Fraser River: managing the gravel reach

gravel mining is not the solution

Summary

It is claimed that gravel accumulation in the reach of the Fraser River between Laidlaw and Sumas Mountain is causing water levels to rise, hence increasing flood hazard in the reach. Gravel certainly does accumulate in the reach. But the real concern is water level, and evidence indicates that channel alignment, not gravel accumulation is the main control of water level along the river; significant gravel accumulation occurs chiefly in locations where channel constrictions and bends create backwaters with reduced currents and are the consequence, not the cause, of locally high water. The general rate of gravel accumulation is slow and does not justify regular gravel mining.

On the other hand, gravel mining from the river places at risk elements of the extraordinarily rich aquatic ecosystem, a source of commercial, recreational and cultural value to the population of the Fraser Valley. Maintenance of this ecosystem should be the highest priority for long-term management of the river.

The following actions are called for in order to achieve an improved level of management for the river

- Since management of water levels is the main concern related to public safety, increased effort should be made to secure and analyze records of water level by direct observations and by numerical modelling with updated survey information;
- The system of dykes should be brought entirely up to standard and consideration should be given to increasing dyke setbacks where this would be feasible;
- There should be continuing efforts to improve knowledge of the sediment budget and its long-term trend;
- There should be increased efforts to understand the structure and function of the aquatic ecosystem of the river and its response to engineering disturbances;
- Consideration should be given to designing a 'most efficient' program to monitor the status of the aquatic ecosystem;
- *A plan should be developed for the long-term stewardship of the river, to include reservation of riparian lands, zoning to limit development within the floodplain, reopening of side-channels and 're-naturalising' the reach;*
- A meeting should be held amongst river scientists, engineers and ecologists with knowledge of the reach to seek consensus on whether it is useful to continue the program of sediment removals and, if so, under what arrangements (annual? occasional?) and by what methods;
- A program should be initiated to better inform the public of the conditions along the river and options for long-term management.

The ‘problem’ defined

The Fraser River drains 250 000 km^2 of south-central British Columbia, mostly mountains and high plateaus that accumulate a significant winter snowpack. Consequently, there is a significant spring snowmelt freshet every year. Annual peak flood flows are of order 10 000 m^3s^{-1} in the lower river. In the natural, pre-development state these flows covered extensive portions of the floodplain of the river every spring in the Fraser Valley.

After the great flood of 1894, efforts commenced to protect growing human settlements and the occupied floodplain from the river, resulting today in an extensive system of dykes that confine the river to its channel and, in flood, to channel islands and restricted bits of the floodplain.

The river and its tributaries follow steep, confined courses through the mountains and interior plateaus, where they pick up rocks, gravel, sand and silt from their banks and tributaries and transport them downstream. Within the Fraser Valley, the gradient of the river quickly declines as the river approaches the sea. The larger material (cobbles and gravel), which cannot continue to be moved on the reduced gradient, is deposited in the river channel, mainly between Laidlaw and Sumas Mountain in the so-called ‘gravel reach’ (Figure 1). As a result, the river slowly raises its bed (‘aggrades’) there. This process also causes the river to shift laterally (sideways) by eroding its banks as the water seeks a way around the gravel deposits.

Throughout the 20th century, as the dyke system has been developed to improve flood protection, bank protection has been added to prevent erosion of the dykes and valuable floodplain land. In the gravel reach, this has confined the river within a zone that is considerably narrower than its natural channel.

Important modifications have included cutting off side channels and the elimination of floodwater storage areas on the floodplain and in the former Sumas Lake (drained in 1928). This has raised floodwater levels within the remaining channel zone above their natural (unconfined) limits and potentially increased the rate of rise of the river bed because water and sediment are confined within the restricted area.

The rise of the bed (‘aggradation’) in the long term will reduce the magnitude of the flood against which the dykes provide assured protection from flooding. It is claimed, then, that the problem with the Fraser River in the gravel reach is how to prevent a steady increase in the flooding hazard posed by the river as the result of sediment accumulation. But a critical underlying question is whether or not gravel accumulation is, over a time span of decades, the fundamental reason for a rise of water levels to occur in the river.

There is also a significant additional dimension to the ‘problem’. Gravel deposition and lateral movements of the river channel have created a complex of islands, bars and secondary channels in the river between Laidlaw and Sumas Mountain (Figure 2). These features form aquatic and riparian[1] habitat of exceptionally high quality that supports an abundant fishery. The natural shifting of the channel renews habitat at a rate to which the river fauna successfully adapt.

[1] “riparian” refers, literally, to the river bank. Practically, it refers to land immediately adjacent to the river the quality of which is substantially influenced by the presence of the river.

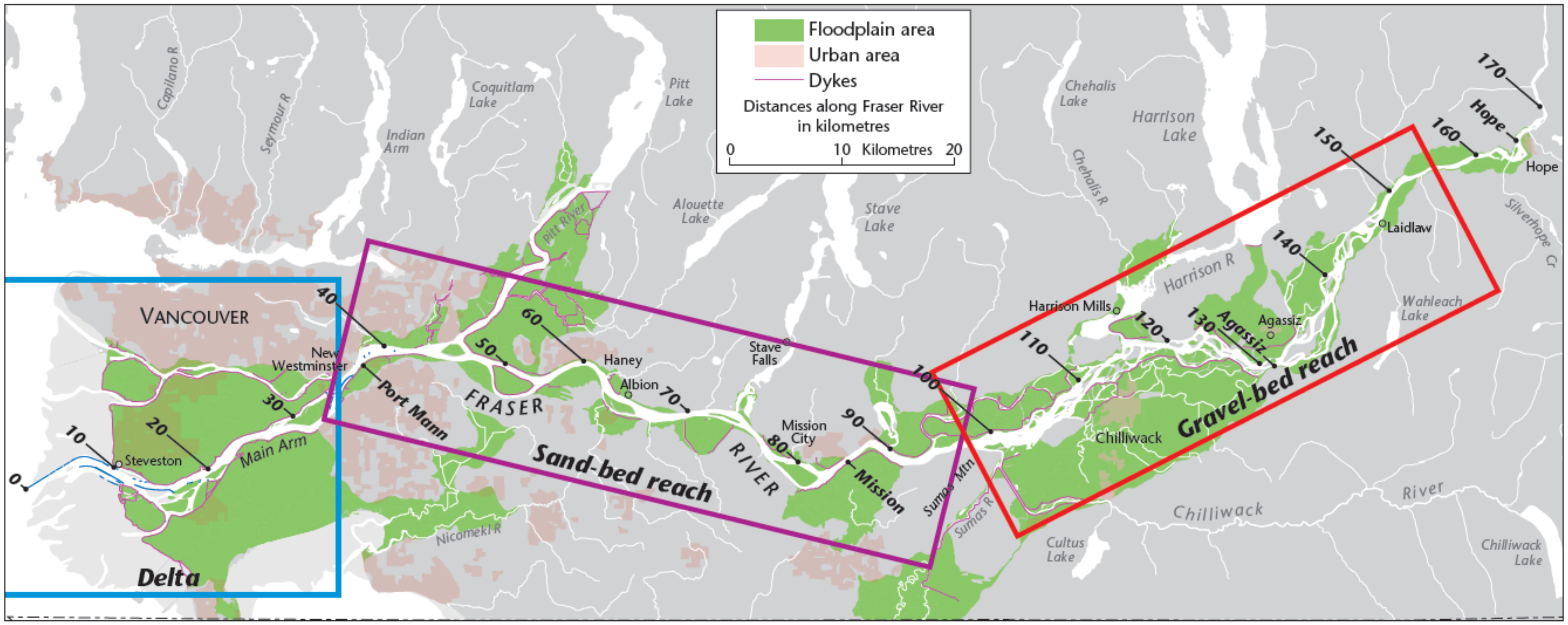

Figure 1. Fraser River in the Fraser Valley, showing three major reaches. This report is about the gravel-bed reach (red).

Figure 2. The Fraser River in the gravel-bed reach, view upstream toward Laidlaw from over Herrling Island. Photo taken during spring freshet: the gravel bars are under water.

Habitat renewal is an essential process for the maintenance of habitat quality. The ecological wealth of the Fraser River in the gravel reach – which contributes substantial economic value through various fisheries and is a culturally and economically significant aspect of First Nations[2] society – is sustained by the gravel transport and the consequent natural shifting of the river channel. Any action taken to mitigate flood hazard must consider the consequences for aquatic habitat, environmental quality and the cultural significance of the river.

The real problem with the Fraser River, then, is how to manage water levels in the river without doing harm to the aquatic habitat.

Elaboration of the problem

What is the river doing?

The gravel deposited between Laidlaw and Sumas Mountain forms a confined 'alluvial fan' – a wedge of river sediment confined within the relatively narrow valley between the Coast and Cascade Mountains, northeast of Sumas Mountain (Figure 3). An alluvial fan is an accumulation of river-transported sediment deposited where the river encounters a sharply reduced gradient. Such stream deposits are common at mountain fronts (see the inset of Figure 3). Alluvial fans continue to accumulate sediment so long as the river delivers material that cannot be transported across the fan and beyond. This is the situation on the Fraser River and the reason why the river is, in the very long term (i.e., over thousands of years), raising its bed ('aggrading') as additional

[2] In the gravel reach, in particular, of the Sto:lo – the 'people of the river'.

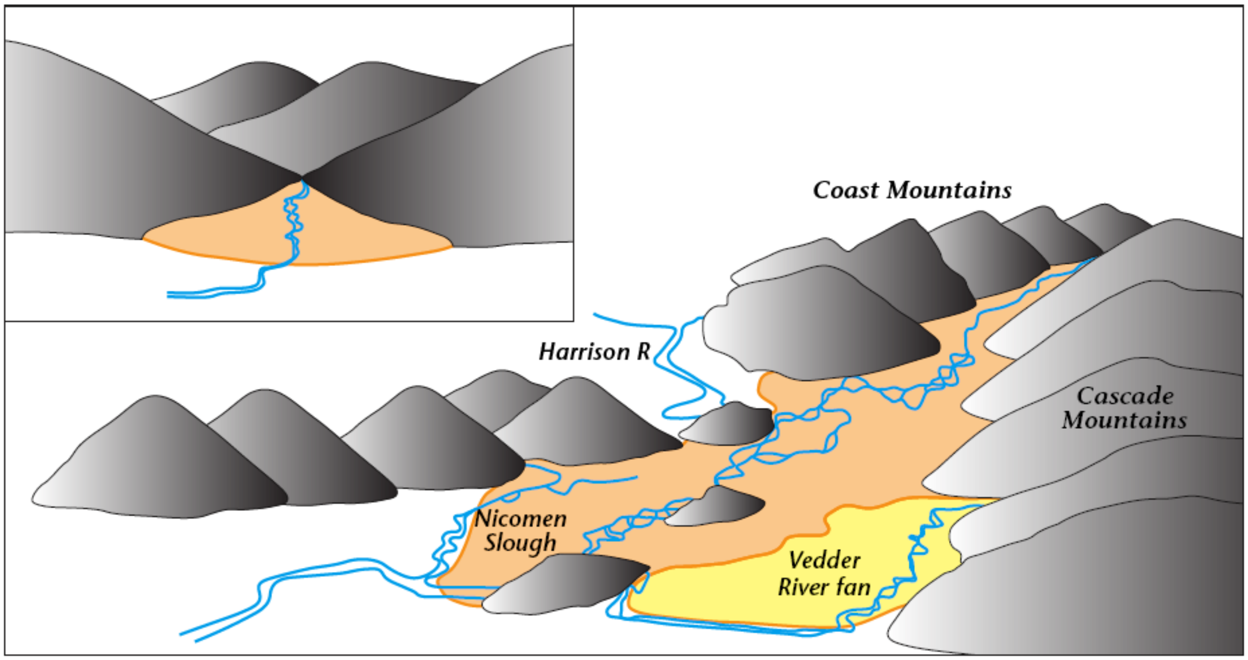

Figure 3. Cartoon to illustrate the confined alluvial fan (orange) formed by gravel deposited in the eastern Fraser Valley. Inset: a more common, small alluvial fan at a mountain front.

sand and gravel are deposited there year after year.

This is a natural process that has been going on for 13 000 years – since the end of the Ice Age – and will continue. However, the gravel load of the river is relatively small, consisting of only 1 or 2 percent of the total sediment load, which is composed mostly of sand and silt, so the process is not a rapid one.

Gravel is heavy, hence it travels along the bed of the channel (whereas sand and silt are carried in suspension in the water, buoyed up by turbulent eddies in the flow). As the river moves around bends, cross-channel currents push the moving gravel to one side or another of the channel. Gravel is deposited on the inside of river bends in sheets that are stacked laterally against a bar edge, so the bar grows out into the river (Figure 4). The current is forced toward the opposite bank, where it erodes sand and gravel that approximately replaces the deposited volume. In this way, gravel moves downstream by movement from bank to bar.

As bars grow and banks are eroded, the channel shifts laterally. This process is intrinsic to gravel transport in the river. During the 20th century however, much of the river banks have been stabilised by the placement of boulder 'rip-rap' against the bank to inhibit lateral movement of the river and erosion of valuable land. In many places this has resulted in constriction of the channel zone. Where this bank 'hardening' constricts the river, increasing the strength of the current, the transported gravel is forced to move farther downstream before coming to rest: bank hardening simply displaces the problem of gravel deposition.

Gravel is not uniformly deposited along the river. Major deposits occur where currents slow down, becoming less able to move the gravel. This occurs immediately upstream of places where the river encounters obstacles to flow, such as sharp bends or channel constrictions (Figure 5).

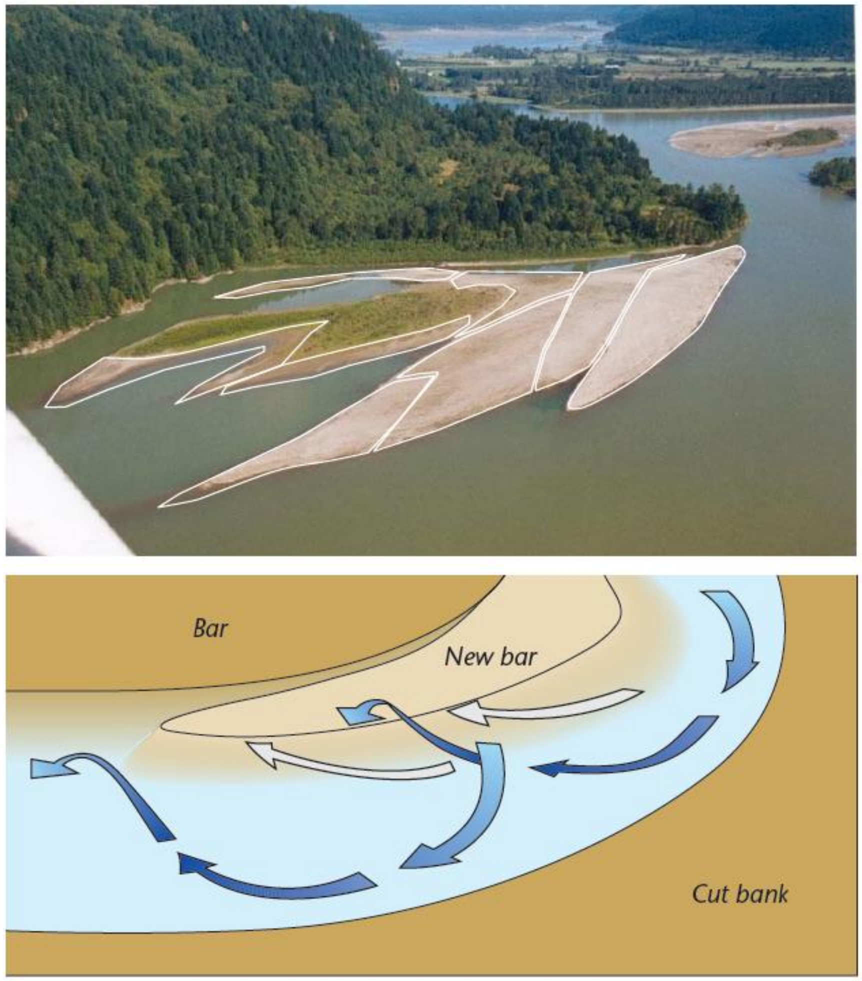

Figure 4. Calamity Bar on Fraser River by Harrison Knob. On the photo, successively deposited gravel sheets are outlined. In the illustration below, the blue arrows show the spiralling current in the channel bend, which sweeps gravel onto the face of the bar, shown by the white arrows.

Water then ‘piles up’ (forms a backwater) upstream of this ‘pinch point’ until the gradient through the bend or constriction is sufficient to drive the water through the bend or constriction.

Alternately, an abrupt change of channel alignment occurs.

In the upstream, backwatered reach, gravel deposition may further raise the water levels. Water levels are raised in proportion to the severity of the constriction. While overall rise of the channel bed occurs over centuries, during a period of decades the chief threat to dyke security is localised in the areas where backwaters develop, and the primary reason is not the gravel accumulation. River channel alignment is the dominant, factor.

The river fishery

River bars, some of which develop into islands (older bars that have been colonised by vegetation) create the remarkably diverse habitat that is the basis for the ecological wealth of the river. It is appropriate to focus attention on the habitats used by rearing juvenile fish, for if the

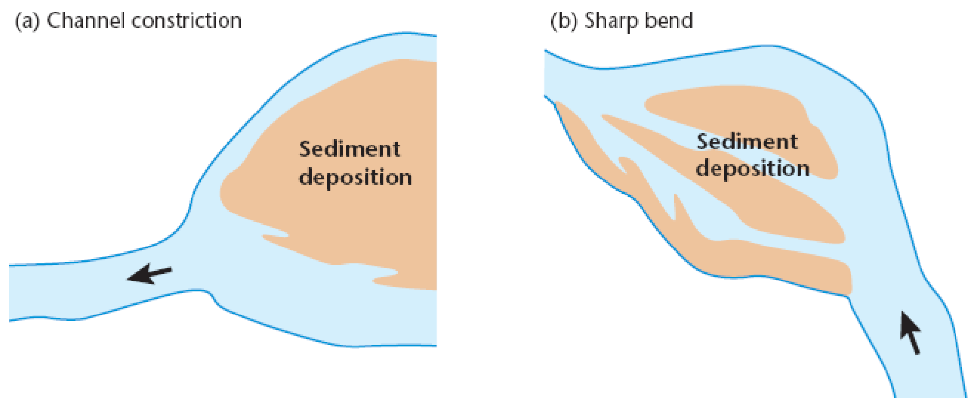

Figure 5. Cartoon to illustrate typical situations that lead to local deposition of gravel.

river cannot successfully rear juvenile fish, it will not be productive. Twelve nearshore habitat types have been identified that host different assemblages of juvenile fish (Figure 6), all of them determined by channel geometry and most by gravel deposition on the bars. Twenty-four of the approximately 30 fish species that inhabit the river have been found in these bar-edge habitats.

There has been no comprehensive accounting of the gravel reach fishery. The principal gravel reach fisheries are conducted by First Nations, which is partly commercial and partly traditional, as well as recreational. The main recreationally fished species are salmon and sturgeon (the latter of which is strictly a catch and release fishery).

In 2011[3] the recreational salmon fishery provided an estimated 73 250 angler- days for an expenditure of $11 million, while the sturgeon fishery provided 20 500 angler-days for an expenditure of $4.2 million. The wholesale worth of the combined First Nations and recreational harvest in the gravel reach is estimated to have been $7.0 million in 2011, a Pink salmon run year.

The Pink salmon run in the gravel reach of the Fraser River may exceed 10 million fish in some years. (Pinks come back to spawn in the Fraser River only in odd-numbered years.) The large side channels of the gravel reach are important Chum salmon spawning habitats. The gravel reach habitats also contribute to large-value fisheries outside this area: the large bars in the gravel reach of the Fraser River may be the most productive of all instream rearing habitats for Chinook salmon in the watershed.

Social value

The river provides other values to society than the fishery. First, it is a central element in the culture of First Nations resident along the river, all of whom sustain a traditional focus on the fishery. For many residents of the Fraser Valley the river is an important site for recreational boating, picnicking and nature study, in addition to its support of a large recreational fishery.

[3] The data following are estimates constructed from DFO data. An angler-day is assumed to be 6.5 hours (based on data in reports for earlier years); average expenditure for an angler-day is assumed to be $150, except $200 for sturgeon fishing. The wholesale value of a Chinook, Coho or Sockeye salmon is assumed to be $10; for Pink and Chum, $5. The recreational fishery data include a small contribution from the downstream sand-bed reach.

Figure 6. Illustrating some of the inshore habitat units around Calamity Bar. These represent a subset of the habitats identified as favoured by rearing juvenile fishes of many species present in the gravel-bed reach.

Most important, perhaps, the river and its remaining riparian zone are the most significant elements of the landscape to provide relief from the increasingly pervasive urbanism of Fraser Valley. With the population of the region projected to grow by more than 40% in the next 25 years (BC Stats: www.bcstats.gov.bc.ca/data/pop/pop/popproj.asp) from 2.7 million[4] (2011 census) to a projected 3.9 million, the river will more and more become the central element in the maintenance of a 'liveable environment'. All these reasons argue for the maintenance of the river in its natural state, with as little human interference as possible.

'Managing' the river

There are a number of ways by which additional protection might be secured against rising water levels, including:

- raising the dykes;
- repositioning the dykes with more generous setbacks from the river so as to increase the area within the expanded floodway, hence lower water levels;
- maintaining or lowering high water levels locally by sediment removal to lower the stream bed or to remove local constrictions to flow;
- maintaining or lowering high water levels by channel realignment (possibly including reopening of side channels cut off since the late 19th century);
- adopting administrative and institutional measures to maintain social protection (such actions would include some mix of restricted land use zoning and building codes near the river, flood insurance, and emergency measures planning).

Protection for the river environment would be secured by measures such as:

- reserving riparian land for parkland or wild land;
- re-opening side channels;
- removing bank hardening in non-critical locations;
- restricting or eliminating gravel mining.

The two sets of criteria are in part incompatible but also, in part, mutually reinforcing.

At the present time, sediment removal to maintain the water profile is the strategy preferred by government to manage the perceived problem of aggradation. Dyke raising or reconstruction (for the purpose of offsetting a rise of water levels) are perceived to be too expensive and the effect of channel realignment too uncertain, while administrative measures are thought not to be socially acceptable. Sediment removal threatens ecological values. Improving the floodway by reopening side channels and/or committing riparian reserve areas to the possibility of being flooded would improve ecological value whilst possibly having some effect on water levels.

[4] The census region includes the mountains to the north of the Fraser Valley, but they are virtually empty of population.

Dykes are the traditional means to protect society from high flows in a river. Dyke construction costs vary widely. The provincial government has recently estimated that it may cost at least $6.4 billion to raise 250 km of dyke in the Fraser Valley by 1 metre; that is, $25.6 million per kilometre. This figure includes substantial costs for necessary land acquisition and modifying facilities such as pump houses. On the other hand, recent dyke improvements in Chilliwack (topping the existing dyke) have cost less than $1 million per kilometre. In addition, bank protection may cost more than $550 000 per kilometre. These are expensive propositions.

The 'problem with the Fraser River', then, is the apparent conflict between a desire to engineer adequate protection from flooding and erosion along the river at the least expense to society, in the perceived presence of channel bed aggradation, and a desire to maintain a diverse and valuable aquatic habitat and a major natural feature of the Fraser Valley. The problem might be restated as 'how to find the optimum set of actions from amongst those above (or others) that will provide best protection for both society and the riverine ecosystem, at affordable cost'. To sort this out, we need to understand how the river works.

What do we need to know?

To resolve the gravel reach problem we require information about what is happening along the river. Specifically, we require the following information:

- water level history at many places along the river: water levels at flood stage are the primary information by which we can gauge the flood hazard in relation to the height of the dykes for particular flows;
- changes in river alignment and its effect on water levels at flood stage;
- volume of sediment introduced into the reach and where it is deposited, leading to estimates of the local rate of rise of the bed;
- the source of the deposited sediment;
- knowledge of the way in which aquatic organisms, especially fishes, use space in the river;
- knowledge to develop an effective program to monitor the immediate and longer term impacts of any management actions along the river on both the river morphology and processes, and on the aquatic habitat and organisms.

Water level is the fundamental quantity required to gauge the hazard posed by flood flows in relation to the condition of the dykes. In particular, data gathered over a period of years are required to determine what is known as 'specific gauge' – the water level (at the gauge site) for a specified flow. An increase in specific gauge is the critical indicator of rising water levels for particular flows.

Changes in river alignment are important to know in order to appraise the likely effect of stream direction and pinch points on upstream water levels and to anticipate erosional attack on the river banks.

The volume of sediment deposited in the reach and the location of deposition and erosion can be determined by periodic survey and comparison of successive surveys. We also need to know where the sediment comes from in order to gain insight into whether sediment deposition in the gravel reach is apt to increase or decrease in the future. Large-scale gravel removal will do significant harm to the river ecosystem, and even small removals may pose serious problems if there is a diminishing supply.

Knowledge of the aquatic ecosystem is gained by field sampling of organisms and measurement of their environment (water properties, bed condition), and by study of organisms' life cycle activities. These are intensive (and expensive) research activities, but knowledge is cumulative over time. Such knowledge is necessary to anticipate the response of the ecosystem to particular river management actions.

Knowledge is also required to develop an effective program to monitor the actual impacts of management actions. It is gained by field observation of the results of specific actions – in effect, by regarding each intervention (such as, sediment removal) as an experiment. In each case, it is necessary to compare the treated site with similar sites that have not been disturbed so that other environmental effects (for example, an unusual flood season) can be discounted.

What do we know now?

Water level

The principal focus of interest for flood security is water level. Surprisingly, this has received less attention than gravel influx volumes in recent considerations of flood hazard. Water levels have been recorded for many years during high flows at a series of gauges along the Fraser River. The recent gauge network is shown in Figure 7. The key information is specific gauge.

In Figure 8 specific gauge is displayed for the former Water Survey of Canada gauge site at the Agassiz- Rosedale bridge. Since 1970 Big Bar has developed immediately downstream from this site. This might have been expected to create an upstream backwater that raised water levels at the gauge site, but in fact specific gauge has declined during the years since 1980. This result suggests that backwater effects of bed level changes are very local, a result reinforced by numerical modelling of the effect of sediment removal from bartop surfaces (nhc, 2007). It was found that significant reductions in water level extended upstream only to about half the length of the excavation and was of the order of only 10 cm for a bartop sediment removal of order 1 million m^3 (which is larger than any historical removal).

Channel Alignment

Changes in river alignment have been mapped at approximately 10-year intervals since 1928 (Church and Ham, 2004). Figure 9 illustrates successive positions of the main channel in an active reach of the river between Agassiz and Carey Point. Changes occur incrementally for many years at a time but, if the channel bend become too tight, the river breaks through into a new channel. Such a change happened behind Gill Island after 2000 as the result of the tight bend against Mount Woodside. Lateral changes of this type perform the important role of renewing aquatic habitat.

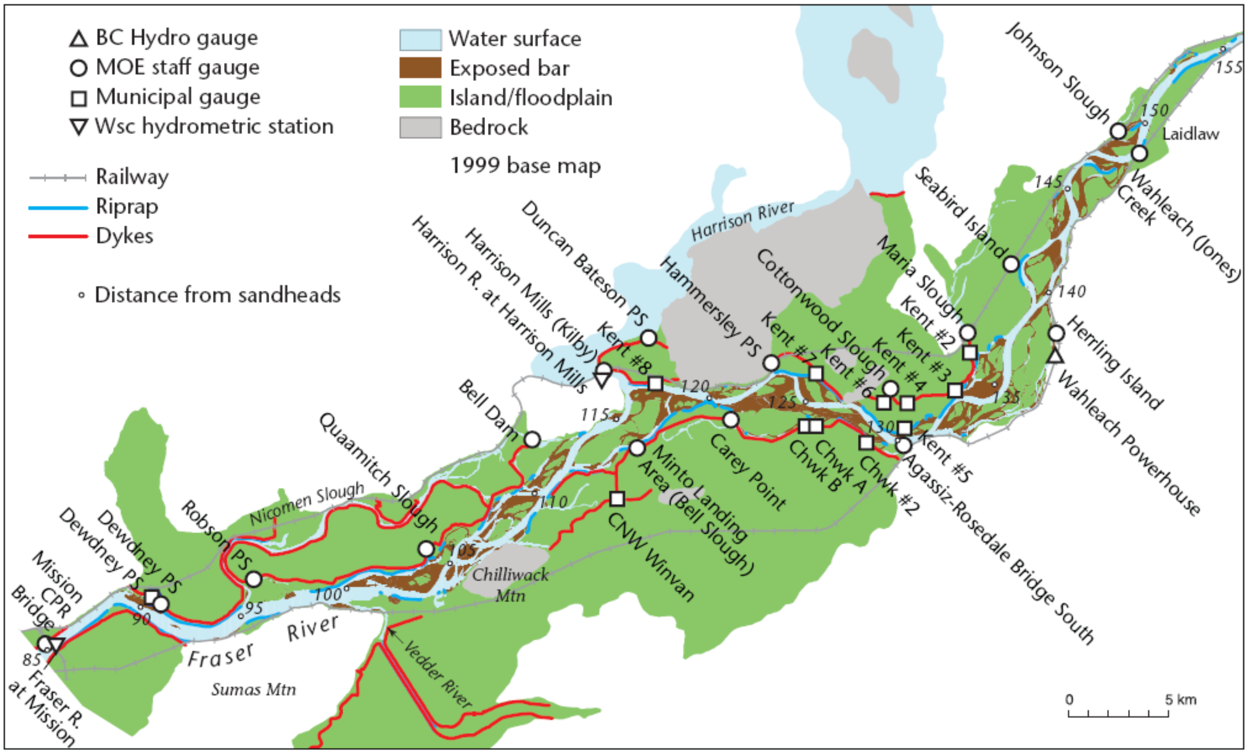

Figure 7. Water-level gauges in the gravel-bed reach. Most are non-recording (i.e., not continuous). Extent of bank 'hardening' by riprap and riprap-faced dykes is also shown.

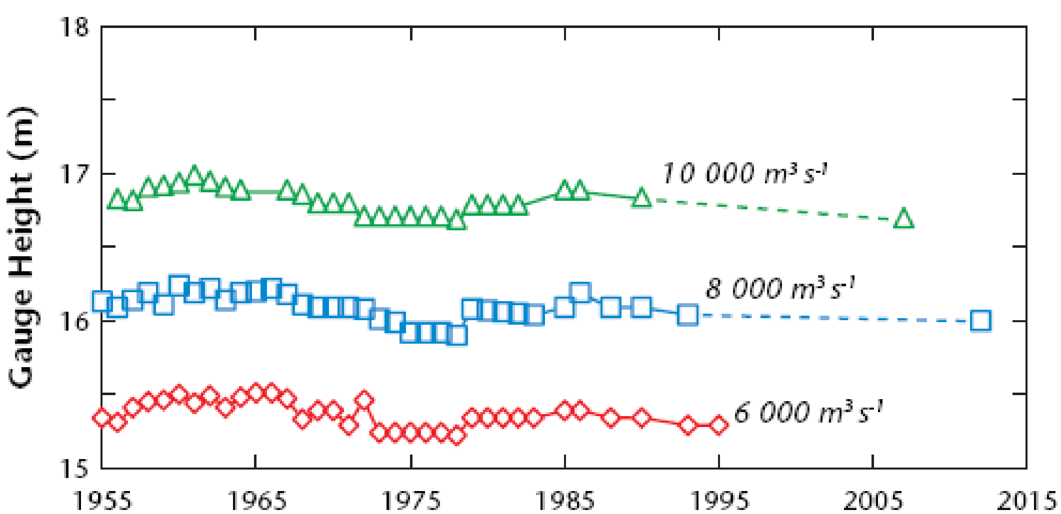

Figure 8. Specific gauge at the Agassiz-Rosedale Bridge. Each line represents the variation of water level over time for the specified flow.

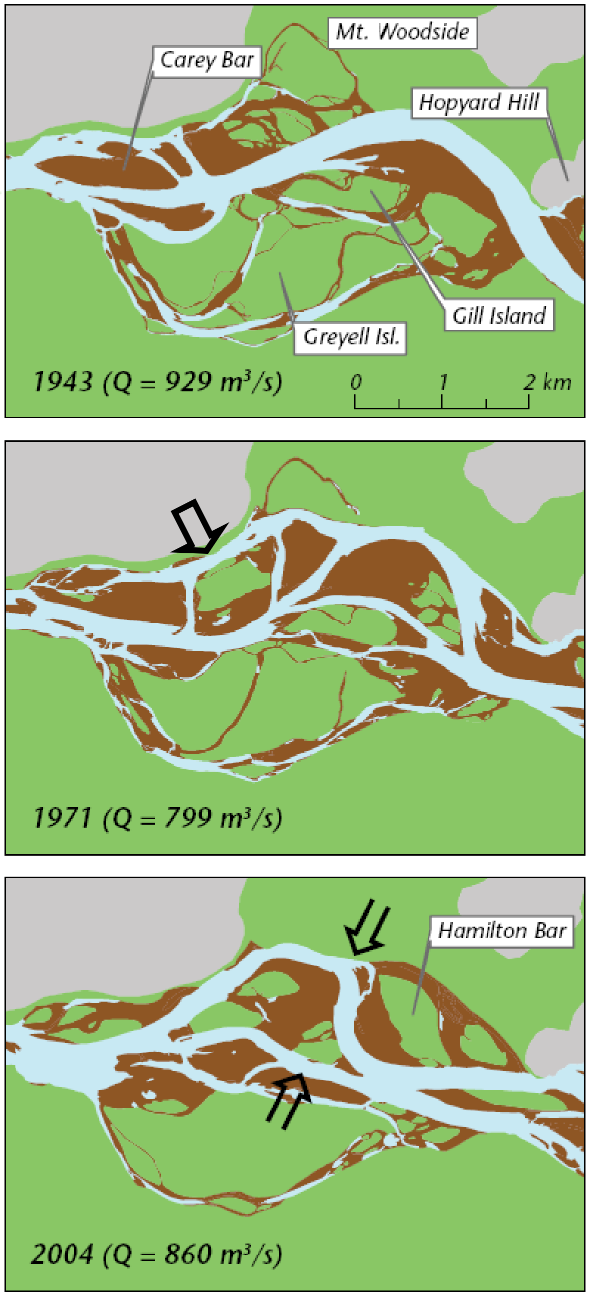

Figure 9. Alignment of the channels around Greyell Island, 1943-2004. The open bend present in 1943 became tighter over time (upper arrow in third frame) until, in about 2000, the main channel took up the alignment (lower arrow) of the former minor channel behind Gill Island. By 2005 it was the main channel of the river. The brown areas represent higher-elevation gravel bars and minor channels that are only seasonally flooded. An additional channel switch behind Carey Bar is noted in the middle frame.

To understand the effect of alignment on water levels more precisely it is necessary to survey river bathymetry to provide input data for numerical hydraulic model calculations. Historical surveys are available for 1952, 1984 (partial), 1999, 2003 (partial) and 2008. The survey task is expensive and can be accomplished for the entire reach only once in every decade or so. Hydraulic model calculations based on data from these surveys can be tolerably precise only for the time when the survey was conducted. After that, ongoing changes in the river render results approximate at best. This is the reason why direct observations of water levels remain critical.

Analyses using river survey data and a hydraulic model (UMA, 2000; 2001; nhc, 2006, 2008) have revealed that, at some places along the river the present dykes are not sufficiently high to assure protection against the water level for which the dyke system was designed (the 1894 flood). However, the reasons for this are mainly due to the limited technical capabilities that existed in the past to predict water levels during extreme floods, not due to build-up of gravel deposits.

Further test calculations to examine the effects of river alignment and gravel removal on water level have shown that gravel removal by means of bartop scalping (the permitted method) has a minimal impact in comparison with the effect of river alignment (nhc, 2007).

Channel zone width

Throughout the 20th century, river banks have been 'hardened' by the placement of rip-rap (large rocks that the river cannot move) along the banks to prevent bank erosion (Figure 10). This has been done to protect the dykes from river attack, to protect the railways where they are routed along the river bank, and to protect increasingly valuable land. This action has resulted in 69% of the outer channel banks now being protected (see Figure 7 for the extent of dykes and riprap). Together with the cutting off of more than 100 km of side channels (Rosenau and Angelo, 2000), this has significantly reduced the zone within which the river can move laterally to distribute this

Figure 10. Well-constructed rip-rap placed to prevent bank erosion.
This rip-rap protects a hydroelectric power line pylon.

and renovate habitat (Figure 11). Both local gravel accumulation and habitat quality are unfavourably impacted by this history.

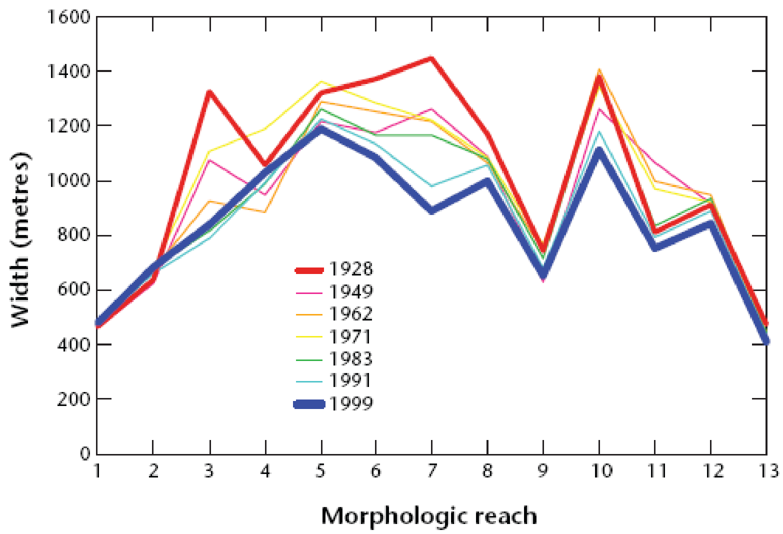

Figure 11. Change of river channel zone width between Laidlaw (right side) and Mission (left side), 1928-1999. The distances are given as 'morphological reaches', that is, lengths of channel with a similar habit and width. The total distance is 70 km, the same as in figures 12 and 13.

Sediment budget

An approximate sediment budget for the gravel reach has been established for 1952-1999 by means of comparing channel bed elevations from successive surveys (Church et al., 2001; Figure 12). The long period of evaluation lends confidence that the results represent a reasonable estimate of the average annual gravel deposition. However, there are a number of reasons why this sediment budget must be regarded as only approximate:

- a small error in determining the reference elevation in successive surveys might create a significant error in the total sediment budget because of the very large riverbed area over which the budget is calculated;
- transit of sand through the reach is far larger than the influx of gravel, and temporary storage of sand in the reach, varying between surveys, may introduce significant bias into the estimation of net deposition of gravel sediment (but this is an effect that is minimized by the long period between surveys). Further, the replacement of sand by gravel in the sediment deposits would result in underestimates of the gravel budget;
- it is assumed that all gravel is deposited upstream of the mouth of Sumas River (at Sumas Mountain), whereas a small but unmeasured volume is known to move farther downstream;

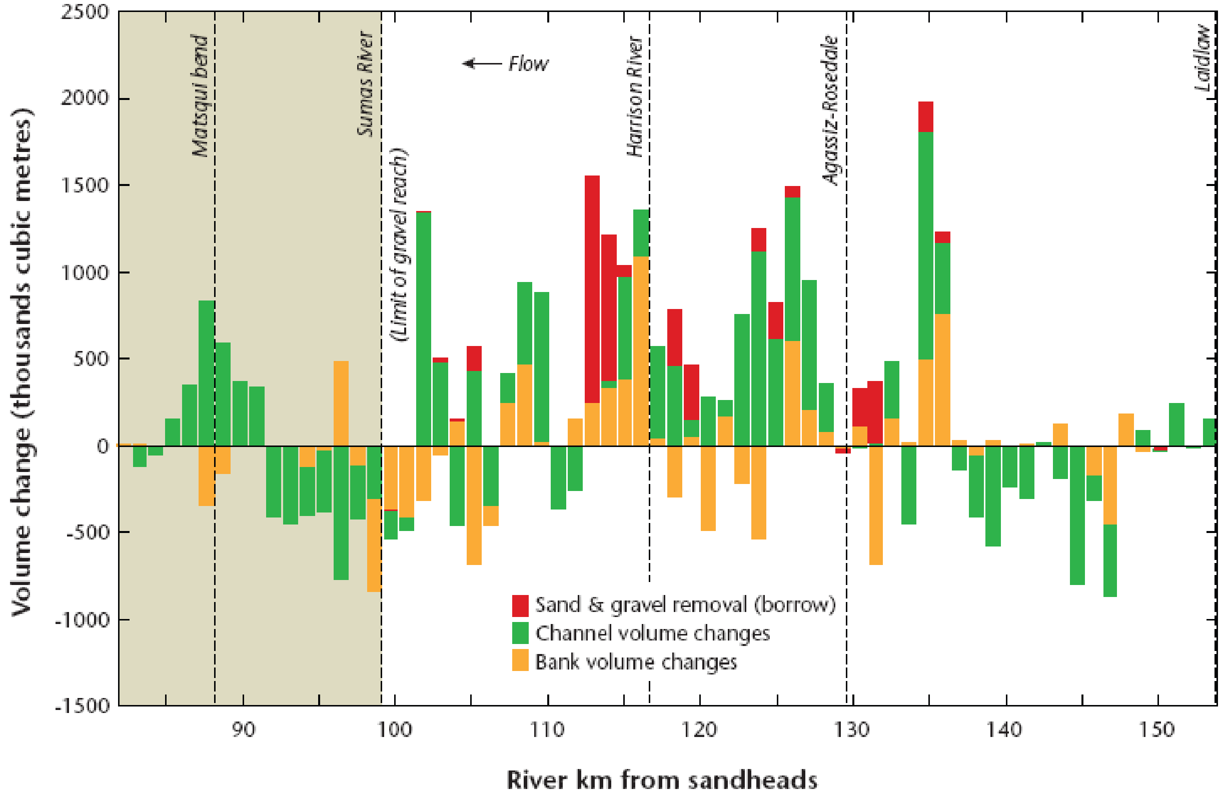

Figure 12. The sediment budget for the gravel reach of Fraser River, 1952-1999. Each column represents the change in sediment storage in a 1-km long portion of the channel.

- to account for bank erosion, assumptions must be made about the proportions of sand and gravel in eroded floodplain deposits. These assumptions are based on field sampling, but the samples are inevitably limited in comparison with the extent of the floodplain.

These problems are the focus of continuing work to improve the sediment budget. Despite them, however, successive revisions over more than a decade have not resulted in a major change in the budget. It is, furthermore, clear (Figure 12) that deposits vary along the river; that is, gravel accumulation is a local, not a general problem.

Using the estimated sediment budget, we can calculate that in the period 1952-1999, the gross sediment deposition was sufficient, if uniformly distributed along the reach, to raise the bed by about 8.6 cm. This figure is comparable with the precision of model computed water level predictions along the river. However, gravel has regularly been mined from the channel (Figure 13), reducing the *net* average rise to 2.1 cm. For a 47-year period, this is not a significant change. But of course, the deposits are not uniformly distributed – the actual rise in the bed was more than a metre locally, while in other places the bed was lowered (Figure 12). Between the Agassiz-Rosedale bridge and Sumas Mountain, where the main deposition occurred, sediment influx was equivalent to 18.7 cm bed rise, and 10.9 cm after gravel mining is considered.

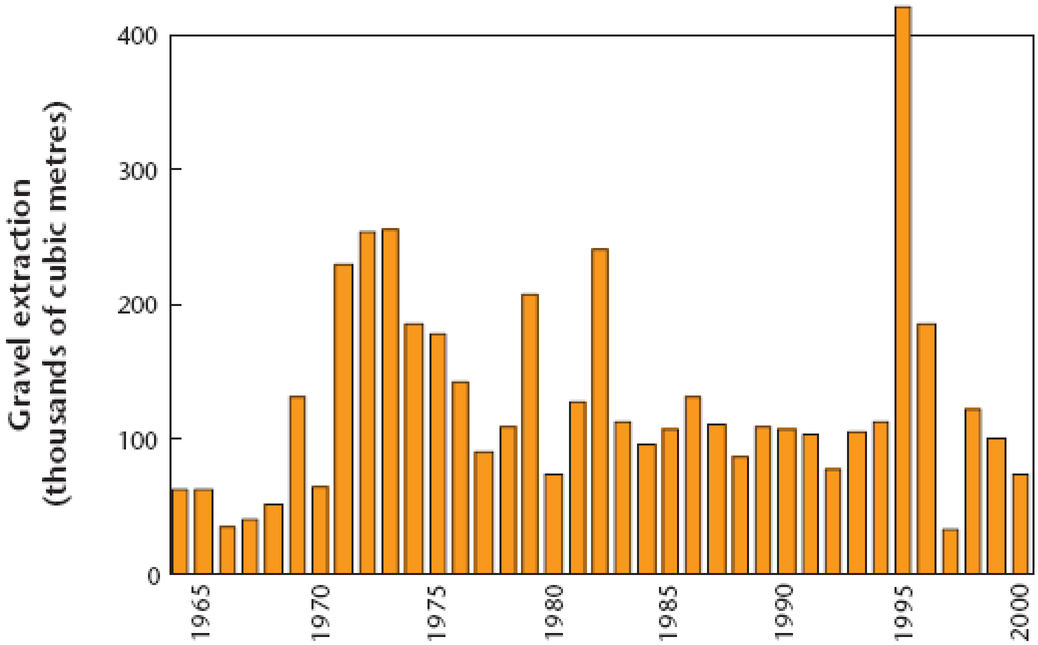

Figure 13. Volumes of gravel removed from the gravel-bed reach, by year, 1964-2000. Before 1964 some removals occurred but there are no reliable records.

Historic sediment removals from the river have, in the past half century, approached the volume deposited in the reach, yet we have observed no immediately major effect on river processes or morphology: from this observation, we learn that some modest level of gravel removal apparently can be tolerated. But we know from experience in many rivers around the world that removing sediment in quantities that exceeds the rate of deposition leads to significant changes in river morphology that are generally ecologically unfavourable.

Sediment origins

The question of the source of gravel deposited in the reach is important because, if gravel removed is not replaced, that will eventually change the river and impact the fishery. It is also a difficult question because it entails analysis of events that have occurred over more than a century. (This is because the heavy gravels move only a few kilometres downstream in each flood, so material coming from far upriver requires many decades to reach the Fraser Valley).

Recent research (Nelson and Church, 2012) points strongly to the possibility that 20^{th} century gravel accumulation may have been unusually high because of 19^{th} century gold mining as far up the river as Cottonwood River, beyond Quesnel. Miners typically dumped waste soil and rock into the river and mobilised much more by working the river bars. Some of the major 19^{th} and 20^{th} century engineering projects in the Fraser canyons (railways; highways) have made incremental contributions to sediment in the river as well. There is no such source today, suggesting that future gravel influx will be smaller than it has been during the 20^{th} century.

Aquatic ecosystem

Monitoring of the aquatic ecosystem to establish ecosystem structure and function, and to assess the response to river management actions (sediment removal; bank hardening; side channel cutoff; channel constriction; floodplain land use) is a difficult exercise. The effects of an experimental gravel removal conducted at Harrison Bar in 2000 were intensively monitored (Rempel and Church, 2009). They found that the inherently high variability of the biological data (on the occurrence of fish and aquatic insects) produced very low statistical power to detect persistent effects of sediment removal. Monitoring of subsequent gravel removals has similarly been inconclusive (G3 Consulting, 2009). To the extent that the data are interpretable it appears that normal seasonal variations in populations of organisms dominate the observations.

We do know from direct experience, however, that a poorly planned or executed sediment removal can have devastating effects. A 2006 excavation at Big Bar stranded a large number of pink salmon redds (egg pockets), resulting in significant loss of fish. We also know that permitted excavations on bar tops have minimal effect on water levels.

An adequate monitoring program would have to be extensive, both spatially and temporally, paying attention not only to treated sites, but also to undisturbed sites in order to gauge environmental effects not associated with the treatment, (e.g. river flows and the effects of weather). Such an exercise, properly executed, would require a dedicated organisation and would be expensive.

What have we learned?

As a result of work on the river to date we may draw the following conclusions:

- water levels along the river are not, in general, rising rapidly, but important local rise may occur as the result of changes in river alignment and consequent sedimentation;
- sediment removal from the river at a rate that approaches but does not exceed the rate of influx has had no immediately major impact on river processes and morphology;
- sediment removal by bartop scalping has little effect on local water levels;
- historic sediment removals appear in general, not to have had lasting impacts on fish or insect populations in the vicinity, but sediment removal that is not properly planned or executed can have immediate and serious effects;
- effective environmental monitoring of fish and insect organisms requires a large and expensive continuing effort because of the very large natural variability in their occurrence, both spatially and temporally;
- we still lack sufficient baseline information about water level trends, sediment budget and the aquatic ecosystem to be able to confidently establish a sustainable, long-term river management plan.

What should we do?

The British Columbia government, with the agreement of the federal government, is currently committed to an annual program of sediment removal from designated sites in the gravel reach of the Fraser River in an attempt to ‘maintain the profile’ of the river – meaning to prevent the rise of water levels as the result of gravel accumulation -- over the long term. The aim is to remove volumes of sediment that are approximately equivalent to the influx from upstream. It had been hoped that the program might also be used to reduce water levels at sites where the margin of safety provided by the dykes is inadequate. However, it is now recognised that this is impractical because locally high water levels are primarily the consequence of river alignment and resistance to flow rather than to sediment blockage. Furthermore, the permitted method for gravel removal – scalping sediment from bar tops during winter low flow – has minimal effect on water conveyance and water levels.

The average rate of bed level rise is small, so there is a question whether the program of annual gravel removals need be pursued at all. This question is important because sediment removal may have important consequences for the diverse and productive aquatic ecosystem. We have been unable to detect any immediate impacts of bar top sediment removals of modest volume, But we do not know if there will be long-term cumulative impacts, particularly if reaches where gravel tends preferentially to be deposited, are repeatedly mined. Nor do we know anything about the levels of stress that animals may suffer as the result of instream activities. One effect that we may anticipate is that removal of bar top sediments lowers the bar surface so that there will be increased flow and velocity over the bar tops during flood. Yet these are the ‘escape’ areas used by fish to avoid the high flood velocities of the main channel. The current method of sediment excavation reduces the area of escape terrain, while not significantly enhancing water conveyance.

In light of these concerns the following actions should be taken:

- Since management of water levels is the main concern related to public safety, increased effort should be made to secure and analyze records of water level by direct observations and by numerical modelling with updated survey information;
- The system of dykes should be brought entirely up to standard and consideration should be given to increasing dyke setbacks where this would be feasible;
- There should be continuing efforts to improve knowledge of the sediment budget and its long-term trend;
- There should be increased efforts to understand the structure and function of the aquatic ecosystem of the river and its response to engineering disturbances;
- Consideration should be given to designing a ‘most efficient’ program to monitor the status of the aquatic ecosystem;
- A plan should be developed for the long-term stewardship of the river, to include reservation of riparian lands, zoning to limit development within the floodplain, reopening of side-channels and ‘re-naturalising’ the reach;

- A meeting should be held amongst river scientists, engineers and ecologists with knowledge of the reach to seek consensus on whether it is useful to continue the program of sediment removals and, if so, under what arrangements (annual? occasional?) and by what methods;
- A program should be initiated to better inform the public of the conditions along the river and options for long-term management.

Gathering more detailed information of water levels along the river will result in documentation of the principal cause for concern. The reason to emphasize direct observations is that model calculations become less accurate as channel conditions change between the extensive (and expensive) surveys required to update channel conditions. The installation of additional gauges is a current program of the provincial government.

Upgrading dykes to their design standard is an obligation to ensure public safety. The relocation of some dykes would increase the channel zone for conveyance of floodwaters while at the same time providing the opportunity to improve riparian conditions for maintaining the riverine ecosystem.

The sediment budget remains only approximately known and its long-term trend is unknown. To appraise the real concern that should be associated with gravel accumulation and with temporary storage of sand in the gravel reach, the budget needs better confirmation. The long-term trend is of particular importance because, if sediment continues to be removed from the reach and is not replaced as a result of declining input, the long-term effect will be a simplification of the river channel and a major deterioration of the valuable aquatic ecosystem.

That ecosystem needs to be much better known than it is to improve understanding of ecosystem responses to stresses that result from management and use of the river. Further, since ecological monitoring is so time-consuming and expensive, a strategy is required that returns and permanently records reliable information at least relative effort. This probably will entail identifying and focusing attention on certain key indicator organisms (G3, 2009).

A plan is needed for long-term stewardship of the river because, with increasing settlement in Fraser Valley, in the absence of a river-focused plan riparian areas will be developed for uses not oriented toward the river. Such uses will deprive the river of overbank ‘resources’ needed for continued ecosystem function (including food sources; flood terrain; habitat for riparian animals). The value of the river as a principal element of a desirable human environment in the Fraser Valley will thereby be lost. *The rate of development makes this proposal urgent.*

It is not clear that the present program of annual sediment removals is serving an essential purpose, while it does place at some risk elements of the aquatic ecosystem. It appears increasingly doubtful that a program of regularly scheduled gravel removals is necessary at all. This situation justifies expert review of the program and the development of a more rational basis for management of the sedimentation and the larger question of flood protection along the river.

Any successful program for long-term management of the river needs public approval. To gain such approval, the public must understand the issues involved, hence the proposal for increased public information and discussion.

Perspective

How to deal with the problem of the Fraser River is a decision for the community, most especially for the people who live along the river and gain sustenance or pleasure from it. It is perhaps helpful to suggest, however, that the most comprehensive solution in the long term, for public safety, for economic value, and for the enhancement of the environment of the Fraser Valley, is a solution that most nearly preserves the natural features of the river. This will entail providing the river with room to pass floodwaters safely and to continue the natural process that has characterised it for millennia, including the processes of sedimentation and channel change. In such an approach there would be no need to remove any gravel from the river except in very exceptional circumstances.

Such a solution requires the re-establishment of an adequate channel zone for the river. This would involve increasing dyke setbacks, where feasible, to allow a channel zone of at least 1500 m width, re-opening side channels, and 'naturalizing' the river banks, to include forest planting and removal of riprap wherever feasible. It would entail designating land within the dykes as riparian reserve. This would not mean abandoning all use of land within the dykes, but it would require the land to be dedicated to interruptible activities such as recreation, wildlife reserves, and certain agricultural activities.

The riparian floodplain is part of the river: it will be wise to respect that fact.

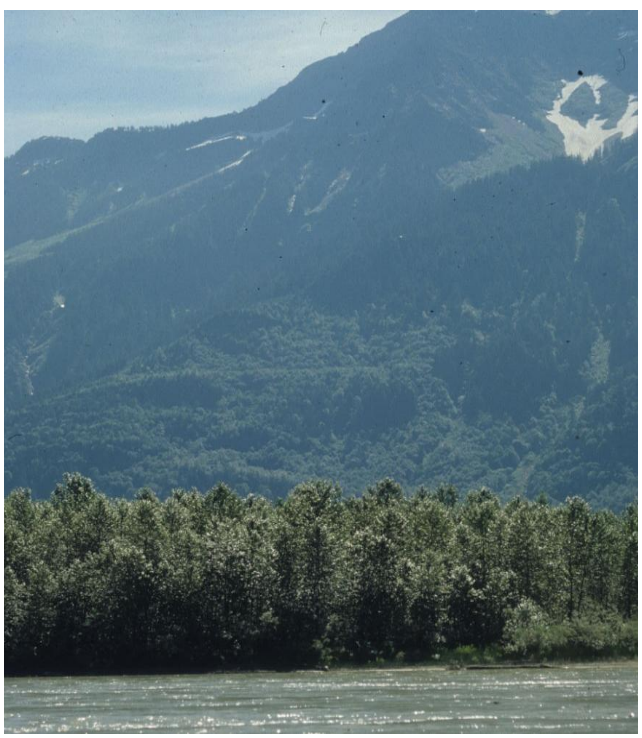

Figure 14. An ecologically desirable section of river bank, near Laidlaw. The bank is unconfined and forested with cottonwoods, which provide shade and nutrient sources to nearshore waters.

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