the above limitations in mind, the shear stress determined using Equation 1 should be regarded as an average estimate. According to Equation 1, a critical shear stress of 0.029 kN/m^2 is required to initiate bed material transport in the Study Reach.

Bed Material Transport

Once the bed material is entrained by erosion it is moved downstream when the average bed shear stress exceeds the critical shear stress for an extended period of time. The distance over which particles are transported depends mostly on the size and shape of the individual grains, and the duration of high flows. The average bed shear stress is calculated from the following formula:

$$\tau = 0.75\ \gamma\ y\ S \qquad (2)$$

Where:

τ = the average bed shear stress in kN;
γ = specific weight of water, 9.81 kN/m^3;
y = average depth of flow, m; and,

S = Reach average channel slope, 0.004 m/m (0.4 %)

The coefficient, 0.75, in Equation 2 accounts for the fact that not all of the shear stress in the River will be available for transporting sediment. In this study is it assumed that 25 percent of the total shear stress (1 – 0.75) would be used to overcome internal shear and the external resistance imposed by gravel bars, streambanks, debris etc.

Equation 2 is used to determine the average shear stress for a range of depths, y. The discharge corresponding to each value of shear stress is back-calculated from Manning's Equation with 'n' equal to 0.04. A plot of discharge vs. shear stress is then produced (Figure 9).

The threshold discharge (Q_t) required to transport sediment is that which corresponds to the critical shear stress, 0.029 kN/ m^2. From Figure 9, Q_t for the Study Reach is approximately 30 m^3/s. This discharge has a return period of between 1 and 2 years (Table 2), which means that it occurs about once a year on average.

Figure 10 shows the number of days per year for which Q_t was equalled or exceeded at the WSC gauge 08MH006. It is important to emphasize that the amount of sediment transported in a given year is dependent upon the annual duration of flooding in excess Q_t, and not just on the magnitude of the annual peak discharge, as is often assumed. For instance, the annual peak discharges in 1997 and 1998 were about equal (Figure 3), yet the duration of Q_t in 1997 was twice that 1998 (Figure 10). This means that twice as much sediment was moved through the system in 1997.

Adjustment of Channel Slope and Pattern

Channel slope and channel pattern are variable in time and space, and all streams adjust their position in response to increases in discharge and/ or sediment supply.

Meandering streams adjust to high flows and increased sediment supply by eroding their banks and depositing excess bed material on point bars (Figure 7). On the other hand, braided streams adjust by depositing excess bed material randomly in the channel, which can result in the erosion of both stream banks simultaneously. By their nature, braided streams tend to have steeper slopes and wider channels then their meandering counterparts.

Riprap bank protection, roads and roadway crossings have resulted in severe confinement of the Study Reach, such that it is no longer able to adjust its position in a stable and predictable manner. The opportunities for adjustment are limited to a few locations, including the Subject Property, where the streambanks remain readily erodible (Figure 5). Furthermore, since the River's energy is focused on these few locations, the rate of erosion tends to high.

Another noticeable trend in the Study Reach has to do with the disappearance of available in-channel sediment storage. The potential for existing gravel bars to grow and take on new bed material is impeded by the channel's confinement. Thus, bed material has a greater tendency to collect at random locations within the channel as high flows recede, which encourages braiding. Braiding behaviour in a confined channel is inherently unstable because the channel cannot widen uniformly to accommodate the loss of flow area taken up by the deposited bed material. Exposed banks in such areas may be subject to sudden and excessive erosion.

Evidence of Channel Changes

Bankline Comparisons in the Study Reach

Historic airphotos are presented to provide evidence of channel changes that have occurred in the Study Reach over the past 40 years.

Comparisons between different years are made by first adjusting each photo to a common scale, then tracing the banklines, and finally by overlaying the traces on one another. Since none of the airphotos have been ortho-corrected, the bankline comparisons are somewhat affected by distortion. The following comparisons are provided:

- Figure 11: 1964 vs. 1984
- Figure 12: 1984 vs. 1996
- Figure 13: 1996 vs. 1999

In each of these figures, the blue trace line represents the earlier year in the comparison, while the magenta line represents the later year. Key observations from the bankline comparisons are summarized below.

1964 vs. 1984

- Meandering behaviour is evident between Station 0+200 and Station 1+300, where the channel position shifted as much as 25 m between 1964 and 1984. The bank protection that exists between these two Stations today was evidently not in place prior to 1964.

- There is no evidence of braiding (multiple channels) in the Study Reach.

- Bank protection appears to have been constructed between Station 0+000 (132nd Ave.) and Station 0+100 (P1 to P3 in Figure 5), judging by the fact that the left bank shifted eastward against the natural migration of the meander bend.

- The reduction is surface area at Gravel Bar #2 (immediately upstream of the Subject Property) reflects stabilization due to the growth of vegetation. Further development of this bar is inhibited by the bank protection along the outside of the bend at Station 0+100.

1984 vs. 1996

- Two noteworthy floods occurred in the latter half of this period: a 40-year event in 1986 and a 15-year event in 1990 (Figure 3). As well, a significant amount of sediment moved through the Study Reach in these two years (Figure 8).

- The large gravel bar between Station 1+000 and 1+100 formed during this period, most likely as a result of above average sediment supplies in 1986 and 1990.

- Meander migration and bar development is reduced between Station 0+200 and 1+000, indicating that the area was protected sometime between 1964 and 1984.

- Braiding is evident near Station 0+400; local confinement of the channel may have led to mid-channel deposition of bed material and subsequent erosion of both banks at once.

- Gravel Bar #2 appears to have grown slightly in the upstream direction, but overall the area immediately upstream of the Subject Property did not change significantly. Sediment supplied to this area in 1986 and 1990 would likely have been transported past Bar #2 and deposited downstream instead, possibly adding to the size of Bar #1 and increasing erosion of the bank at the Subject Property.

1996 vs. 1999

- Two noteworthy floods occurred during this period: a 5-year event in 1997 and a 10-year event in 1998 (Figure 3). As well, a significant amount of sediment moved through the Study Reach in 1997 (Figure 8).

- Increased braiding and some channel widening is evident near Station1+050.

- Meander migration and bar development is very limited. In fact, the areal extent of many gravel bars appears to be reduced, having been reclaimed by vegetation.

Evidence of Channel Changes near 132nd Avenue

Photos 29 and 30 provide upstream views toward Bar #2, and were taken in 1994 and 2003, respectively. The comparison provides further evidence that the size of Bar #2 has remained relatively constant over the years, likely due to protection of the opposite bank.

Figure 14 compares surveys of MOE Sections 111 and 112, which are located upstream and downstream of the 132nd Avenue Bridge, respectively. The black lines represent MOE's 1989 survey, and the red lines represent the survey completed by **nhc** in October 2003.

- At Section 111, downstream of the bridge, bed material aggradation near the centre of the channel is balanced by sediment degradation near the left bank;

the average bed level at this Section does not appear to have changed. The thalweg has shifted against the toe of the right bank.

- At Section 112, upstream of the bridge and near the Subject Property, Bar #1 has grown outward and caused the thalweg to shift 6 to 7 m towards the Subject Property. The average bed level at Section 112 increased by about 0.2 m.

The growth of Bar #1 and subsequent bank erosion at the Subject Property documented in Figure 14 is evidence of the River's natural tendency to meander at this location. Photo 31 provides a recent, upstream view of the channel taken from 132nd Avenue, and shows the extent to which Bar #1 has advanced toward the Subject Property. Photo 32 was taken during the recent flooding in October and clearly shows the secondary currents which drive the meandering process.

Ultimately, the erosion due to meandering at the Subject Property may be impeded by confinement of the channel upstream where the left bank is protected (P2 and P3 in Figure 5) and downstream where the channel is trained by the 132nd Avenue Bridge. These two 'fixed' points place a limit on the local planform geometry of the channel, which will eventually prevent the Subject Property bank from translating farther eastward in a uniform fashion. This is already evidenced by the fact that the thalweg has not shifted directly up against the toe of the bank; in fact the bank has self-armoured its toe with 30- to 40 mm gravel (Photos 28 and 31).

It should be noted that once the meandering at the Subject Property is halted, there will be an increased tendency for braiding to occur in the adjacent channel, which could further threaten the bank.

@ EDGE

Bridge Hydraulics at 132nd Avenue

Former Bridge Arrangement

The former bridge was designed by Gower, Yeung and Associates Ltd. A cross-section view of the bridge opening is provided in Figure 15 (black ink) and a plan view of the pier and abutment layout is provided in Figure 16 (labelled as 'Exist Col.').

The former bridge had a total span of 36.9 m and a centre clear span of 18.3 m. The abutments and piers of the bridge were composed of timber piles and planking, and were skewed by about 40 degrees relative to flow in the River (Figure 16). Abutment A2 and pier P4 were connected by a solid timber plank wall, which extended up through the full height of the bridge (Photo 33). The left side of the bridge opening, between Pier 2 and left abutment, A1, was infilled with sediment (**nhc**, 1994; Photo 35).

The skew angle of the piers and abutments reduced the effective width of the bridge to about 9.8 m as shown in Figure 13. The resulting constriction caused and maintained a deep scour hole through the bridge opening, and gravel infilling to the left side of Pier 2 (Photo 30; Figure 14, Section 111).

Existing Bridge Arrangement

The existing bridge (Photos 31 and 32) was designed by Earth Tech (formerly Reid Crowther and Partners Ltd.) and constructed in 1995. Cross-section and plan views of the bridge opening are again provided in Figure 15 (red ink) and Figure 16, respectively.

The existing bridge has a total span of 37.6 m and a centre pier aligned with the flow. The centre pier consists of a concrete cap supported by seven steel pipe piles. Both abutments are vertical with spill-through riprap embankments. The riprap at the upstream right-hand corner of the bridge forms a spur that extends about 1.5 m farther into the channel than the rest of the embankment (Photo 34).

The left side of the bridge opening between the pier and left abutment is infilled with gravel (Photo 36), and as a result, the right half of the bridge conveys most of the flow over the typical range of discharges. The right half of the bridge has a width of approximately 18 m, which slightly exceeds the average bankfull width for the Study Reach.

Hydraulic Impact of the Bridge Replacement

The hydraulic design of the replacement bridge addressed two issues: (1) to widen the channel to its more natural width, as directed by the DFO; and, (2) to reduce upstream flood levels, particularly for the 200-year design flow. The new bridge nearly doubles the effective width of the bridge opening from 9.8 m to a more natural width of 18.8 m; and, numerical hydraulic modelling estimated that the 200-year water level upstream of the bridge was reduced from El. 11.0 m to El. 8.6 m as a result of wider section (**nhc**, 1994).

At lower flows the new bridge section is also less constrictive, which results in overall lower velocities and allows for greater bed material storage across Bar #1. This in turn allows the natural meandering behaviour of the River to develop upstream of the bridge (Figure 14, Section 112).

The older bridge included a solid timber plank wall between the right abutment and right-most pier, which tended to fix the flow further out from the right bank. The former timber wall is now mimicked by a rock spur at the upstream right corner of the abutment which extends further into the channel (Figure 15). Without this riprap, erosion at the Subject Property would likely be worse than it is now.

Summary and Conclusions

- The existing 132nd Avenue Bridge was constructed in 1995 to replace a timber bridge. The owner of the property on the right bank upstream of the bridge (the Subject Property) maintains that bank erosion alongside her property has increased in recent years due to the hydraulic effect of the existing bridge.

- Recent floods that have occurred on the North Alouette River include successive 5- and 10-year events in 1997 and 1998. A more recent flood in October 2003 appeared to have any even higher return period, though this has yet to be confirmed by the Water Survey of Canada.

- **nhc** has determined that the threshold discharge required to initiate sediment transport (Q_t) along the Study Reach is about 30 m^3/s, which has a return period of between 1 and 2 years. In 1997, Q_t was exceeded six times over the space of five separate flood events, which means that the total volume of sediment introduced to the North Alouette in that year was three to six times the annual average.

- During an inspection of the Study Reach, **nhc** noted that nearly 40 percent of the streambanks in the reach have been protected with riprap. Of the remaining streambanks that are exposed to flow in the River, more than 70 percent are currently experiencing erosion. The most severe erosion, including that at the Subject Property, was noted along the right bank of the channel, where the bank material is composed of loose, non-cohesive sediment.

- The new 132nd Avenue bridge provides for a wider, more natural cross-section compared to the old bridge. The widened section has given the thalweg of the channel the freedom to shift towards the right bank at the Subject Property; therefore, the bridge may indeed be partly to blame for the increased erosion noted by the property owner.

- In **nhc's** opinion however, erosion at Subject Property is due in greatest part to the natural meandering flow pattern that exists at this location. Secondary currents associated with this flow pattern originate from the upstream meander bend (Station 0+100) and impinge directly of the Subject Property bank.

- Since bank erosion is a primary means of channel adjustment in response to increased flows and sediment supply, the rate of bank erosion can be expected to rise in proportion to both the magnitude of flooding and the volume of sediment supplied. As such, relatively high rates of erosion would have occurred at the Subject Property in 1997 and 1998, and quite likely in 2003 as well.

- Ultimately, the extent of erosion at the Subject Property is restricted by the protected upstream bend and the 132nd Avenue Bridge. It should be noted, however, that since meandering at the Subject Property is limited, there will be an increased tendency for braiding to occur, which could further threaten the bank.