Matsqui Bend Erosion

prepared for
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October 18, 1999

TABLE OF CONTENTS

Problem Statement 1

Morphology and sediment transport in Fraser River: Laidlaw to Mission 3

Historical channel changes in the vicinity of Matsqui Bend 4

Possible future developments at Matsqui Bend 12

References 14

LIST OF FIGURES

Figure 1 Air photo mosaic of the study reach, March 20, 1999; Mission flow 699 m^3/s. Airphoto 15BCB99001-34; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks. To facilitate comparisons, a similar scale is maintained for Figures 3 and 4. 2

Figure 2 Long profile of lower Fraser River between Hope and Mission, where the gradient declines most rapidly. Sumas Mountain, upstream from Mission, represents the limit of tidal influence on the river. 3

Figure 3 Air photo mosaic of the study reach, March 19, 1971; Hope flow 799 m^3/s. Airphotos BC5046-75, 77, 127, 129; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks. 6

Figure 4 Air photo mosaic of the study reach, April 7, 1938; Hope flow 750 m^3/s. Airphotos BC5046-75, 77, 127, 129; source National Air Photo Library, Canada Department of Natural Resources. 7

Figure 5 Bankline position of study reach in 1949, 1961, 1983 and 1999. 8

Figure 6 Volumetric channel changes in study reach: a) 1952 to 1984, b) 1984 to 1991, and c) 1991 to 1999. 10

Figure 7 Air photo of Matsqui Bar , March 22, 1979; Mission flow 1,430 m^3/s. Airphoto 30BC79003-134; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks. 11

Figure 8 1991 bathymetry of the study reach 13

LIST OF TABLES

Table 1 Volumetric channel changes between survey dates. 9

Problem Statement

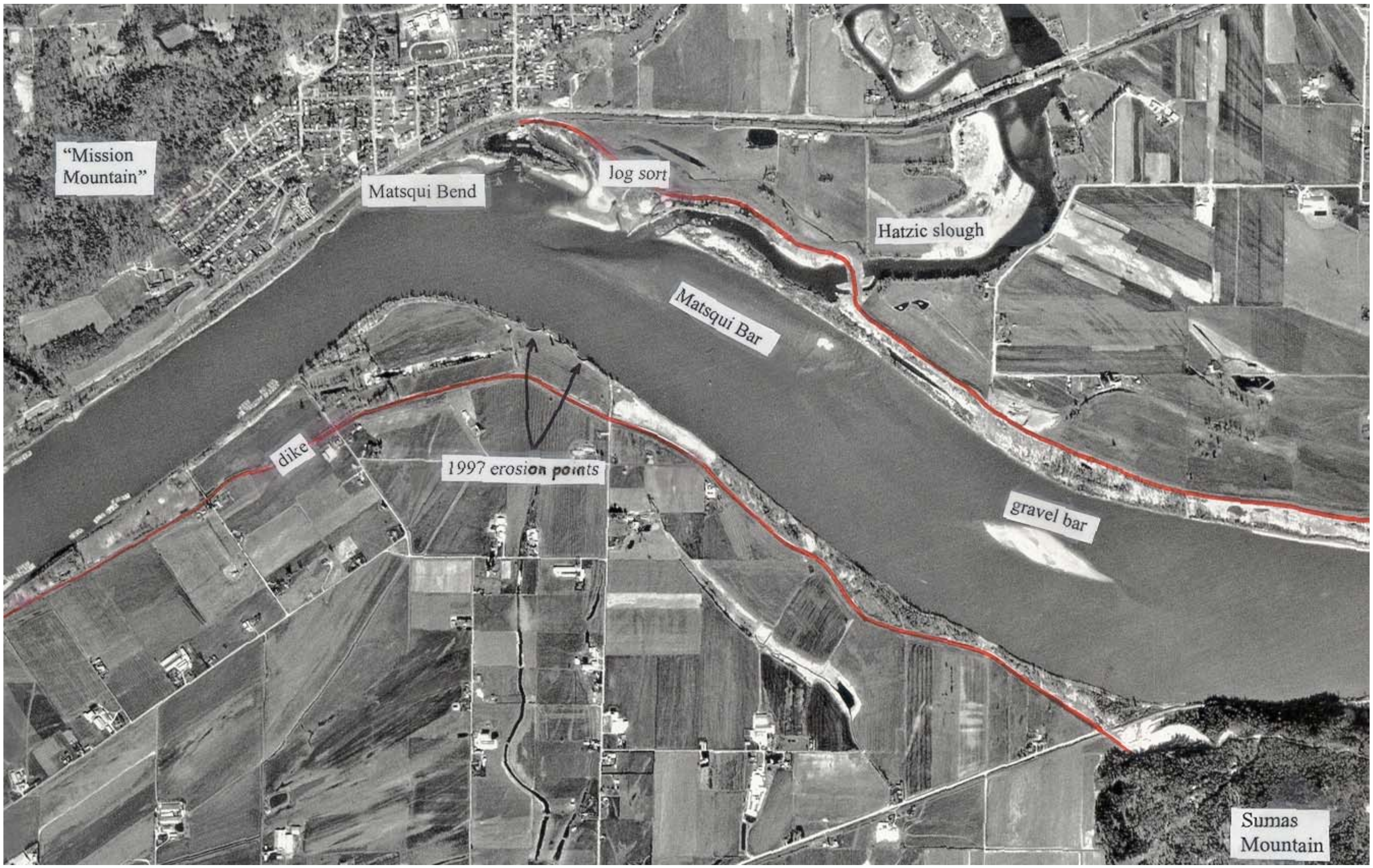
During the above average freshet of 1997, two small bank failure erosion sites developed along the left-hand side of Fraser River at Matsqui Bend, approximately 4 km upstream of the Mission bridge. In total, approximately a half hectare (5000 m^2) of land has been lost to the river. Along this reach of the river, the banks are heavily armoured but the failures have displaced the existing rip-rap. Figure 1 shows the recent erosion sites and the diking system, which is setback from the left bank at this location. The parcel of land on the river side of the diking system is owned by the Greater Vancouver Regional District and has been set aside as farmed parkland.

Contemporary management objectives for the river are focused on the need to prevent flooding outside the channel zone of the river, and to discourage erosion beyond the active channel zone. These objectives reflect the extent of settlement in the Lower Fraser Valley and the increasing value of the land. As such, the erosion points have since been reinforced with additional armouring in an effort to prevent further erosion that could, if left unchecked, attack the dikes.

Despite the recent bank protection, there is concern that erosion at this site will be an ongoing problem. The writers have been asked to prepare a report that discusses the recent erosion and its relation to the morphology of this reach. The basis of this analysis is an ongoing study of the sediment budget (volumetric channel changes derived from channel surveys), and changes in channel morphology of Fraser River between Laidlaw and Mission. This recent work updates a previous study of similar scope conducted between 1982 and 1987 (cf. McLean and Mannerstrom, 1984; McLean and Church, 1999).

The report is organized as follows. The next section provides a brief summary of the conditions and processes in Fraser River that affect this reach of the river. The following section describes recent changes in the morphology of the river in the vicinity of Matsqui Bend and relates these observations to the recent erosion. The final section indicates possible future developments in this reach.

Figure 1 Air photo mosaic of the study reach, March 20, 1999; Mission flow 699 m^3/s. Airphoto 15BCB99001-34; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks. To facilitate comparisons, a similar scale is maintained for Figures 3 and 4.

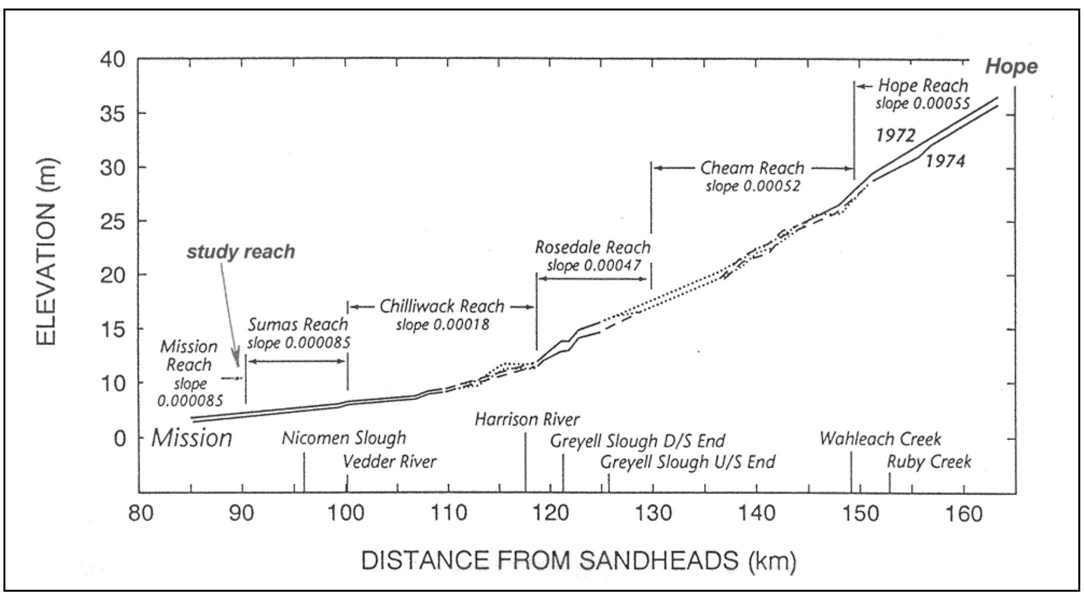


Morphology and sediment transport in Fraser River: Laidlaw to Mission

Between the downstream end of Fraser Canyon and Sumas Mountain, Fraser River flows on a gravel bed consisting of sediments transported and deposited by the river. Such deposits build up where the gradient of a river declines so that the flow is no longer sufficiently powerful to move the entire sediment load further downstream. Fraser River encounters a rapidly declining gradient after it leaves the Canyon and approaches the sea in the Lower Mainland (Figure 2).

The declining gradient causes all of the gravel transported by the river to be deposited between Laidlaw and Sumas Mountain (typically these deposits include 10 to 20% interstitial sand). Significant accumulations of sand and gravel deposited in the channel zone cause the river to flow around them, leading to bank erosion and lateral shifting of the channel. In this way, existing sand and gravel deposits are reworked and moved further downstream. Once entrained, bed material does not travel a long way. A typical step-length varies between a few hundred metres and few kilometres. The material is redeposited where flow slackens. The deposited material forms large bars in the channel that redirect the flow, or, where the bars build to sufficient height, islands. In this manner, bed material is staged down the river over many years and a “wandering” channel pattern is created, characterized by mid-channel islands that commonly subdivide the river into several channels.

Figure 2 Long profile of lower Fraser River between Hope and Mission, where the gradient declines most rapidly. Sumas Mountain, upstream from Mission, represents the limit of tidal influence on the river.



Between Hope and Sumas Mountain, where the valley walls prevent unrestricted lateral expansion of the gravel deposits, the river has created a confined alluvial fan. Deposition on the fan continues over a long period until the channel has become sufficiently steep to move the sediment load further downstream. In this manner, the front edge of the fan slowly progrades. At the present time, the fan extends to the vicinity of Sumas Mountain, immediately upstream of the study site. McLean identified the last gravel bar in the river at km 92, opposite the end of Sumas Mountain (see Figure 1). Channel-bed samples obtained by McLean in the vicinity of

Lower Sumas Mountain in August 1984, contained only modest fractions of gravel (up to 33%) and some were nearly entirely sand. Barhead samples in the vicinity are, however, predominantly gravel. On this basis, McLean placed the gravel-sand transition in the river between the western end of Sumas Mountain and Nicomen Slough (upstream).

Beyond this reach, gravel is no longer in transport and the channel pattern changes abruptly to a single thread, sand bed channel. Only sand and finer sediment is transported beyond this point. This abrupt change in sedimentation coincides with a change in slope from 8.5×10^{-5} to 5.5×10^{-5}. The focus of this report, Matsqui Bend, is of particular interest as it lies near the gravel to sand bed transition.

Although the river is large, 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, 1999; bed material here is defined as material larger than 2 mm in diameter, that is, all material larger than sand). Of course, as material is sequentially entrained and deposited downstream, much larger volumes of material and area are disturbed each year along the reach.

However, it takes many years for the distal end of the fan to aggrade sufficiently for gravel transport past Sumas Mountain.

Historical channel changes in the vicinity of Matsqui Bend

The channel zone in the vicinity of Matsqui Bend is relatively narrow and stable (Figure 1). Channel widths through this reach vary between 450 m downstream of the bend (400 m in the bend) and 750 m upstream. The relatively stable channel here results from a combination of factors. First, as noted in the previous section, this reach is the start of a single thread, sand bed channel. Because the river is sufficiently powerful to move sand and finer material in approximately the quantities supplied, no persistent buildup of deposits has occurred in the past. Secondly, the dikes are situated relatively close to the river (Figure 1) so the banks have been heavily rip-rapped to prevent erosion. Lastly, topographic confinement upstream at Sumas Mountain steers the river in its present alignment, whilst confinement by "Mission Mountain" constrains the right bank[1] of the river immediately downstream of the bend.

However, the erosion in 1997 is an indication that the channel morphology of this reach is not fixed. A review of the historic airphotos reinforces this point. Air photography of March 20th, 1999 reveals that a major lateral bar, herein referred to as Matsqui Bar, has developed on the right-hand side of the river upstream of the Hatzic Slough log sort and booming ground and downstream of the gravel bar at km 92 (Figure 1). The effect of this deposition is to divert flows toward the left bank of the river. The erosion points of 1997 are in line with the diverted flow. This bar is also visible during low flow in both 1991 and 1979, but not on March 19th, 1971 when flows were extremely low (799 m^3/s) (Figure 3). It appears then that Matsqui Bar has developed within the past thirty years.

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[1] By convention looking downstream.

Air photography from 1938 (Figure 4) indicates that the channel alignment has remained relatively unchanged, for the most part, over the past sixty years. However, it is apparent that some bank erosion occurred on the inside of the bend between 1938 and 1971. That photo also reveals no evidence of the gravel bar at km 92, which has been present since at least the 1960's.

Historic channel maps of channel bar, island, and bankline positions between Laidlaw and Mission have been created at the Geography Department of University of British Columbia by digitizing aerial photographs using a stereoplotter. The data are then transferred to a Geographic Information System (GIS) for analysis. At present, channel maps have been created for 1949, 1962, 1983, 1991 and 1999. These maps can be used to quantify areas of erosion and deposition between mapped years. Bankline positions from 1949, 1962, 1983 and 1999 for the Matsqui Bend reach have been plotted on Figure 5. For the most part, the channel has remained stable since 1949. An exception is the inside bank of the river meander where bank erosion has occurred. Between 1949 and 1962 approximately 76,000 m^2 (7.6 ha) of bank were eroded, while about 21,000 m^2 (2.1 ha) of bank were eroded between 1962 and 1983.

The earlier phase of bank erosion probably pre-dates extensive rip-rapping of the bank. The left bank in this reach consists of erodible alluvial and floodplain deposits. Since the right bank is constrained by topography past Hatzic Slough and is non-erodible, the river would tend to increase its cross-section through the bend by attacking the left bank. The historic bank erosion observed on Figure 5 reflects this tendency. In the 1970's however, significant upgrades to the dike system and additional bank armouring were completed along Fraser River including extensive rip-rapping along the left bank in this reach. As a consequence, we have observed almost no changes in bankline position during the past twenty to thirty years.

A more detailed understanding of erosion and deposition in this reach is obtained by comparing bathymetric channel surveys. For this stretch of the river, surveys were completed in 1952, 1984, 1991 and 1999. By comparing the survey data in a GIS environment, erosion and deposition volumes between survey dates can be calculated.

A comparison of the channel bathymetry between 1952 and 1984 indicates that the net change in the reach is -100,000 m^3 of sediment (the reach extends from the downstream end of Sumas Mountain to one kilometre upstream of the Mission Bridge, a distance of 6.7 km and a channel area of 4.4 km^2). Consistent with the general depositional trend along the gravel-bed reach, however, this value is not indicative of localized erosional and depositional changes. The large bar accumulating upstream of the log sort clearly shows up as an area of deposition in Figure 6a[2]. In response to this aggradation, there has been compensating erosion on the inside left bank as flows have been diverted away from the right-hand side. The most dramatic aggradation has occurred on the outside of the meander where there has been up to 16 m of deposition. Flows normally tend to be highest on the outside of meander bends and scour holes develop in response. In this case, the outside scour hole has been infilled with sediment as the channel and

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[2] Channel changes between survey dates are represented as changes in bed elevation in Figure 6. Darker coloured areas represent deposition (in metres) between survey dates while lighter colours represent erosion.

Figure 3 Air photo mosaic of the study reach, March 19, 1971; Hope flow 799 m^3/s. Airphotos BC5046-75, 77, 127, 129; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.

Figure 4 Air photo mosaic of the study reach, April 7, 1938; Hope flow 750 m^3/s. Airphotos BC5046-75, 77, 127, 129; source National Air Photo Library, Canada Department of Natural Resources.

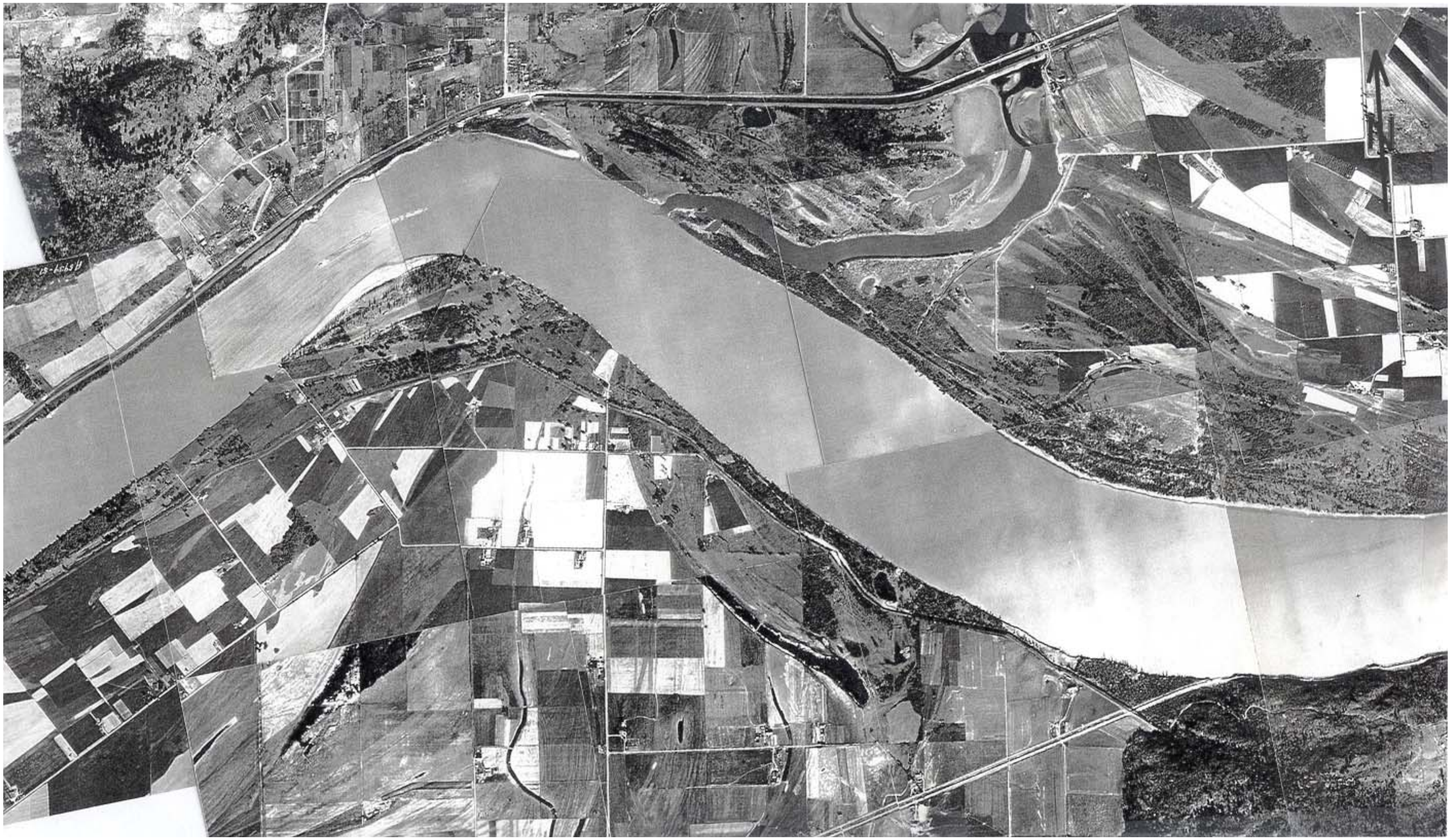


Figure 5 Bankline position of study reach in 1949, 1961, 1983 and 1999.

scoured zone have shifted toward a straighter alignment. The same pattern of deposition and erosion is evident between 1984 and 1991, and 1991 to 1999 (Figure 6 b and c). As before, however, the net change is not large (Table 1). It should be noted that these figures represent bulk volumes, not mineral volume (i.e., porosity has not been accounted for).

Table 1 Volumetric channel changes between survey dates.

Period	Deposition (m^3)	Erosion (m^3)	net change (m^3)
1952 – 1984	+ 3,820,000	- 3,920,000	- 100,000
1984 – 1991	+ 3,075,000	- 2,845,000	+ 230,000
1991 – 1999	+ 3,055,000	- 2,905,000	+ 150,000

When a sinuous or meandering river is unconstrained, deposits usually accumulate on the inside of bends (point bar deposit) while erosion occurs on the outside. In this way, the curvature of the bend tends to increase over time as the point bar builds outward. In general, it has been shown that bank erosion and point bar accumulation are volumetrically equal (Leopold and Wolman, 1957). Eventually, the curvature of the bend becomes too great for the flow to be effectively routed and the channel straightens out. The study reach does not fit this model of point bar development. Further erosion on the outside of the bend is constrained by topography and dike construction, and the meander is not yet at a state of exaggerated curvature. The observed straightening of the river (Figure 5) is the response to sediment deposition toward the right bank.

The question remains why a large bar would develop immediately upstream of a meander bend, particularly in a reach where the river is sufficiently powerful to move sand and finer material in approximately the quantities supplied. One possibility is that the channel has aggraded sufficiently to move gravel into the reach and Matsqui Bar is the end result. The river is sufficiently wide at this point (up to 750 m) that a lateral gravel bar could be accommodated. In contrast, the river is significantly narrower (400 to 500 m) downstream of the meander bend leaving little room for significant deposits.

In fact, Matsqui Bar occupies a position directly downstream of the “Sumas Mountain gravel bar”, which represents the downstream limit of the gravel reach (Figure 1). It appears that the primary redirection of flow toward the left bank is accomplished by that feature, and that the lateral bar has developed in the zone of weaker flow on the lee side of the gravel bar. As a consequence, Matsqui Bar is primarily or entirely a sand structure. The 1979 photography (Figure 7) reveals a spectacular train of sand dunes on its surface. Furthermore, McLean (1990) recorded sand deposits in the channel thalweg of this reach in the 1980’s, well after the bar formed. On the other hand, it appears that Sumas Mountain bar, near km 92, is the result of normal progradation at the downstream limit of the gravel reach. Development was initiated during the 1960’s and has continued since. Sometime before 1971, sand deposition commenced on the lee side of this bar. Once deposition has been initiated, bars tend to grow in a downstream direction due to lower velocities in the lee of the deposit. In this way, Matsqui Bar built up over time to its present position.

Figure 6 Volumetric channel changes in study reach: a) 1952 to 1984, b) 1984 to 1991, and c) 1991 to 1999.

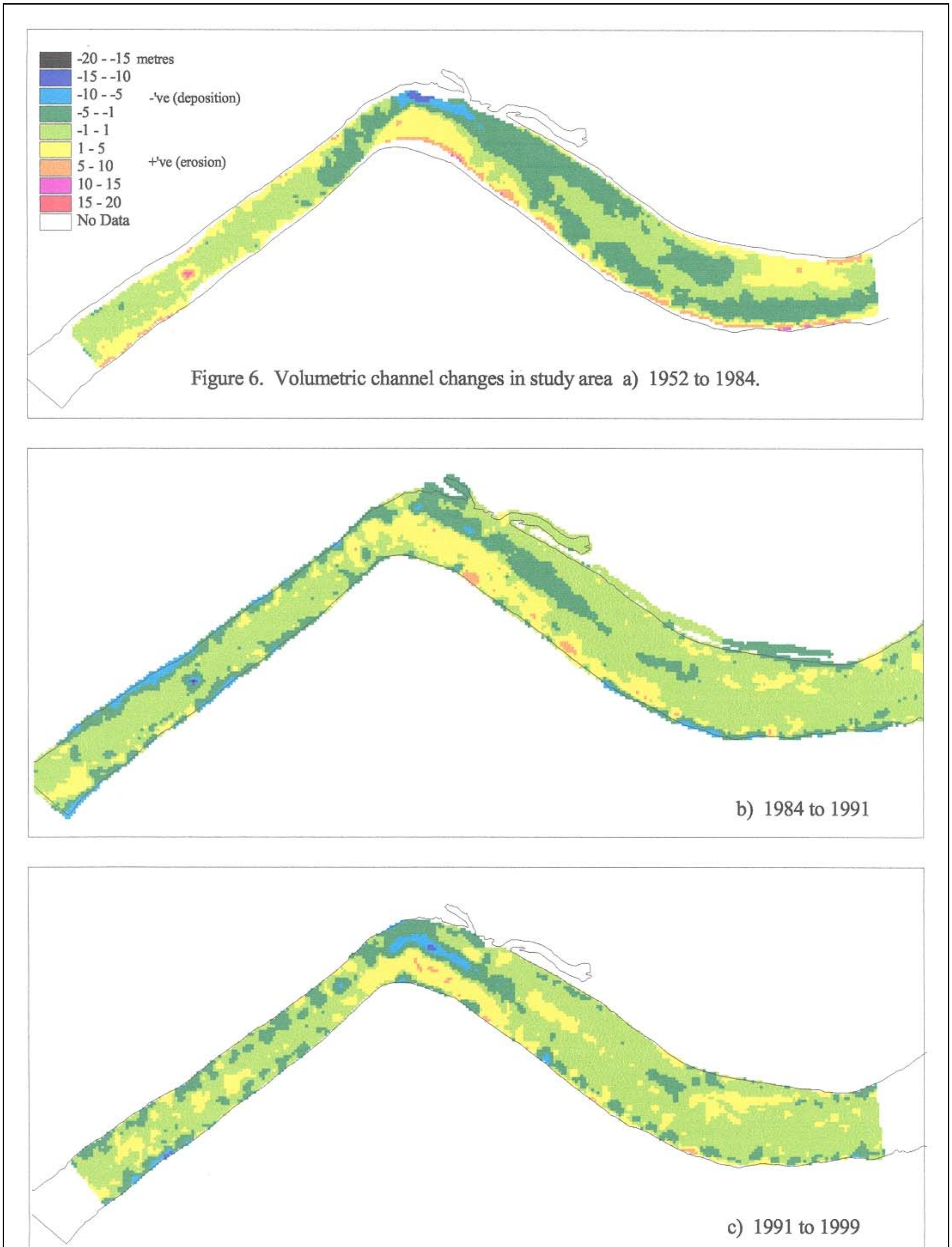
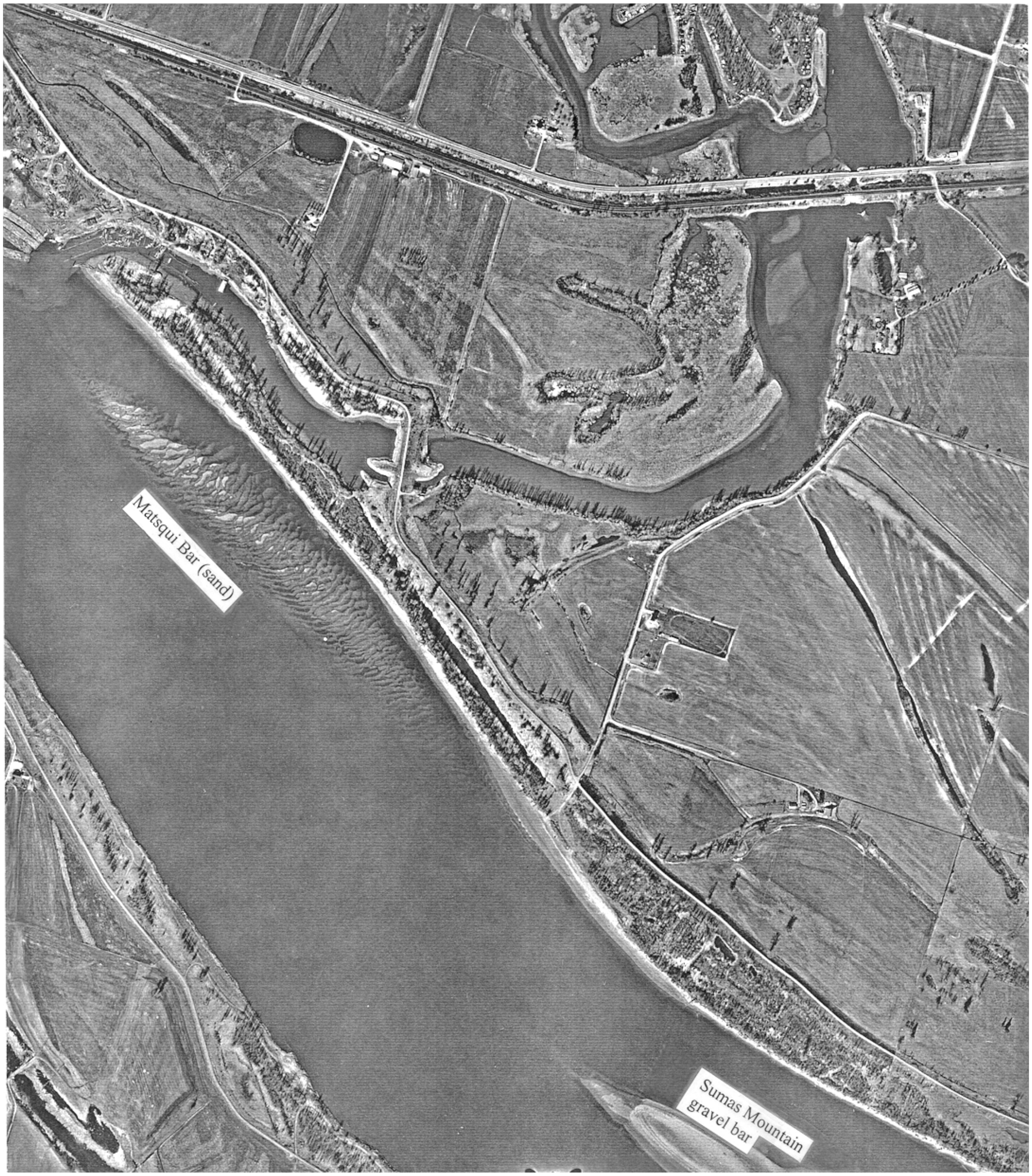


Figure 6. Volumetric channel changes in study area a) 1952 to 1984.

b) 1984 to 1991

c) 1991 to 1999

Figure 7 Air photo of Matsqui Bar , March 22, 1979; Mission flow 1,430 m^3/s. Airphoto 30BC79003-134; source Resource Surveys and Mapping Branch, British Columbia Ministry of Environment, Lands and Parks.



Regardless of its composition, this deposition has diverted the flow toward the left bank where erosion has occurred, maintaining an approximately constant volumetric sediment balance in the reach (Table 1). Diverted flows were initially accommodated by erosion of the left bank on the inside of the bend (Figure 5). Extensive bank armouring in the 1970's, however, has fixed the bank position over the past thirty years while the bar has continued to aggrade. In response, the river has progressively deepened its channel along the left bank to accommodate increased diversion of flows to this side of the channel (Figure 6). It appears that the deepening has reached a point where the toe of the bank armouring can be undercut by the river, leading to the localized erosion points of 1997.

Possible future developments at Matsqui Bend

The bathymetry of the study reach, based on the 1991 survey, is shown on Figure 8. It is apparent that the thalweg[3] is firmly entrenched along the left bank. If the bank was not heavily armoured, the river would adjust to the diverted flow by eroding the inside bank, as observed prior to extensive armouring in the early 1970's (Figure 5).

Extensive armouring of the left bank has fixed the bank position for the past thirty years. In the vicinity of the failures, opposite the downstream end of Matsqui Bar, the deep channel is reduced to about 325 m width by the bar's presence. This appears to be much too narrow. The narrowest point in the reach otherwise is 360 m, immediately downstream of the bend, and it is evident that the stable width of the main channel here is closer to 450-500 m (cf. 540 m total width at mean annual flood at Mission gauge. The channel upstream is wider because of the presence of gravel deposits in the bed). The river has responded to the narrowed configuration by incising downward along the left bank and will continue to do so while the bank remains immobile and the large lateral bar persists. Although the flow capacity of the river remains the same, the flow distribution is much different in comparison to 1952 with the hydraulically effective portion of the channel being much narrower and deeper. As a result, the left bank will continue to be under attack (especially during large freshets) as the river seeks to accommodate the increased flows created by the growth of the lateral bar. During an exceptionally large freshet, this problem could also threaten the dike if a large section of the bank armouring were to become undermined. It is unlikely that natural fluvial processes will erode Matsqui Bar in the immediate future to alleviate the pressure on the left bank because of the persistence of the gravel bar upstream. Consequently, this problem may be expected to persist for years to come.

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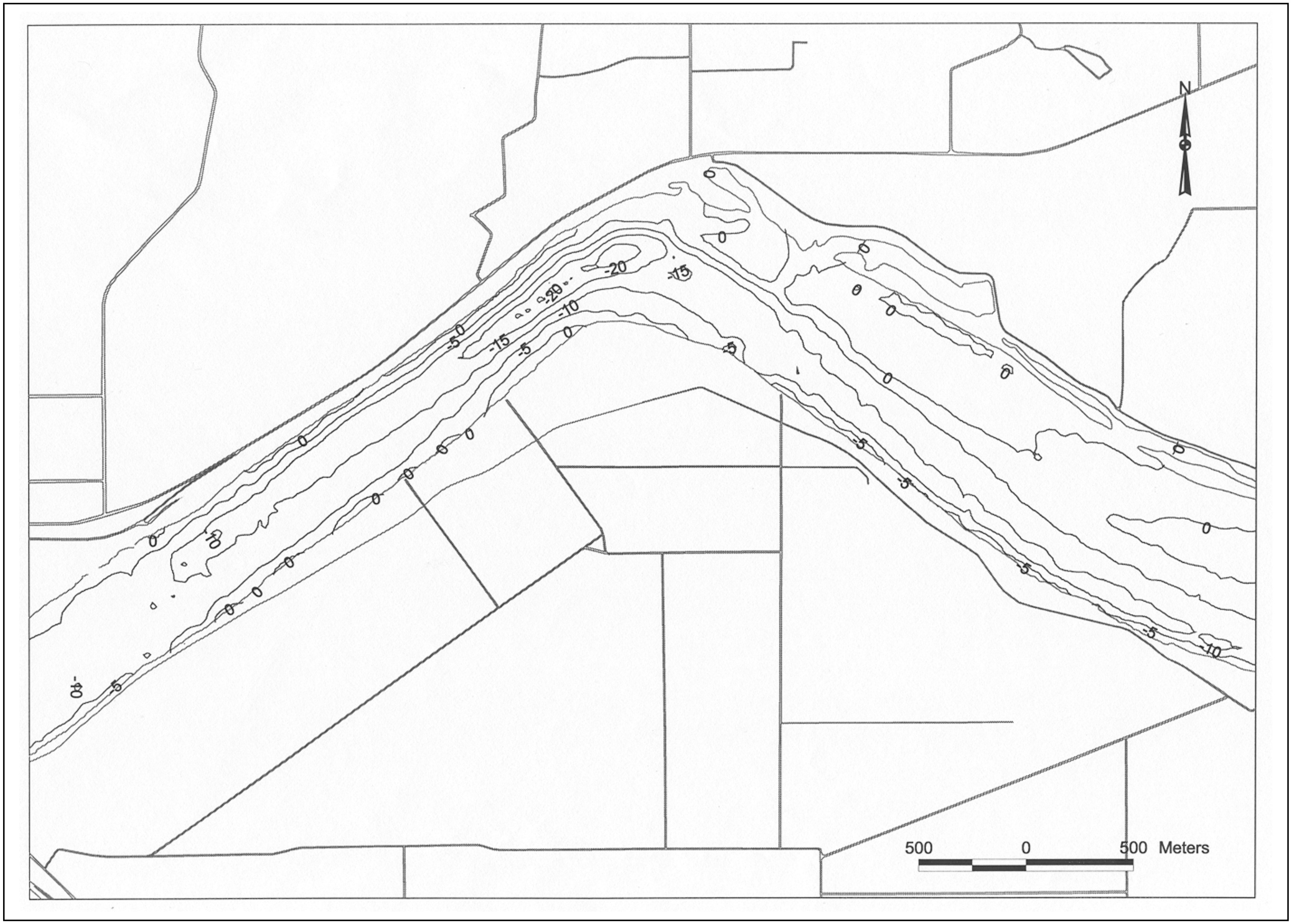
[3] The line of lowest elevation of the channel bed, and of greatest flow depth.

Figure 8 1991 bathymetry of the study reach



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