IMPACTS OF HUMAN INTERVENTIONS ON THE LOWER FRASER RIVER

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ABSTRACT

Over the last century, the lower 40 km of the Fraser River has been dredged and mined for sand, confined by dikes and training walls, and re-aligned to accommodate deep-draft vessels. This paper describes some of the hydraulic and morphological adjustments that have occurred over the last 50 years between District of Mission and the sea at Sandheads. The assessment is based on a review of historical bathymetric surveys, hydrometric data and new results from a one-dimensional hydrodynamic model (MIKE-11) of the river from Sumas Mountain to the sea.

Introduction

The Fraser River is the largest river on the west coast of Canada, draining approximately 252,000 km^2. The Lower Fraser River extends for a distance of 160 km from the end of the narrow canyons near the town of Hope down to the Strait of Georgia. The river is sub-divided into three sub-reaches:

- The anabranching, gravel-bed reach between Laidlaw (Km 160) and Sumas Mountain (Km 110).
- The meandering sand-bed reach between Sumas Mountain and New Westminster (Km 40).
- The Modern delta which extends downstream of New Westminster to the sea (Km 0).

Over the last century the river has been dredged and mined for sand, confined by dikes and training walls, and re-aligned to accommodate deep-draft vessels. These interventions induced both short-term and long-term changes to the hydraulic and sediment transport characteristics of the channel. In order to manage the river in a sustainable fashion, it is important to understand the nature of these impacts and the time-scales for their occurrence. There have been a number of investigations related to sediment transport, dredging and channel response on the lower sand-bed reach of the river (Tywoniuk 1973, McLean and Tassone 1988, nhc 1999 and McLean, Mannerström and Hunter 2005). This present paper describes further progress in assessing the long-term hydraulic and morphological adjustments that have taken place along the lower Fraser River over the last 50 years using new information compiled during a major investigation on flood levels and river hydraulics (nhc 2006).

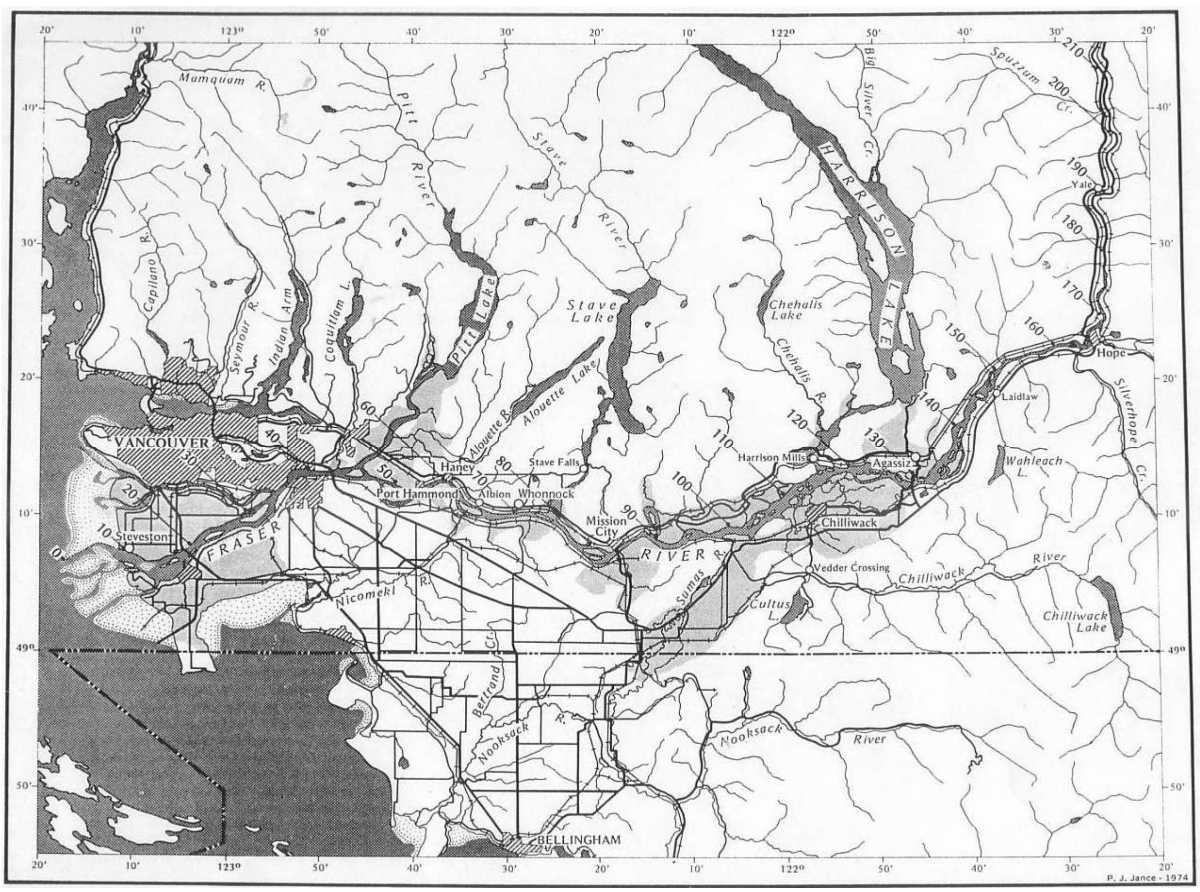

Figure 1: Lower Fraser River

Impacts of Dredging

Dredging on the Fraser River began in 1885 when the main channel was only 2.7 m deep at the river mouth. Pretious (1958) reported that about 1.4 million m^3/year of material was dredged from the main arm in the period between 1946 and 1956 to improve the navigation channel. Between 1976 and 1988, industrial borrow dredging (for construction) often exceeded navigation maintenance dredging volumes. It is believed that borrow dredging was minor prior to 1975.

Figure 2 summarizes the annual dredging effort along the South Arm since 1960. Approximately 140 million m^3 of sand has been dredged from the river over the last 40 years, with most of the removals occurring downstream of New Westminster. The dredging effort (maintenance and borrow dredging) reached up to 6.5 million m^3/year between 1976 and 1990, and has declined to between 1.5 to 2.5 million m^3/year in recent years. Since 1999, the total annual dredging effort on the South Arm has averaged less than half of the value for the period 1975-1991. Virtually all of the dredging on the river has taken place downstream of Port Mann (Km 42), with most of the effort confined to the navigation channel downstream of New Westminster. Since 1999, 65% of the total dredging effort has been in the lower 11 km reach of the river between Steveston and Sandheads.

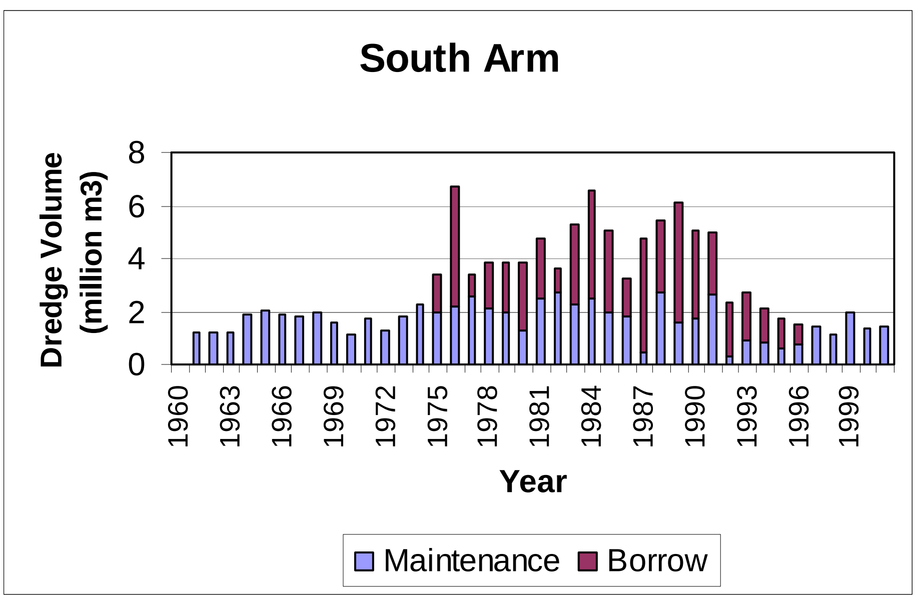

Figure 2: Annual Dredging Volumes on South Arm of Fraser River

River Bed Changes Below New Westminster

The river channel has deepened appreciably below New Westminster in response to dredging, river training and confinement by bridges and dikes. An extreme example of bed lowering has occurred near New Westminster at the site of the Patullo Bridge and CN Rail Bridge. Surveys from 1903 indicate the bed has lowered by up to 10 m, probably mainly in response to local pier scour and the constriction induced by scour protection. Similar magnitude changes to the river bed occurred after Alex Fraser Bridge was constructed. This permanent bed lowering reduced the need for maintenance dredging in the reach of St. Mungo Bend (Km 28).

Annual river surveys from Publics Works have been used to produce time series plots of bed levels in the navigation channel to illustrate the long-term overall channel response. Average bed levels in the channel have typically lowered by 3 m over a 30 year period or approximately 0.1/year (nhc 1999), with the greatest bed lowering occurring in the 1980's. This is consistent with the period when the rate of sediment removal consistently exceeded the incoming bed material load. Since the mid-1990's the rate of bed lowering has slowed considerably or in some locations (below Steveston Cut, Km 8-11) actually reversed in some years due to the reduced dredging effort, as shown in Figure 3.

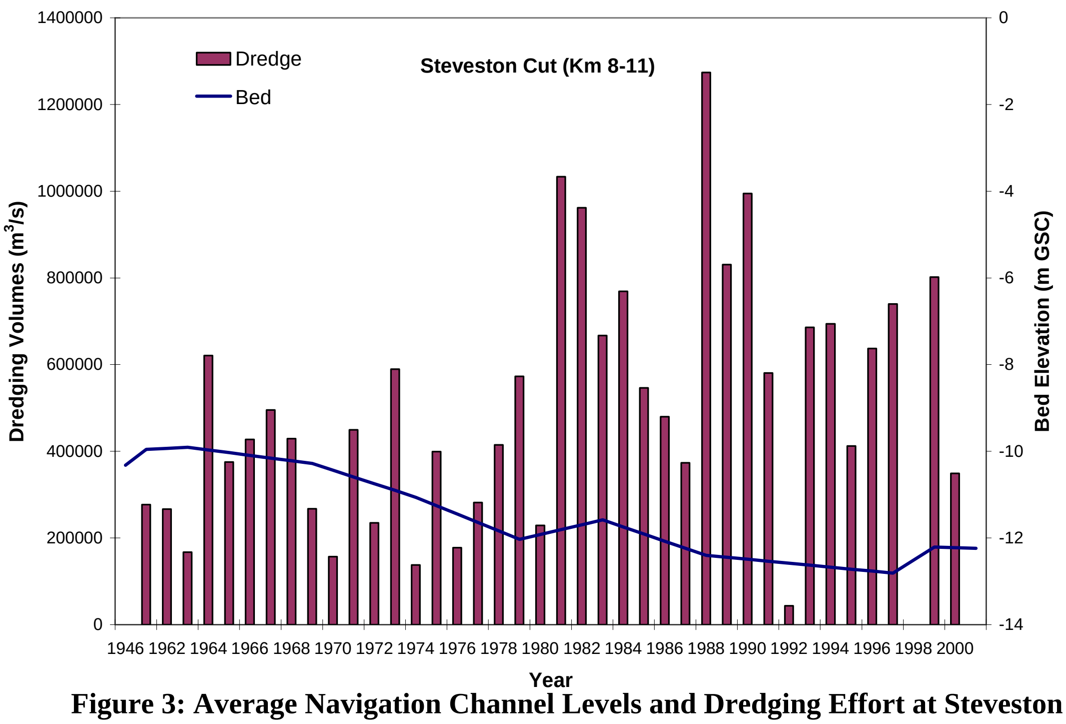

Figure 3: Average Navigation Channel Levels and Dredging Effort at Steveston Cut

Table 1 summarizes overall channel changes on the South Arm of the Fraser River between Sandheads (Km 0) and New Westminster (Km 35) for various time periods. The volumes represent net changes (deposition – erosion) computed from a comparison of annual surveys by Public Works & Government Services Canada (PWGSC) or their predecessors.

Table 1: Channel Changes Downstream of New Westminster

Period	Total Dredging Volume		Net Channel Changes	
	Total Volume (million m^3)	Annual Average (million m^3/year)	Total Volume (million m^3)	Annual Volume (million m^3/year)
1952 – 2005	140	2.6	-59	-1.1
1963 – 1974	22.5	2.0	-7.4	-0.7
1974 – 1984	44.3	4.4	-17.6	-1.8

Upstream Morphological Response

Dredging and channel excavation below New Westminster appears to have initiated progressive degradation that is slowly migrating upstream towards the end of the sand-bed reach at Sumas Mountain. This degradation was initiated by hydraulic changes along the river, notably the flattening of the water surface profile between Sandheads and New Westminster and steepening of the profile between New Westminster and Sumas Mountain. A simplified model of the degradation process was presented in McLean, Mannerström and Hunter (2005) using the one dimensional sediment program GSTARS 3 (Yang, 2002). These simulations showed the degradation would take nearly half a century to approach equilibrium 50 km upstream at Mission. Impacts of large-scale dredging activities in the mid-1980's should be reaching their full effect at Mission in the mid-2030's.

Relatively complete surveys of the channel between New Westminster and Mission were made in 1952, 1991 and 2005, which provides a good basis for assessing channel changes in this reach. The survey data were recently compiled and compared using digital terrain modelling techniques to identify systematic channel changes in this reach. This involved computed net channel volume changes between Douglas Island just upstream of Port Mann (Km 47) and Mission (Km 85). Net channel changes are summarized below in Table 2. Approximately 21 million m^3 of sediment has been removed from the channel reach between Port Mann and Mission over the last 50 years by degradation. This sediment has been transported downstream into the delta and has probably contributed to the dredging burden in the navigation channel.

Table 2: Net Channel Changes between Port Mann and Mission

Period	Net Volume Change (million m^3)	Average Change (million m^3/year)
1952 – 2005	-21.0	-0.40
1991 - 2005	-9.1	-0.65

Impacts of Dredging on Water Levels

The tide gauges at Steveston and New Westminster and hydrometric stations at Port Mann and Mission provide a good record for assessing the long-term cumulative impacts of dredging and other river training works on water levels. The lowest recorded water levels at New Westminster decreased consistently from the mid 1960's until the mid 1990's, then remained approximately constant. The lowering at New Westminster amounted to approximately 0.7 m in 25 years (McLean and Tassone, 1988). It is believed this lowering is primarily due to channel bed lowering due to dredging and river training.

Water levels at average flows and moderate freshet flows show a similar trend of decreasing water levels over time. These trends are particularly evident on the Fraser River at New Westminster and Port Mann and the Pitt River near the confluence with the Fraser. The water level trends are complicated by several factors including variations in discharge patterns, tides and other factors. Therefore, in order to reduce the effects of other variables, a "specific-gauge analysis" was carried out using hourly data at Port Mann and Pitt River near Port Coquitlam. This involved plotting recorded water levels for specific river discharges (as recorded at Mission) and specific tide levels. Separate curves were prepared for the minimum, mean and maximum tide levels at a Mission discharge of 8,000 m^3/s. Figure 4 shows plots at Port Mann and Pitt River near Port Coquitlam at a mean tide condition.

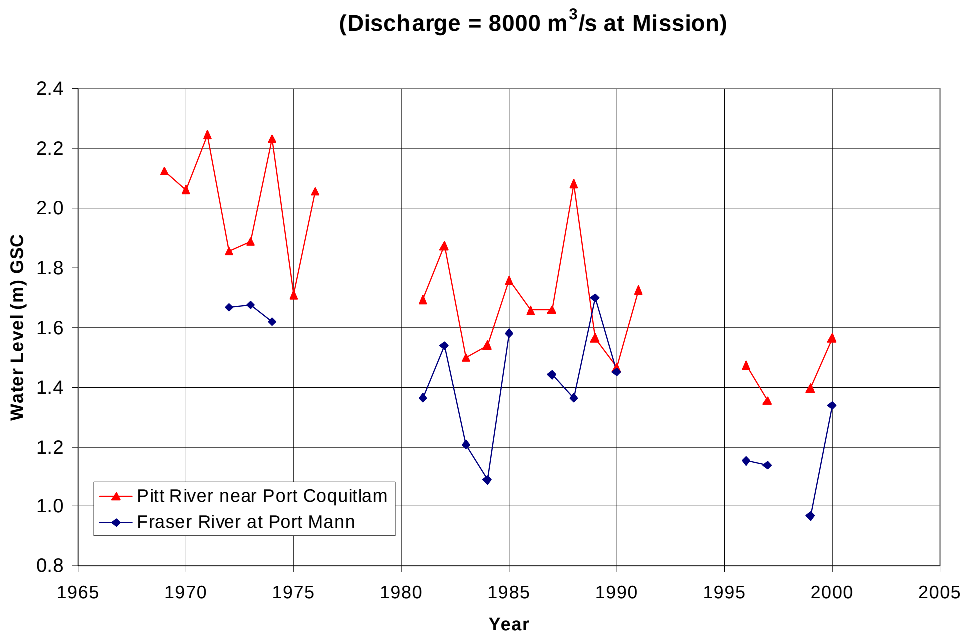

Figure 4: Trends in Water Levels at a Constant Discharge and Tide Level

At a discharge of 8,000 m^3/s, the corresponding water level decreased by approximately 0.6 m at the mouth of the Pitt River and Port Mann over the last 35 years. An analysis of discharge measurements at the Water Survey of Canada gauge at Mission (08MH024) showed a similar trend, although the magnitude of the changes was considerably smaller. At a constant discharge of 8,000m^3/s, water levels have lowered at Mission by approximately 0.2 to 0.3 m over the last 40 years.

Impacts of Diking and Channel Confinement

During extreme floods, the effects of past dike construction and floodplain development upstream of New Westminster appears to have a greater effect on water levels than historical channel changes caused by dredging or river training in the lower reach. The importance of these upstream interventions became evident when new flood profile simulations were made for the reach of the river between Sumas Mountain and the Strait of Georgia (nhc 2006). The flood profiles were made using the hydrodynamic model MIKE-11 with 2005 channel/floodplain geometry. A simulation was made for the adopted 1894 flood of record (using inflow discharges at Sumas Mountain) and then compared to the historically observed flood profile. Under present conditions, the estimated flood level was approximately the same as the 1894 historic level up to New Westminster, but then diverged further upstream. At Mission (50 Km upstream of New Westminster), the preliminary computed flood level exceeded the historic level by 1.5 m, assuming confined flow and channel roughness calibrated to the 2002 flood. The higher water levels extended as far upstream as the mouth of the Harrison River, past Chilliwack. These results are subject to further verification.

A re-construction of conditions during the 1894 flood from Hope down to Mission was made using historic accounts of the flood, analysis of available water level and floodplain topography and a simplified flood routing procedure to assess flood storage effects and attenuation from spilling. This analysis indicated that large spills and overbank flows occurred during the 1894 flood, which allowed a considerable volume of water to be stored outside of the channel zone. This included flooding and inundation of areas such as Kent (Km 120-137), Nicomen Island (Km 96-115), Hatzic Prairie (Km 90-96), Chilliwack (Km 102-131), Sumas Prairie (Km100-102) and Matsqui (Km 82-58). The Sumas and Chilliwack areas provided the largest storage volumes. However, although Kent had a smaller floodplain, the spill through Kent diverted water into Harrison Lake, thereby reducing flows on the Fraser River. Subsequent efforts to improve the system of dikes downstream of Hope have attempted to eliminate these spills. Additional confinement effects have also occurred in the reach downstream of Mission to New Westminster as a result of dike improvements and upgrading. Consequently, if a flood occurred today with a similar magnitude as the estimated 1894 flood of record at Hope, the water levels between Chilliwack and Port Mann are expected to be considerably higher than the historic level. Downstream of New Westminster, water levels are mainly governed by the tide and become increasingly insensitive to river discharge.

Questions have arisen on the flood control benefits that are associated with navigation dredging along the Lower Fraser River. The channel has been modified to such an extent over the last 60 years by river training and jetties that it is difficult to measure the effect of dredging in isolation from these other works using only the historical data that is available. We have attempted to address this question by assessing what would happen if dredging operations were significantly reduced in the future. This was done by carrying out a sensitivity analysis to illustrate the effect of raising bed levels on the computed flood level. Past trends in channel bed levels and dredging volumes were assessed over the last 40 years for each reach on the river, by producing plots similar to Figure 3. The effect of local river training structures installed during the time period was also assessed. Estimates were then made of the channel bed elevation that would be re-established if dredging were curtailed in the future. In reaches where only dredging has occurred, it was assumed the river bed would return to conditions in the 1960's. In these reaches, the navigation channel was raised on average by 2 to 3 m. Portions of the channel in St. Mungo Bend (Km 26) and Annieville Channel (Km 30) have experienced considerable confinement by training walls and bridges. In this case, an estimate was made of the equilibrium channel bed level using a "regime-type" equation relating top width and channel depth. In these reaches, it was concluded that only minor bed adjustments would occur (typically less than 1 m on average). Figure 5 shows the impact of curtailing dredging along the river. Allowing the river bed to rise by up to 3 m in the lower 11 km of the river (below Steveston) would have only a small effect on peak water levels during the 1894 flood event, resulting in a rise of approximately 0.1 m at New Westminster. Allowing the river bed to rise in all reaches between Sandheads and Port Mann resulted in an increase in flood stage of up to 0.4 m near New Westminster and Port Mann. The impact decreased further upstream, reaching approximately 0.1 m at

Mission. This result is consistent with the observed trends at the Port Mann and Mission hydrometric gauges.

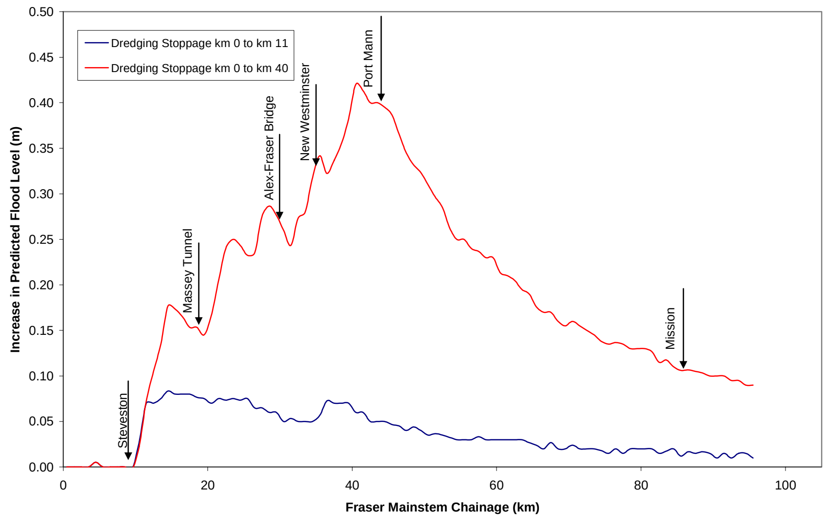

Figure 5: Potential Effect of Curtailing Dredging Operations on 1894 Design Flood

Conclusions

Past dredging and river training downstream of New Westminster appears to have induced bed lowering along the entire sand-bed reach of the river as far upstream as Mission (85 km from the sea). This degradation has occurred in response to hydraulic changes along the river, with the water surface profile flattening between Sandheads and New Westminster and steepening between New Westminster and Mission. Over the past 53 years, approximately 20 million m^3 of sand has been eroded from the bed in the 40 km reach between Port Mann and Mission, which has added to the burden of maintaining the navigation channel below New Westminster.

Historical water level data at hydrometric gauges shows water levels at low flows and moderate flows in the freshet season have lowered over the last 40 years in response to the bed lowering. A specific-gauge analysis at Port Mann and at the mouth of the Pitt River indicate the levels decreased by approximately 0.6 m. Water level changes at Mission are smaller-in the order of 0.2 to 0.3 m.

During extreme flood conditions, the effects of past dike construction and closure of spill channels on the floodplain has a more important effect than any changes to the channel induced by past dredging. Consequently, if a flood occurred today with a similar magnitude as the 1894 flood of record at Hope, the resulting flood levels would be substantially higher today in the reach between Port Mann and the town of Chilliwack.

The flood control benefit of dredging the navigation channel downstream of New Westminster was assessed using the MIKE-11 hydrodynamic model. The impact of curtailing dredging operations on flood levels would be greatest between New Westminster and Port Mann, with water levels potentially increasing by 0.4 m. The impacts would decline rapidly with increasing distance upstream and would be virtually undetectable by Mission. Dredging downstream of Steveston has virtually no impact on upstream flood levels, since water levels in this reach are controlled mainly by the tide. At present, most of the dredging effort on the river (65 %) takes place in this lower reach.

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