Historical Changes of Minto Channel during the Twentieth Century

prepared for

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by

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This report is a preliminary draft of the intended final report. The reason for its draft form is that certain information we have requested has not yet been delivered to us. In particular, we do not yet have the data of the 1984 Fraser River channel survey, which included Minto Channel, and we are still awaiting receipt of certain cross-section surveys which we have requested.

In addition, federal air photography of 1928 has not yet been delivered to us and we have been able to examine only a partial photo coverage of the study area at that date on file at the University of British Columbia. It also remains to confirm some details of gravel borrow volumes.

We expect to be able to receive and analyse the outstanding information by December 15, 1998.

Nonetheless, the information presented in this report represents the bulk of all the information that exists on Minto Channel. We do not expect the main observations and conclusions to be affected by acquisition of the additional information. That information will, however, enable us to present certain conclusions in a more quantitataive fashion. A revised report will be issued as soon as all the information is received, or on December 15.

Purpose and organization of this report

Minto Channel is a major left-bank side channel of Fraser River which runs from near the mouth of Harrison River to a point downstream of the City of Chilliwack (Figure 1). In the late 19th century the main channel flowed on the left side of the river, but the growth of the island group which separates Minto Channel from the main channel today isolated the left bank from the main flow early this century. Continuing channel changes around the mouth of Harrison River, the effect of the natural sedimentation of Fraser River, determine the flow of water and gravel into Minto Channel. It is conceivable that Minto Channel could again become the main channel in this reach of the river.

The settlement of the land and growth of the nearby City of Chilliwack this century lend particular significance to the possibility for changes to flow and sedimentation in Minto Channel. In particular, changes which would increase erosional attack on the left bank would threaten dykes which protect the city and would consume valuable property. It is therefore imperative to foresee situations in which Minto Channel might be destabilized, and to take steps to prevent that happening.

A factor influencing the current condition of Minto Channel is the extraction of gravel from the channnel which has been carried on for many years. The downstream portion of the channel is deeper than it naturally would be and has a larger potential water conveyance capacity. This circumstance could influence the flow through the channel should the diversion of additional water into the channel be initiated upstream.

The purpose of this report is to document the historical changes of Minto Channel during the twentieth century to provide the basis for forecasting new changes that may result from the continuing development of Fraser River channel. The report describes some changes that appear to be possible in light of the current configuration of the river and the recent history of channel development.

The report is organized as follows. The next section provides a brief summary of the conditions and processes in Fraser River which create channel instability, and briefly describes the style of instability in the river. The following section describes the history of Fraser River this century between the mouth of Harrison River and the downstream limit of Minto Channel. The next section documents changes in the channel geometry in Minto Channel, which have been influenced greatly by gravel removal. The final section indicates possible future developments of Fraser River in this reach, with particular reference to Minto Channel.

Sedimentation and morphology in Fraser River in the gravel-bed reach

Between the downstream end of Fraser Canyon and Sumas Mountain, Fraser River flows on a gravel bed which consists of sediments transported and deposited by the river. Deposits build up where the gradient of a river declines so that the flow is no longer sufficiently powerful to wash all of the sediment load farther downstream. Fraser River encounters a rapidly declining gradient after it leaves the Canyon and approaches the sea in the Lower Mainland, hence a significant volume of sediment is deposited here.

Gravel and sand, the larger materials carried by a river (in comparison with silt and clay) is transported on or near the bed. When it is deposited, it comes to rest within the normal channel. (Silt and clay are commonly carried in suspension by the turbulent flow and deposited in quiet water zones in back-channels, on flooded bar tops, and overbank during flood.) Significant deposits of sand and gravel in the channel zone cause the river to flow around them, leading to impingement of strong currents on the river banks, bank erosion, and lateral shifting of the channel. This phenomenon occurs in Fraser River downstream from Laidlaw (figure 2). The deposited material forms large bars in the channel and, where the bars build to sufficient height, islands. This morphology is typical of rivers that persistently deposit material and aggrade (build up) their bed. If the river is not confined by valley walls, the entire deposit forms an "alluvial fan" -- a cone shaped deposit which on smaller rivers is sufficiently steep to be noticed as a specific landform. Between Hope and Sumas Mountain, Fraser River is flowing over a confined alluvial fan (that is, an alluvial fan that is prevented by valley walls from unrestricted lateral expansion; see figure 3). If a river is further confined by human activities such as dyking, construction of roadways or railways along the banks, or bank stabilization works, the zone within which the channel may move laterally and deposit material is further constrained and the rate of vertical aggradation within that zone is increased. Deposition continues until the channel has become sufficiently steep to move the sediment load farther downstream. The situation described here is not peculiar to Fraser River. Nearly all of the larger, gravel-transporting rivers that flow out of the Coast Mountains display similar reaches. Fraser River is decidedly the largest of them.

Material that is deposited in the channel bed is referred to as alluvial bed material (alluvial = deposited by the river). Once deposited, bed material is susceptible to be reentrained and moved farther downstream during subsequent high flows. The pattern of onward movement of this bed material is the key process determining the river morphology. The morphology of the river is the product of the movement and rearrangement of the alluvial sediment deposits by the water flow. Aggradation occurs when, on average, more material is deposited than is reentrained.

The bed material is moved only sporadically. In Fraser River, significant gravel movement (i.e., greater than 100 tonnes/day) begins only after the river reaches about 4000 m^3s^{-1} water discharge which, on average, occurs about 22% of the year, within the period mid-May to early August. Once entrained, bed material does not travel a long way. A typical step-length varies between a few hundred metres and a few kilometres. Then the material is redeposited. Finer material travels farther. Material is deposited where flow diverges and loses velocity. In such places, material accumulates to form the major bars that redirect the flow.

The process of redirection of channel flow by deposited material initiates attack on adjacent banks, new erosion and replacement of part or all of the lost load. In this manner, bed material is staged down the river over many years (figure 4). The process varies along the channel so that, locally, deposition or erosion may be dominant. Hence, local fluctuations occur in the magnitude of bed material transport. Furthermore, persistent deposition and persistent erosion tend to be localised in the same vicinity for some years. Only after the cumulative change of years is channel realignment sufficient to relieve and relocate the processes. As a result, certain reaches of the river become known, over several years or decades, as sites of persistent instability, whilst other reaches appear to be stable.

The reason why it takes years to "reorganize" the channel and change the local channel activity is that the river is large, whilst the total load of bed material transported down the river remains modest. From a 20-year record of sediment transport measurements conducted by the Water Survey of Canada at Agassiz and Mission, we know that the average annual transport of bed material past the Agassiz-Rosedale bridge is in the order of 200 000 tonnes (McLean and Church, 1986; bed material here is defined as material larger than 2 mm diameter; that is, all material larger than sand). A sediment budget determined by McLean (1990) for the Agassiz-Mission reach of the river indicates that bed material transport downstream from the mouth of Harrison River is less than 100 000 tonnes per year, on average. Such a quantity of material piled 5 m deep (the depth of the main channel in the Agassiz-Harrison reach at half-flood), would occupy a square of only 110 metres on a side. Of course, as material is sequentially entrained and deposited downstream, much larger total volumes of material and area are disturbed each year along the reach[11]. But at any one place, it takes many years of progressive change to effect a realignment of the 500 m wide main channel.

For the same reason, major flood years do not stand out as years when exceptional channel changes occur, even though much greater volumes of sediment are moved in these years. Observed annual volumes of gravel transported past Agassiz vary from 60 000 tonnes to 320 000 tonnes.

All of the gravel is finally deposited before Mission. On balance, there is more material deposited along the reach than is eroded. However, this balance is not strictly observed locally and the reduction in gravel transport does not occur smoothly. Most of the gravel is deposited in a restricted number of deposition zones where notable local aggradation (increase of sediment deposits and rise of the streambed) and channel instability occur.

The river morphology that results features many gravel bars with surfaces exposed for most of the year, smoothly sloped river bottom from the main channel floor onto aggrading bar surfaces, and multiple channels around the bars. Many bars build to the point that they have slack water

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[1] To a first approximation, the ratio: (volume disturbed/transport rate) = 1/2(reach length/transport distance) can be used to estimate the amount of sediment disturbed, the factor 1/2 being introduced to cover the fact that total gravel transport declines downstream to zero at Mission. The transport rate referred to would be an average for the entire reach. For the 50 km reach between Sumas Mountain and Laidlaw, the ratio for an estimated average transport distance of 2.5 km is of order 10:1, so the amount of bed material disturbed each year along the entire reach could easily exceed 1 million tonnes.

across the top, even in flood. Sand begins to be deposited there, vegetation becomes established, and the surface builds up to form an island. Islands may persist for centuries before they are eventually attacked by the river again and removed. The secondary channels along the river are established by the process of island formation dividing the river: they are not the product of the river flowing out of its former channel. The longevity of many islands is another indicator of the slow pace of major change along the river. Where erosional attack occurs, banks are steep or vertical and the water is deep and fast immediately offshore. “Scour holes” may exceed 25 m in depth where the main current runs directly onto a shore.

This morphology is ideal fish habitat, with about 20 species occurring in the reach. The episodically reworked, but seasonally stable gravels provide spawning substrate for chum and pink salmon. The secondary channels and slackwater zones provide rearing habitat for several salmonid species while the multiple channels provide extensive bankline where hiding zones and drop-in food sources occur. Scour holes form sturgeon habitat. Furthermore, the smoothly varying bottom off building bar edges guarantees that a range of flow depths will be available for the fish and for the invertebrates upon which they feed at all stages of flow. Kellerhals et al. (1987) gave a detailed discussion of the use of the river by salmonids.

The quality of the habitat depends not just upon the morphological complexity, but also upon continued change. Gravel transport maintains a relatively loose streambed which the fish can work to excavate spawning redds, and it cleans fine material out of the gravels, allowing life-supporting water circulation through the egg nests. Bar and island reconstruction maintains the pattern of secondary channels, slack water zones and extensive edge environments that provide the necessary range of rearing habitats and migration corridors. The extent and complexity of the channel zone also provide habitat for many river-oriented small mammals and birds. Conventional channelixation of the river would disrupt the processes of change and significantly degrade habitat quality.

Historical channel changes in Minto Channel and vicinity[2]

Minto Channel forms part of a complex series of islands and channels extending from Foster Bar to the downstream end of Minto Channel, in the vicinity of the confluence of Fraser and Harrison Rivers (figure 1). There appears to have been significant aggradation in this reach throughout this century. The sediment budget since 1952 (McLean, 1990) confirms this circumstance.

The first maps of the channel derive from the first land surveys and the Township Survey conducted late in the 19th century. The land survey notes have been used by North and Teversham (1984) to construct a map of river conditions ca. 1875 (figure 5a). That map shows a line of islands extending from the left bank[3] near Cary Point, diagonally downstream to the right bank at the upstream end of Nicomen Slough. The islands carried forest vegetation, indicating some degree of permanency. The configuration of the islands, along a long diagonal riffle, is a typical one for a gravel-bed river, so this map appears to be relatively accurate. It also implies

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[2] For the location of geographical features named in this and the following sections, see figure 17.

[3] River banks are conventionally named according to their relative position when the observer is facing downstream: hence, the left bank of Fraser River is the south/east shore.

that the sloughs on the left bank (Nelson Slough, Camp Slough, Greyell Slough, Shefford Slough) were more active back-channels in the 19th century. The left-bank channel that subsequently has become Minto Channel appears already to have been present on the downstream side of the diagonal riffle, but located riverward of the modern Minto Channel. The Township Survey (figure 5b), made only 10 or 20 years later, shows substantially fewer islands, and none at the mouth of Harrison River. The main channel appears to have been toward the left bank, but that bank was still considerably farther to the northwest (i.e., riverward) of the modern bank. Movement of the main channel to the low side of the riffle would be a normal development. Furthermore, in the period between 1878 and 1894 there were several major floods, culminating in the 1894 flood of record, which may have effected cumulatively important changes in river alignment. But whilst the banklines of the river undoubtedly were accurately placed in the Township Survey, it is possible that details of the morphology and channels of the river were only sketched. Hence, the overall reliability of the depiction of river features on this map, especially in comparison with the earlier map, is difficult to establish.

The first aerial photography was flown on 15 July, 1928, when the river was relatively high (5780 m^3s^{-1} at the Hope gauge[4]). Consequently, details of the channel bars are not visible (figure 6). The major island group that is present today opposite lower Minto Channel was already present, but was much less extensively developed. If the Township Survey is relatively reliable, these islands largely developed in mid-channel during the early years of the century and split the flow of Fraser River about them, so that there was significant flow on both sides of the developing islands. At the mouth of Harrison River, the complex of bars and small islands that is still present today was already evident, although the detailed morphology was considerably different. It is likely that this bar complex is a permanent feature since Fraser River flows slacken upstream from the confluence and would tend to deposit material here. Significantly, only one island is shown in this vicinity on the Township Survey (still present in 1928), suggesting that channel zone features probably were not noted in detail on that map. The entrance to the left bank channel -- what has become Minto Channel -- was farther north than its subsequent location, adjacent to an island at the mouth of Nelson Slough. However, the islands developing downstream had already displaced the channel to the south, so that substantial erosion occurred on the left bank along lower Minto Channel between 1900 and 1928. Minto Landing, located where the turn-of-century channel (and current) moved offshore, marked the upstream limit of this erosion. The current left bank of lower Minto Channel was largely established by 1928.

On 7 April, 1938, photographs were taken at low flow (figure 7). Minto Channel, the entrance to which was still north of the island off Nelson Slough, was filled with gravel and sand. One of the exits from Nelson Slough flowed into Minto Channel. Only the lower part of the channel contained water. Since this is the first view we have of the channel bed, one might ask whether the channel had always been so shallow, hence whether the earlier appearance of a major channel on the left bank was false. It is unlikely that Minto Landing -- established before the turn of the century -- would have been sited where it is if a perennially navigable channel did not formerly

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[4] All flows in this report are referred to the Hope gauge, even though Fraser River flow increases at the confluence with Harrison River. Mission flows are available only from 1966.

exist along the left bank. At the mouth of Harrison River, the former main channel through the centre of the bar complex there, had silted up by 1938, with successor channels about each side of the bar. The left branch flowed against the Nelson Slough island and then turned sharply northwest. Significant erosion was occurring at this bend. The right branch flowed toward the mouth of Harrison River, and then turned sharply left against Harrison Knob with the Harrison River flow.

Photographs taken on 5 December, 1943 (figure 8), reveal important changes at the upstream end of Minto Channel. The left branch of Fraser River channel about the island complex at the mouth of Harrison River has become clearly the dominant branch. It has nearly entirely removed the island at the entrance to Minto Channel and then turns sharply right to rejoin the balance of the river north of the Minto island group. Fraser River flow now occupies the channel behind the island, formerly an outlet channel of Nelson Slough. This delivered flow into Minto Channel, even at the low flow of 929 m^3s^{-1} on that date. Elsewhere there was incremental erosion and deposition, but no major changes. Vegetation on the island group defining Minto Channel filled in notably between 1938 and 1943 and island growth was evident on Harrison bar, whilst the channels leading into Shefford Slough appear to have been silting up throughout the preceding period. The changes that occurred between 1938 and 1943 near the head of Minto Channel are typical of channel change along Fraser River. In the late 1930s the main channel, which had been moving to the left upstream, took up a configuration which intiated erosional attack on the island guarding Minto Landing area. It was then eroded rapidly, opening access to Minto Channel.

Our next photographs date from 23 March, 1949 (figure 9)(1948 photography was flood photography, which does not reveal the condition of the channel bed). Continuing the rapid changes at the upstream end of Minto Channel, Fraser River has established a single major channel through the south side of the Harrison River mouth bar, and has deposited a major gravel bar on its left side upstream from the remaining remant of the Nelson Slough island. This activity had the effect of extending the entrance to Minto Channel 1 km upstream. The bar features on the 1949 photography exhibit the high avalanche faces typical of major deposition during a large flood, so it is likely that a substantial portion of the post-1943 change occurred during the 1948 flood (maximum daily flow 15 400 m^3s^{-1} at Hope). There is evidence of substantial fresh sand deposition on the Minto group of islands and bar features within Minto Channel changed substantially from 1943 to 1949, all of which would be expected given the 1948 flows. Sediment deposition on the main body of the Harrison bar and in the channels on the Fraser River right bank cut off the right bank branch, so the mouth of Harrison River effectively migrated south to the southern tip of Harrison Knob.

The 1949 configuration of Fraser River featured a single major channel with two open bends, to the left past Harrison bar, and then to the right past the Minto island group. There were abundant flood channels through both bar complexes, and Minto Channel carried water at low flow. From the viewpoint of adjacent settlement and land use activity, this is an attractive configuration since it threatens no acute attack by the river at any vulnerable place.

Photographs taken on 7 May, 1954 (figure 10), reveal no major changes since 1949, even though there was a major freshet in 1950 (12 500 m^3s^{-1} maximum daily discharge at Hope, at the time the second highest recorded flow). There has been additional sedimentation on the upstream end of what was now the very extensive Minto bar complex and notable island consolidation on the south side of Harrison bar. There was, as well, some erosion on the left bank of the river where it turns to the right at the upstream end of Minto bar -- about 75 m cumulatively from 1949 to 1954.

The 1963 photography (figure 11) was taken on 28 April at the relatively high flow of 3060 m^3s^{-1}. In comparing the 1954 and 1963 photo mosaics, the much higher flow of 1963 must be kept in view. There was no fundamental change in channel configuration from that of 1954, but some important changes occurred in detail. Upstream, gravel has accreted onto the outside of Foster bar. On the right bank of Fraser River, opposite, compensating erosion has substantially trimmed the upstream end of the Harrison bar complex (by up to 250 m). The eroded material was deposited at the point of Harrison bar 2 km downstream, pushing the main channel to the left by 500 m. The consequence was the erosion of about 400 000 m^2 area from the head of the Minto bar complex. The net result of these changes was to tighten both of the bends of Fraser River established by 1949, with the tightest bend at the upstream end of Minto bar near the shallow entrance to Minto Channel. The configuration in that vicinity was superficially again like that of 1943. Elsewhere, there was some expansion of vegetation on the downstream portion of Minto bar, indicating extension of island development.

The trends identified in 1963 continued through the 1960s. By 1969 (figure 12) there had been a huge accretion to Foster bar, forcing the river channel to the right bank by one entire channel width. The effect of the sharp curvature induced here was to increase resistance to flow sufficiently for the river to reoccupy the old right bank channel around Harrison bar, so that divided flow was reestablished around the now substantially enlarged Harrison bar/island complex. Erosion from the upstream portion of Harrison bar, opposite Foster bar, continued to be deposited on the sourthern edge of the bar, forcing the left branch of the river hard against the left bank near the outlet of Nelson Slough. The appearance of substantial accretion along the upper portion of Minto bar is difficult to confirm because there is no realignment of the channel here, and the appearance may thus be the consequence of the substantially lower flow in 1969, in comparison with 1963. The left branch of the river has, however, clearly become relatively tortuous.

Our next view of the river (1974: figure 13) follows the flood of 1972 (maximum daily flow 12 900 m^3s^{-1} at Hope). The major change is the switch of the main channel to the right branch around Harrison bar. This change entailed the complete and nearly complete erosion of two substantial islands near the mouth of Harrison River. At the mouth of Harrison River, Fraser River was forced to turn sharply left against the hard ground of Harrison Knob, and then turned again at the northeast corner of Minto bar. The channel shift occurred in 1971, before the 1972 flood, and was the ultimate consequence of the realignment of the approach channel forced by the growth of Foster bar. The old left channel -- the remains of the 1949 channel -- was still present, but much reduced. Continued accretion of material to Foster bar made the entrance to this channel nearly a 90^o takeoff from the new main channel, which would sharply reduce the entry of additional bedload into it. Elsewhere, changes were surprisingly minor.

Between 1974 and 1979, the northward flowing portion of the old main channel/left branch, which divided Minto bar from Harrison bar, completely filled in (figure 14), so the two bars were joined into one very large flow flow island/bar complex. This extended the entrance to Minto Channel upstream to Foster bar. In the mainstem, a new “Harrison bar” began to develop immediately upstream from the confluence with Harrison River. The backwater effect induced by the addition of Harrison River water and the sharp bend undoubtedly produced slack water here which induced gravel deposition in the middle of the channel. Foster bar continued to grow both outward and downstream, forcing the uppermost reach of what was now Minto Channel to migrate westward by about one channel width. Elsewhere, changes were minor. Hence, by 1979 there was no trace left of the 1949 channel past the mouth of Harrison River.

Photography of 4 September, 1986 (figure 15), was taken at substantially higher flow than preceding sets (in fact, at just below mean annual flow level). It reveals substantial flow through Minto Channel at half flood, entering by spill over Foster bar. The low flow entrance to the channel has shifted no further since 1979. There was also development of Harrison bar, at the mouth of Harrison River. However, the main development in the early 1980s was the substantial extension of perennial vegetation on the old Minto/Harrison bar complex, giving the appearance of the development of a major island here.

1993 photography (figure 16) was taken at an even higher flow, just above mean annual level. Again, the filling in of forest vegetation on the large island is the major evident change. Altogether, there was very limited change in channel configuration between 1979 and 1993. In this period there was no further notable accretion of Foster bar either. In general, the period between the mid-1970s and the early 1990s experienced relatively low freshets, so the stabilisation of the channel configuration that occurred in this period is perhaps the consequence of that. There was similar stabilisation of the bar complex off the old entrance to Nicomen Slough, opposite the outlet of Minto Channel. Nonetheless, significant realignment of channels, with accompanying sediment transfers, were occurring upstream in the Cary Point reach.

Photographs taken on 23 July, 1996 (figure 17), at half-flood again show the recent configuration of the river and emphasise the broad but shallow entrance to Minto Channel at higher flows. The main flow moves straight past this sharply angled entrance. However, backwater induced by conditions at Harrison River undoubtedly increase the spill into Minto Channel at higher flows and the increasingly complete forest cover on the large island holds most of this flow in Minto Channel. Contemporary conditions appear to be favourable for larger flood flows through Minto Channel than have occurred before. However, there are no measurements upon which to base a comparison.

Cross-sectional geometry in Minto Channel

Surveys of Minto Channel have been taken irregularly and fall into two groups. In 1952, 1984, and 1991, complete hydrographic surveys were undertaken. The 1952 survey was conducted by Public Works Canada as part of complete survey of Fraser River channel between New Westminster and Yale following the 1948 flood. The 1979 and 1984 data are from channel surveys conducted by the Water Resources Branch, Environment Canada, the latter as part of a survey of the channel between Mission and Agassiz to establish the sediment budget of the river. The 1991 survey was a navigation survey conducted by the Canadian Hydrographic Service (Canada Department of Fisheries and Oceans). This was a channel survey only, so that bankline positions and elevations are not available on that date. In other years, cross-sections have been surveyed at specific locations as part of the monitoring of gravel removals. For this report, we have extracted cross-section data from the hydrographic surveys in order to make comparisons at various dates. The locations of the cross-sections are shown on figure 1 and the sections are displayed in figure 18.

Cross-sections 1 through 4 (figure 18(a) through (d)) are downstream of the reach where the main gravel extraction has occurred. Line 1 exhibits 0 to 3 m of degradation between 1952 and 1991over 250 m of repeated survey. This could easily result from changes in confluence conditions with the main channel over this 39-year period. Lines 2 and 3 reveal up to 5 m and 8 m of degradation, respectively, over the same period. But the degradation occurs over only about 125 m of the 300 m wide channel. At Line 4, the degradation is about 9 m over 174 m width. A dramatic drop occurred in the right hand side of the channel to -14 m between 1979 and 1981, which mainly was recovered by 1991. However, the 1991 channel was substantially wider than the 1979 channel, indicating significant net degradation between those two dates. At Line 5 (figure 18e), at the downstream end of the gravel extraction zone, the degradation was up to 10 m concentrated in a 100 m wide zone, but significant degradation covered 200 m width in 1991. Most of the degradation here appears to have occurred before 1979, with the channel thalweg (the thalweg is the line connecting the lowest points along the channel bed) shifting toward the left bank since. Whilst the lowest elevation at the downstream end of the channel was +0.6 m in 1991, it was -3.4 m at Line 4 and -3.8 m at Line 5. A rise in the channel bed is possible if there is a sand bar draped across the downstream end of the secondary Minto Channel, but it is unusual in a gravel-bed channel. The strong degradation in Minto Channel is the relict effect of the dredging of gravel from the channel in the years before 1991.

Lines B, J and R occur in the channel reach where bar scalping has regularly been undertaken. Data for 1991 and 1993 are from survey lines run to confirm scalped volumes. This material is taken from a left-bank bar that has formed in the lee of the channel bend at Minto Landing and on which some degree of replenishment occurs in most years. Sections B and J (figures 18(f) and (g)) display 1990 and 1991 data. The general similarity between them lends confidence that all surveys have been properly reduced to a common datum. These sections show up to 3 m of degradation since 1952. Again, most of the degradation appears to have occurred before 1979, since when the channel thalweg has shifted toward the right bank. The recent elevation of the bed at the lowest point has been about 0 m. About 1 m of fill is evident in the thalweg between 1990 and 1991.

Line R (figure 18(h)) is immediately below the corner at Minto Landing. It reveals substantially greater degradation over most of its length between 1952 and 1991 (the maximum was 7 m). This may have been due in large measure to natural erosion since the bar in 1954 was very wide (figure 10). Between 1991 and 1993, 1 to 2 m of aggradation occurred over most of the channel bed. It is reported that bar scalping commenced in about 1971, but the 1954 air photography shows evidence of excavations on the bar, which represented either small-scale extraction or poorly organised placer activity.

Lines 6 to 10 (figures 18(i) to (m)) are upstream of Minto Landing. They generally show quite dramatic degradation between 1952 and 1991. At Line 6, moderate degradation was accompanied by 60 m of lateral erosion on the left bank. Line 7, in the narrowest part of the channel, exhibits a deep talweg with bottom at -4 m, 6 m below the 1952 level. Section 8, off the downstream end of Hog Island, remained considerably wider and shallower, with the recent bed in the vicinity of +2 m. Hence, there is a dramatic drop in the channel bed between lines 7 and 8 in a distance of less than one-half kilometre.

Lines 9 and 10 again show increasing scour between 1952 and 1991. This may very well be the relict effect of the development of the left branch of Fraser River through this vicinity in the period 1963-1974 (see figures 11 to 13), and the shallower bed at line 8 could correspondingly reflect the upward step into the secondary Minto Channel of that day. But if these interpretations are correct, they imply that sedimentation of the channel bed is not great in upper Minto Channel. But at lines 7 and 8, 1994 surveys by Northwest Hydraulics Consultants show significant changes in the channel bed over 3 years, though it is not clear that general aggradation has occurred. This implies that bed material transfer through the channel is significant.

Table 1 summarises the known volumes of gravel extracted from Minto Channel since 1966. The total is greater than 2.1 million cubic metres (hence averaging more than 66 000 $m^3 yr^{-1}$). These figures are at present of unknown reliability: we have received reports of both larger totals and additional removals. The figures through 1986 probably represent minimum estimates. In the 3.5 km reach of Minto Channel downstream from the late 1960s entrance, 2.1 million cubic metres represents 3 m of degradation over a 200 m bed width. This is comparable with the observed degradation through this reach and indicates that gravel extraction could be responsible for the observed degradation, provided that little compensating influx of bed material occurred. At present, the status of bed material supply to the channel remains unknown.

In an independent study comparing the 1952 and 1984 channel surveys in Minto Channel, McLean and Church (in review) found that 1.8 million cubic metres were lost from lower Minto Channel, and 0.65 million cubic metres from the upper Channel. Up to 1984, more than 1.3 million cubic metres reportedly were removed from the channel, implying either that there was also some natural degradation or that gravel removals to that date are significantly under-reported.

Possible future developments in Minto Channel and vicinity

The 1949 alignment of Fraser River past the mouth of Harrison River (figure 9) was remarkably direct, and effectively guided the main flow away from the vicinity of lower Minto Channel. Since then, persistent growth of Foster Bar has increasingly forced the river alignment to the right toward Harrison Knob. This development initially tightened the river bends in the vicinity of the mouth of Harrison River (figure 11), and then led to the abandonment of the bends after 1970 in favour of a direct route to and around Harrison Knob. That basic alignment of the main channel has been maintained ever since. In the meantime, the former Harrison and Minto island/bar complexes have fused into one large island which keeps the main channel away from Minto Channel today.

The point of greatest potential instability in the present river alignment lies immediately upstream from the mouth of Harrison River. In 1997, a substantial amount of sediment was deposited on the contemporary Harrison Bar. Aggradation here is apt to be persistent. The reason is that the river currents slacken upstream from the mouth of Harrison River due to increased flow resistance created by (i) the confluence with Harrison River flow; (ii) the sharp left bend forced by the rock Knob on the Fraser River flow, and (iii) the increasing sediment accumulation here. The initial effect of this is to raise water levels upstream for any given flow. This will tend to increase spill into Minto Channel. Left to itself, the river will eventually resolve the developing difficulty to convey water past Harrison River mouth in one of two ways:

1. The river will erode an enlarged channel through the south side of the contemporary Harrison Bar, taking a more direct route past Harrison Knob, or;

2. The river will enlarge upper Minto Channel by erosion, and send increased amounts of water that way.

The reason why the main river has not reentered upper Minto Channel (which formed part of the main channel in the early 1960s: see figure 11) is that sedimentation on Foster Bar has held the main flow to an alignment that carries it past the entrance to Minto Channel. At the same time, the bar has continuously prograded into the entrance of Minto Channel, keeping it relatively shallow. Hence, the future sediment balance of Foster Bar also is a significant factor in the possible future development of the river in this vicinity.

At the present time, Foster Bar is gaining a significant amount of material from the rapid erosion of the left bank downstream from Carey Point. That erosion, which has now proceeded more than half the distance from the Point to the upstream limit of Foster Bar, will eventually extend to the Bar. A lateral bar extending into the river off a right bank island opposite the present point of maximum erosion directs the current toward the eroding bank. However, as the locus of erosion moves downstream, the left bank attack should slacken, both because the channel widens beyond the right-bank bar, and because the flow curvature will become less along the channel. When Foster Bar is reached, the main force of the river against the left bank should be spent, so that direct erosion of the river into upper Minto Channel appears relatively unlikely, at least as the sequel to the current left bank erosion. But Foster Bar may then cease to recruit sediment and it may become possible for the entrance to Minto Channel to enlarge if sufficient flows enter it.

The relative size of the freshets may have considerable bearing on the evolution of the channel in the immediate future, a a relatively large freshet being more likely to spill erosive flows into Upper Minto Channel. Within the next five years, the most likely development will be for the river to develop a larger channel on the south side of the present Harrison Bar, especially if a sequence of moderate to modest freshets occurs. However, the substantial island immediately downstream probably will slow the development of that channel.

Over the next ten years, with the completion of the erosional episode on the upstream left bank, it is more likely that flows into Upper Minto Channel will be increased. Erosive flows would lead to the channel capturing an increased share of the flow. If significant flows enter Minto Channel, there is a good possibility for them to flow all the way through the channel, bringing larger flows into Lower Minto Channel than have been experienced for many decades. This might occur because the major island on the right bank of Minto Channel now presents strong resistance to the transfer of flood flows back toward the right bank (main) channel across the middle of the island. even though curvature and relatively shallow depth of Minto Channel off Hog Island might encourage this. In any case, there would be no tendency for such a flow to develop until the division of flow between the two channels has been rearranged to the point that the water surface in the north (right bank) channel is lower than the water surface in Minto Channel.

The present conveyance of Lower Minto Channel is relatively large as the result of the large depths achieved by gravel removal from the channel bed more than a decade ago. Although some filling of the greatest depths has been observed, the deep channel zone has both widened and lengthened in the years since. Extenstion of the overdeepened zone in this manner is the common result of the excavation of deep holes in river beds. With the survey information presented in this report, it is not possible to determine the complete sediment budget of the channel, although analysis of the 1952 and 1984 surveys by McLean and Church (in review), and comparison of the results with the estimated gravel volumes removed indicates that sediment supply to the channel must at present be limited. This is consistent with the limited flows in the channel. It is probable that much of the sediment resupply that has occurred consists of sand rather than gravel. These conditions would encourage the persistence of increased flows through Lower Minto Channel should they initially be directed into it. In view of the close proximity to the channel of developed land, it appears prudent to consider measures that might be taken to control the possible effects of such increased flows, or to prevent their occurrence.

References

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Figure captions

Figure 1. Location map of the Minto Channel study area (Terrain Resource Inventory Map, British Columbia Ministry of Crown Lands). The limits of channels indicate high or vegetated bank lines and the stippled areas indicate bar surface exposed below approximately mean annual flow. Locations are shown of 13 cross-sections in Minto Channel, studied in this report. The location of this figure is shown in figure 2. Scale is 1:25 000.

Figure 2

Figure 2. The gravel-bed reach of Fraser River between Hope and Mission, showing the study area. Photos A30339-76; -107-108, taken 16 July, 1971, Hope flow 6290 m^3s^{-1}; source National Air Photo Library, Canada Department of Natural Resources. Scale is approximately 1:137 000.

Figure 3. Simplified sketch of Fraser Valley in the Hope-Mission region to emphasise the confined alluvial fan over which Fraser River flows. Inset: an unconfined alluvial fan, a typical sediment deposit in mountain regions.

Figure 4. Schematic sketch of the pattern of bed material movement down Fraser River in the gravel-bed reach, showing bar and island development and erosion.

Figure 5. Late 19th century configurations of Fraser River near Minto Landing, redrawn from early surveys. (a) map constructed by M.E.A.North and J.M.Teversham (1984) from early river surveys and land surveyors' notebooks made between 1872 and 1878. The letters on the map indicate vegetation cover: c = grassland; H = alder scrub; o = cottonwood forest; q = cottonwood-cedar forest; r = cedar forest; s = mixed coniferous forest; brackets indicate disturbance. (b) Township Survey, after 1885. (redrawn from McLean, 1990; figure 6.5, p.109). Map scales are approximately 1:75 000 and both have the same orientation.

Figure 6. Air photo mosaic of the study reach, July 15, 1928; Hope flow 5780 m^3s^{-1}. Air photos A288-55, 57, 59, 61, 63, 65, 66 and A296-45, 47, 49, 51, 53, 55; source National Air Photo Library, Canada Department of Natural Resources. Scale is approximately 1:25 000. To facilitate comparisons, a similar scale is maintained for all of figures 6-17.

Figure 7. Air photo mosaic of the study reach, April 7, 1938; Hope flow 750 m^3s^{-1}. Air photos A5869-1, 2, 4, 6, 8 and A5870-1, 2, 4, 6; source National Air Photo Library, Canada Department of Natural Resources.

Figure 8. Air photo mosaic of the study reach, December 5, 1943; Hope flow 929 m^3s^{-1}. Air photos A7077-20, 22, 23, 25 and A7078-60 to 62, 79, 80, 82; source National Air Photo Library, Canada Department of Natural Resources.

Figure 9. Air photo mosaic of the study reach, March 23, 1949; Hope flow 733 m^3s^{-1}. Air photos BC718-29, 31, 33, 35, 37, BC720-117, 118 and BC721-3, 5, 7, 9; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.

Figure 10. Air photo mosaic of the study reach, May 7, 1954; Hope flow 1170 m^3s^{-1}. Air photos BC1683-19, 21, 40, 41, 76, 77, 79, 101, 102, 103 and BC1684-19; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.

Figure 11. Air photo mosaic of the study reach, April 28, 1963; Hope flow 3060 m^3s^{-1}. Air photos BC5062-127, 129, 130, 163, 165, 167 and BC5063-96, 98, 99, 130, 131; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.

Figure 12. Air photo mosaic of the study reach, March 12, 1969; Hope flow 852 m^3s^{-1}. Air photos BC5320-183, 185, 233, 235, 237, 238, BC5321–191, 193, 194, 196, 197 and BC5322-148, 150, 152; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.

Figure 13. Air photo mosaic of the study reach, March 21, 1974; Hope flow 917 $m^3 s^{-1}$. Air photos BC5744-197, 199, 214, 216, 218, 246, 248, 250, 251 and BC5575-37 and 39; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.

Figure 14. Air photo mosaic of the study reach, March 22, 1979; Hope flow 1010 m^3s^{-1}. Air photos 30BC79003-85, 87, 89, 110, 112, 114, 116, 118, 165, 167; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.

Figure 15. Air photo mosaic of the study reach, September 4, 1986; Hope flow 2500 m^3s^{-1}. Air photos BC537-75 to 77, 142 to 152, and 165 to 175; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.

Figure 16. Air photo mosaic of the study reach, August 1, 1993; Hope flow 3260 m^3s^{-1}. Air photos 30BCB93030-78 to 80, 111 to 115 and 30BCB30032-186 and 187; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.

Figure 17. Air photo mosaic of the study reach, July 3, 1996; Air photos 30BCC96083-108 to 110, 163, 165, 167, 169 and 30BCC96084-30 and 32; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.

Figure 18. Cross-sections in Minto Channel at various dates. Section lines (parts (a) through (m)) proceed upstream. View is downstream (i.e., the left bank is on the left side of the section). Sources noted in the text. Some surveys do not include the banks. Distance 0 m represents the position of the contemporary (1991) left bank. Elevations are reduced to datum.