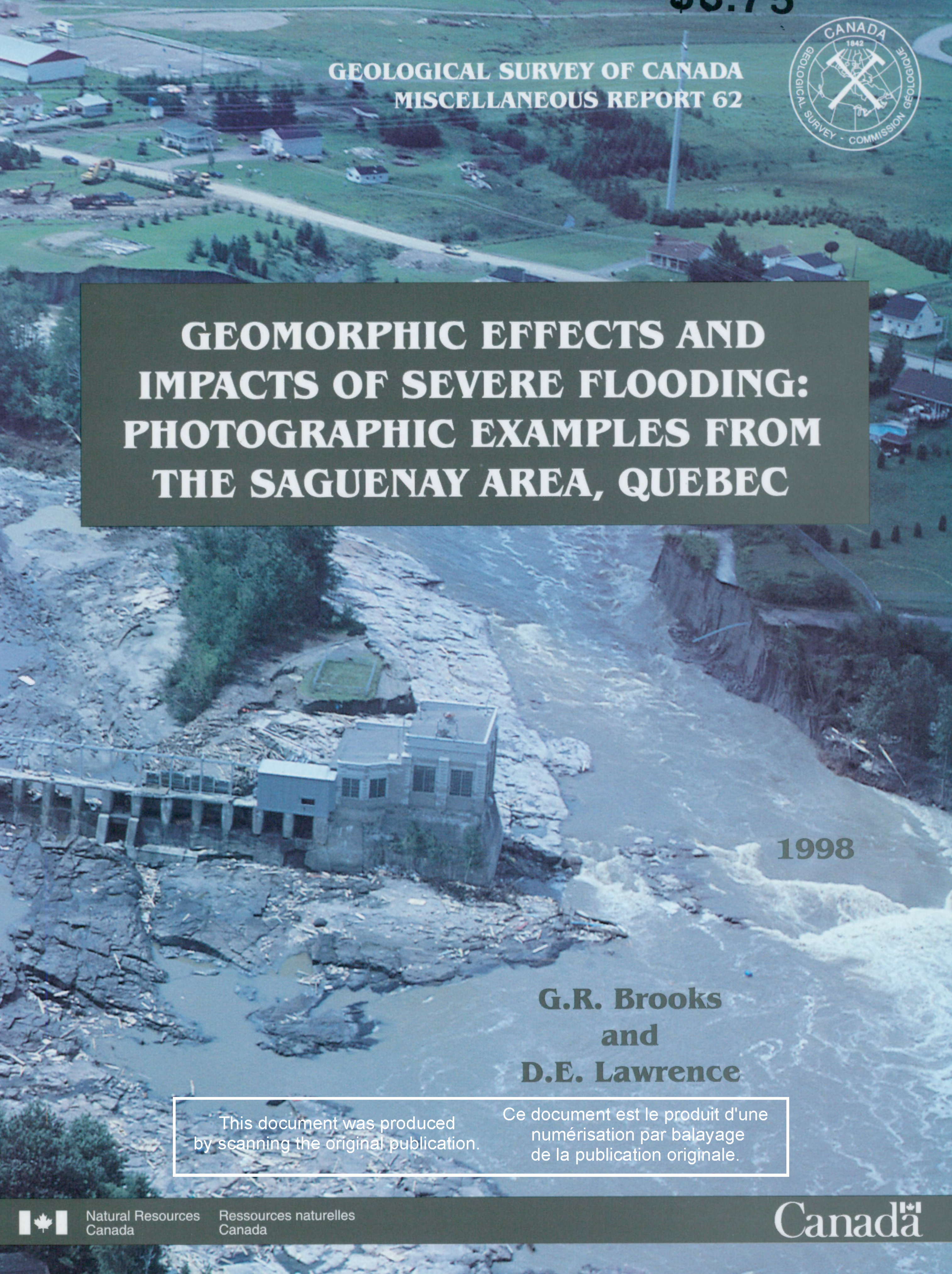

GEOLOGICAL SURVEY OF CANADA
MISCELLANEOUS REPORT 62

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GEOMORPHIC EFFECTS AND IMPACTS OF SEVERE FLOODING: PHOTOGRAPHIC EXAMPLES FROM THE SAGUENAY AREA, QUEBEC

1998

G.R. Brooks
and
D.E. Lawrence

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Cover illustration

Post-flood view of the Chute-Garneau dam along the Chicoutimi River. The entire river flow is contained within a new channel eroded beside the dam (*see* Fig. 16). (GSC 1997-42N)

Critical reviewer

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Geomorphic effects and impacts of severe flooding: photographic examples from the Saguenay area, Quebec

G.R. Brooks and D.E. Lawrence

Abstract

Severe flooding is a natural hazard that occurs regularly in Canada. This report is intended to increase public awareness of the effects of severe flooding. It presents photographically an array of geomorphic effects and impacts on floodplains, bridges, and dams using examples from the 1996 flood disaster in the Saguenay area, Quebec.

Résumé

Des inondations graves arrivent fréquemment au Canada. Le présent rapport a pour but de sensibiliser le public à ce danger naturel. Il contient des photographies d'une gamme d'effets géomorphologiques et d'impacts sur les plaines d'inondation, les ponts et les barrages causés par les inondations catastrophiques de 1996 dans la région du Saguenay, au Québec.

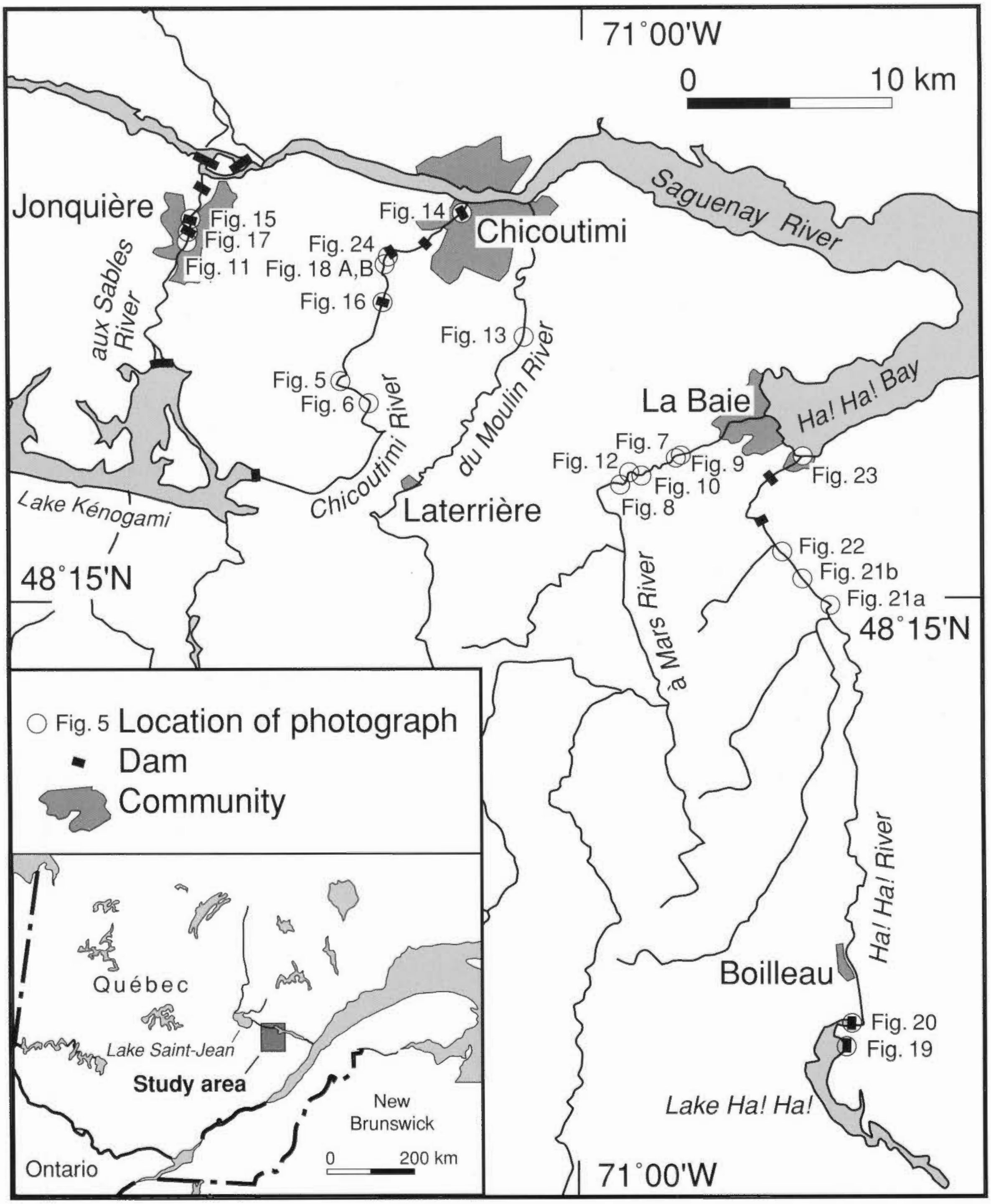


Figure 1. Map of the Saguenay area, southern Quebec, showing the location of the photographs contained in this report.

INTRODUCTION

Flooding along rivers is a frequent geomorphic event that occurs when flow exceeds the capacity of a channel and water inundates adjacent low-lying areas. In Canada, flooding commonly is caused naturally by rapid snowmelt, heavy or prolonged rainfall, ice jamming during spring breakup, and to a lesser extent by the creation and/or failure of natural dams (Andrews, 1993). Damage from inundation, sedimentation, and/or erosion during flooding can occur to settlements, agricultural lands, and infrastructure that encroach on river channels or adjacent low-lying alluvial areas.

For planning and engineering purposes, the occurrence of floods along a river is analyzed as a probability problem using existing records of annual peak discharge. This is based on the notion that floods are random occurrences whereby the floods occurring within a given period of time constitute a sample from an infinitely larger population (Leopold et al., 1964). The recurrence interval of each annual maximum flow in the discharge record is calculated, and the discharge-recurrence intervals for the entire data set are plotted. Estimates of the recurrence interval of low-frequency, high-magnitude floods that exceed those previously recorded are obtained by extrapolating a curve fitted to the data. The plotted flood frequency-magnitude distribution directly reflects the existing discharge record, but will be modified by the occurrence of subsequent floods, particularly large ones. From the distribution, the magnitude of a flood having a given probability of occurrence can be estimated for floodplain management or design purposes (e.g. the 100 year flood – the discharge that corresponds to the recurrence interval of once in 100 years). However, such flood frequencies are statistical probabilities and the recurrence intervals are not predictions of when those discharges will actually occur. There is always a chance that in any given year a major flood will occur that is larger than the selected 'design' flood (e.g. 50 year flood, 100 year flood, 500 year flood).

In 1996, major flooding occurred along a number of rivers in British Columbia, Alberta, Saskatchewan, and Manitoba. The most disastrous flooding, however, occurred in the Saguenay–Lac-Saint-Jean area, in southern Quebec (Fig. 1), due to heavy rain that fell July 18 to 21, 1996 (*see* popular accounts by Germain, 1997, Grescoe, 1997). The Saguenay floods caused severe inundation and extensive erosion along some river reaches, resulting in major channel widening and bank erosion, the breaching of dams and dykes, and damage to bridges and roads. Commercial and industrial areas located along or dependent upon the rivers were severely affected. The flooding resulted in the evacuation of 16 000 people and the destruction of or damage to approximately 1350 homes

(Emergency Preparedness Digest, 1997). Miraculously, only two people were killed in the area (by a small landslide triggered by the rainfall rather than by flood waters) out of a total of ten killed in southern Quebec during the storm. The overall damage in southern Quebec attributed to the July 18 to 21 rainfall and related flooding is estimated to be at least 800 million dollars (Emergency Preparedness Digest, 1997), making this one of Canada's most costly natural disasters.

Increasing public awareness and understanding of natural hazards is important in order to reduce the impact of natural disasters. Although awareness is greatest immediately following a major disaster, physical distance from the location of the disaster and the subsequent passage of time invoke a sense of complacency about natural hazards. The purpose of this report is to present photographic examples of a range of impacts and geomorphic effects that resulted from the severe flooding in the Saguenay area. It is intended that this report and the accompanying 35 mm slide set (sold separately) will contribute to public awareness and understanding of severe flooding, thereby contributing to flood disaster reduction.

BACKGROUND
The storm

Flooding in the Saguenay area was caused by a major storm system that stalled over the mouth of the St. Lawrence River from July 18 to 21, 1996, dropping record amounts of rain (Environment Canada, 1996). As depicted in Figure 2, over 50 mm of rain fell on a large area of southern Quebec during the storm. The zone of largest accumulation was just south of the Jonquière – Chicoutimi – La Baie area of the Saguenay Valley, where over 200 mm of rain fell. Individual locations within this zone reported receiving 210.9 mm (Portages-des-Roches station), 271.9 mm (Pikauba station), and 279.4 mm (Rivière-aux-Écorces) of rain (Environnement et Faune Québec, 1996; Milton and Bourque, 1997). Although these rainfall totals are for a four-day period, in fact, most of the rain in this area fell within a 36 hour period beginning at about 08:00 on July 19 and continuing until approximately 20:00 on July 20 (Fig. 3; Environnement et Faune Québec, 1996).

The intense rainfall from the storm of July 18 to 21, combined with the nearly saturated ground conditions produced by earlier rain in July (Environment Canada, 1996) and the generally thin, discontinuous overburden blanketing the bedrock of the Laurentian Highlands, produced widespread flooding throughout the north shore area of the St. Lawrence River in southern

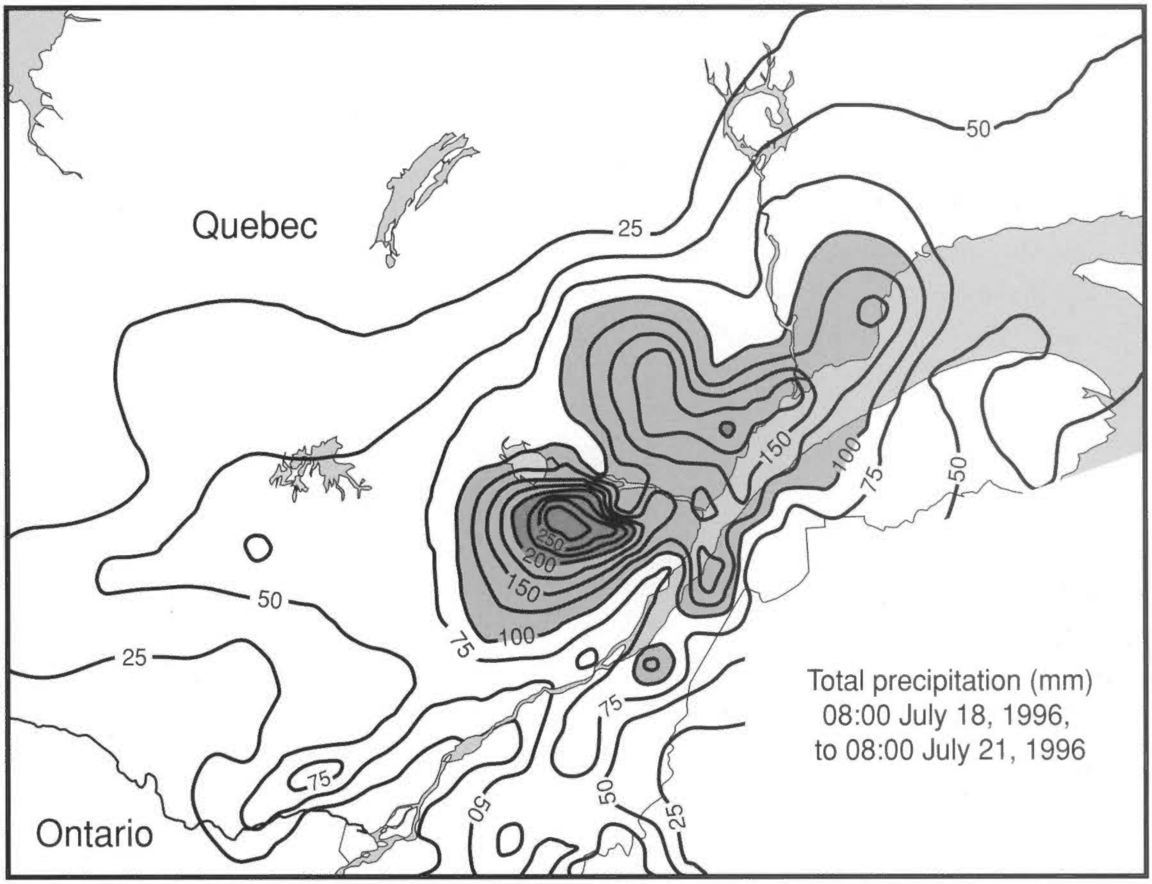


Figure 2. Map showing rainfall accumulation in southern Quebec between 08:00 July 18 and 08:00 July 21, 1996 (after Milton and Bourque, 1997).

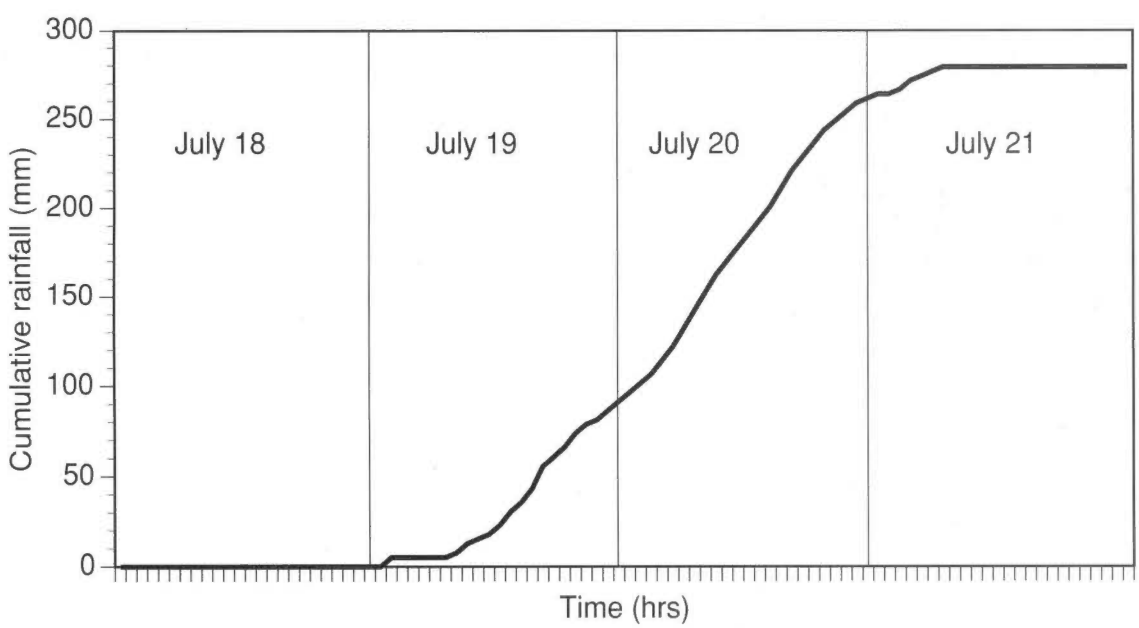


Figure 3. Cumulative rainfall diagram at the Rivière-aux-Écorces station (061020) where the highest amount of rainfall was recorded in southern Quebec during the storms of July 18 to 21, 1996 (Commission scientifique et technique sur la gestion des barrages, 1997).

Quebec. The most severe flooding occurred along rivers flowing northward into the Saguenay Valley and whose headwaters were located within the over 200 mm rainfall accumulation zone. In particular, there was extensive flooding along the aux Écorces, Pikauba, and Cyriac rivers that flow into Kénogami Lake (and therefore are tributaries of the aux Sables and Chicoutimi rivers), and the du Moulin, à Mars, and Ha! Ha! rivers (Fig. 1), although other rivers both in the Saguenay area and elsewhere in southern Quebec also experienced major flooding during this storm.

Discharge levels

Discharge data from the aux Sables and Chicoutimi rivers exemplify the magnitude of the Saguenay floods. Both rivers originate from the Kénogami Lake reservoir, have regulated discharge regimes, and share a common catchment area (Fig. 1). During the flood, discharge levels peaked at 653 m^3s^{-1} along the aux Sables River and 1100 m^3s^{-1} along the Chicoutimi River during the late morning of July 21 (Fig. 4; Commission scientifique et technique sur la gestion des barrages, 1997). These flows are the highest measured since discharge records were first kept in 1917 for the aux Sables River and in 1924 for the Chicoutimi River. The flows are considerably greater than the historic maximum daily flows found in the streamflow records, being about 2.5 times larger than the 265 m^3s^{-1} reported along the aux Sables River and 2.0 times larger than the 561 m^3s^{-1} reported along the Chicoutimi River (R. Couture, Milieu hydrique, Environnement et Faune Québec, pers. comm., 1996).

To put the flood flows in proper perspective, the critical discharge beyond which inundation of private property occurs is 150 m^3s^{-1} along the aux Sables River and 255 m^3s^{-1} along the Chicoutimi River (Fig. 4; Environnement et Faune Québec, 1996). When discharge rates of 170 m^3s^{-1} along the aux Sables River and 310 m^3s^{-1} along the Chicoutimi River are exceeded, houses start to be flooded (Fig. 4; Environnement et Faune Québec, 1996). The peak flows along the two rivers during the July 1996 flood were obviously well above these critical discharge levels.

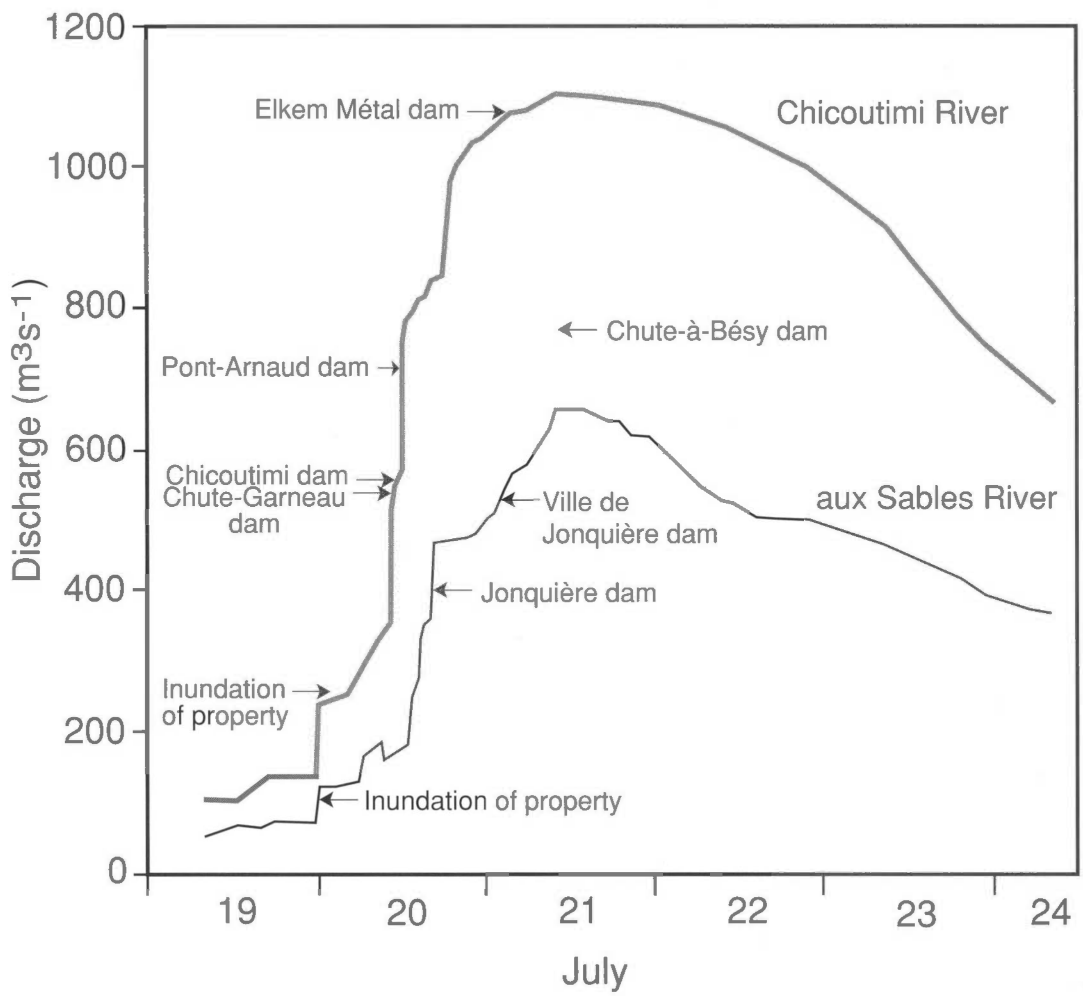


Figure 4. Discharge levels for the Chicoutimi and aux Sables rivers between July 19 and 24, 1996 (Commission scientifique et technique sur la gestion des barrages, 1997). Also shown are the threshold discharge level for each river beyond which flooding of private property begins along the low-lying areas of valley bottoms (Environnement et Faune Québec, 1996), and the maximum spilling capacity of the small dams present along both rivers (Commission scientifique et technique sur la gestion des barrages, 1997). Although the maximum spilling capacity of one of the dams along the aux Sables River is higher than the peak discharge, that dam was also overtopped by floodwaters.

Photographs

The flooding in the Saguenay area caused a broad range of geomorphic changes and impacts, as described above. These varied considerably both from river to river and from one reach to another along the same river, reflecting the influence of different natural morphological characteristics and man-made developments. The photographs in this report depict a variety of these effects and impacts, ranging from the more subtle to the extreme. Although the selected examples pertain to the Saguenay region, they are broadly representative of the consequences of severe flooding.

The photographs in this report are from five of the most severely effected rivers in the Saguenay area: aux Sables, Chicoutimi, du Moulin, à Mars, and Ha! Ha! rivers (Fig. 1). All were taken between July 25 and 29, 1996, shortly after the floodwaters receded. A detailed caption accompanies each photograph and describes the impact or geomorphic effect that is illustrated. The locations of the photographs are shown in Figure 1. The photographs are arranged generally in order of increasing severity of visible impact. Reference to the left or right side of the river is made relative to someone looking downstream in the direction of flow.

Figure 6. *Localized floodplain erosion can occur where turbulent eddies and separated flow develop to the lee of objects (e.g. trees, fences, and buildings) located along the riverbank or on the floodplain surface* (see *for example Miller and Parkinson, 1993). In this photograph, a large, elongated scour hole ('x') occurs on the floodplain along the Chicoutimi River. It was likely formed by turbulence generated to the lee of a row of small trees growing on the edge of the riverbank. Note the two houses damaged by inundation by the floodwaters and undermining by erosion of the scour hole. The arrow indicates the direction of river flow. Photograph taken on July 26, 1996. (GSC 1997-42V)*

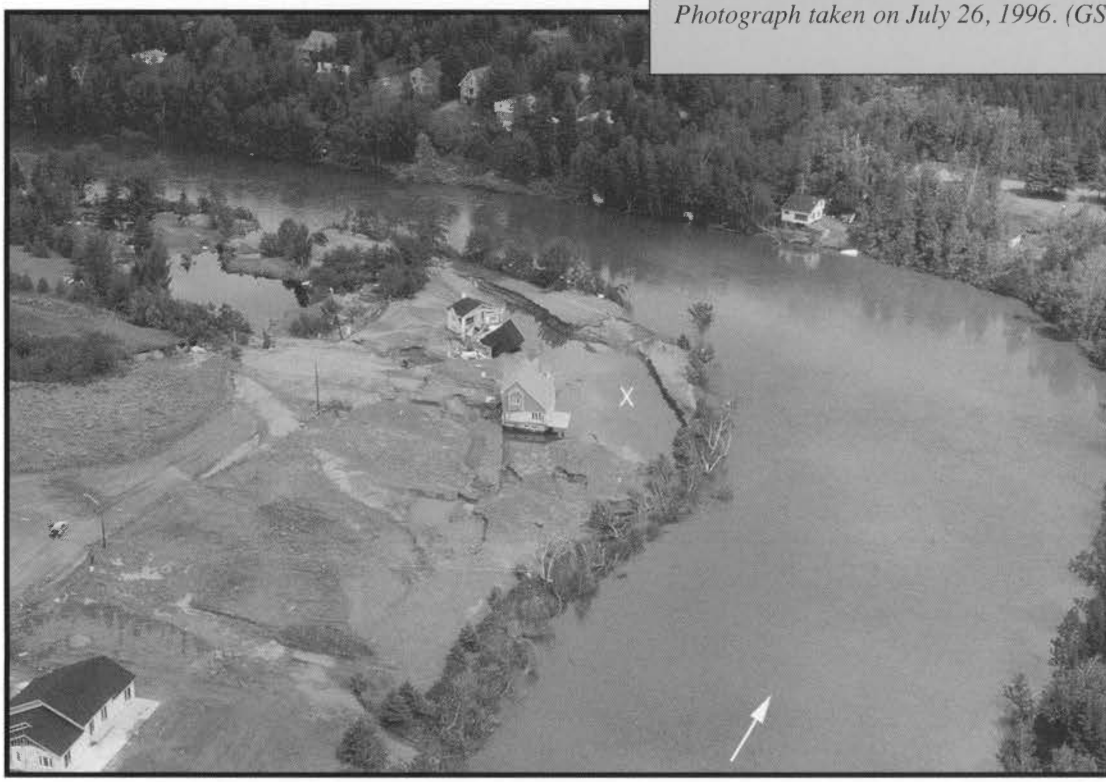


Figure 5. *During major floods, floodplains and other low-lying alluvial areas become inundated by water. This photograph shows a floodplain along the Chicoutimi River that was inundated during the flood and that experienced minor aggradation from the deposition of sediment carried by floodwaters. The houses located on this floodplain were damaged by the inundation. The river flows toward the bottom left corner of the photograph. Photograph taken on July 26, 1996. (GSC 1998-015A)*

Figure 7. *Along some river reaches, once a certain discharge level is surpassed, the strength (or stream power) of the flow exceeds the threshold of resistance of the valley bottom to scouring, and large-scale erosion of both the channel perimeter and floodplain can occur (Baker and Costa, 1987). Stream power reflects not only the discharge, but also the flow gradient and the flow width, while the resistive threshold relates to hydraulic roughness, vegetative cover, morphology, and composition of the valley bottom. Thus, resistance thresholds vary both from one river to another and from one reach to another along a single river, although in some cases, the threshold will not be exceeded under any plausible flood discharges. Once the resistive threshold is exceeded, the amount of erosion that occurs during any given flood will reflect the recent flood history of the river and the duration of the flow above the threshold (Kochel, 1988; Costa and O'Connor, 1995).*

Along the lower 10 km of the à Mars River, the stream power of the flood was sufficiently high that the threshold of resistance to erosion was exceeded. Large-scale erosion of the valley bottom resulted from a combination of concave-bank erosion, channel avulsion, and the reactivation/creation of channels (Brooks et al., 1997). The net result was the formation of a broad flood channel 50 to 380 m wide, which in places is many times wider than the pre-flood channel. The post-flood channel also exhibited a multi-channel or braided planform in contrast to the predominantly single-channelled meander planform of the pre-flood river. The photograph shows the wide flood channel and divided morphology of the post-flood à Mars River, looking downstream from about 5 km above the river mouth. Similar processes also caused extensive channel widening along the lower 3 km of the Ha! Ha! River. Photograph taken on July 27, 1996. (GSC 1997-42X)

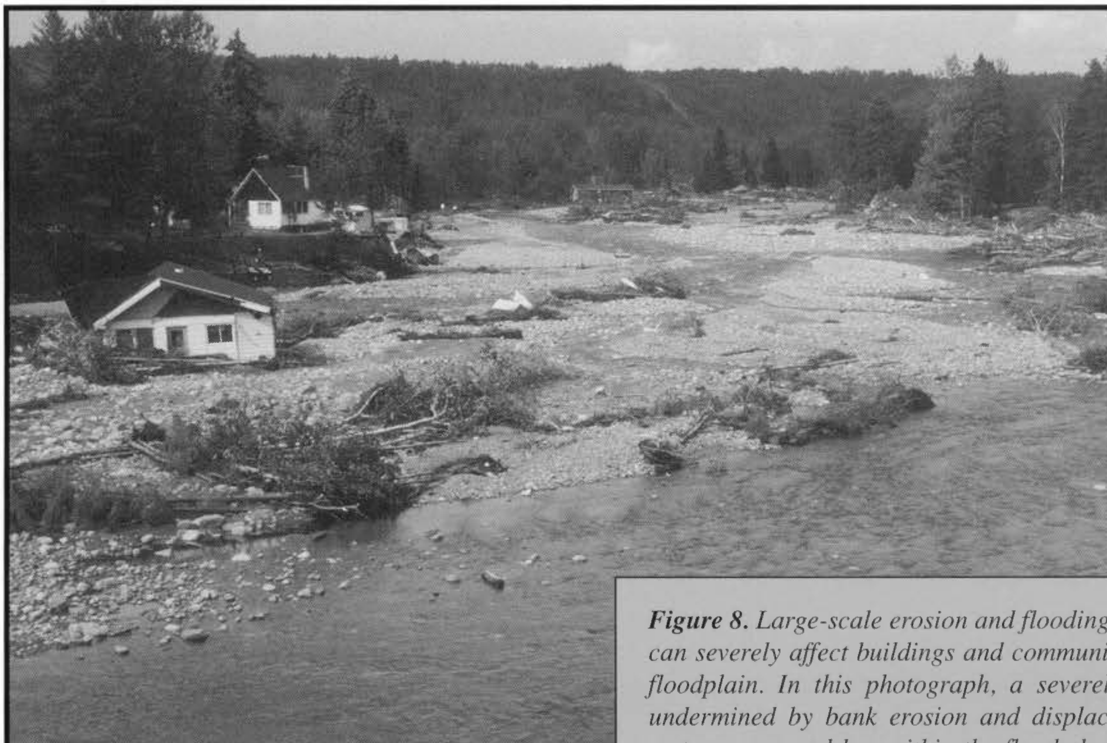
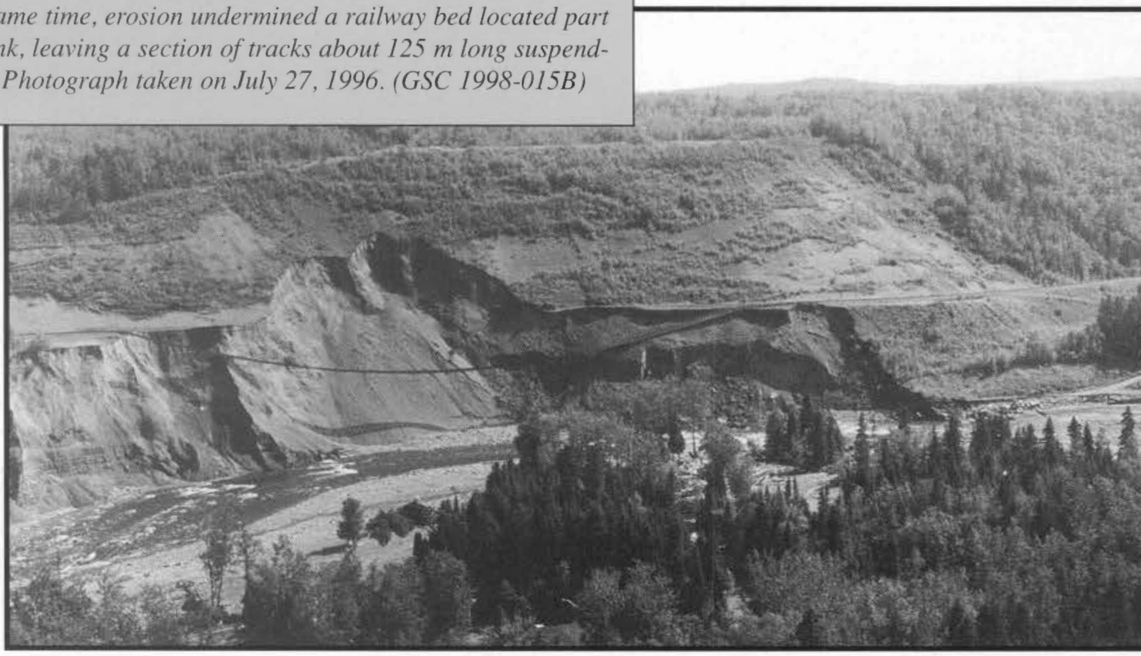


Figure 8. *Large-scale erosion and flooding of a valley bottom can severely affect buildings and communities located on the floodplain. In this photograph, a severely damaged house undermined by bank erosion and displaced by floodwaters rests on a gravel bar within the flood channel of the à Mars River. Photograph taken on July 27, 1996. (GSC 1997-42CC)*

Figure 9. *Inherent to the large-scale widening of a river channel during a major flood is the lateral erosion of floodplain and terrace deposits along the river margins. The extensive widening that occurred along both the lower à Mars River and the Ha! Ha! River during the flood was caused, in part, by the lateral erosion of terrace deposits along floodplain margins. Some houses located near the edge of the eroding terraces were damaged or destroyed by undermining associated with bank erosion. At this site along the à Mars River, one house overhangs the riverbank and several adjacent houses have been destroyed. The loss of or damage to these houses is particularly notable as they are located above the level of flooding. Photograph taken on July 27, 1996. (GSC 1997-42DD)*

Figure 10. *Lateral channel migration along a valley bottom inevitably results in the impingement of a section of channel against the valley side, causing local erosion. Along the à Mars River, this process has produced spectacular cutbank erosion about 7.5 km above the river mouth. Toe erosion of the bank caused a failure 25 to 35 m high that dumped large quantities of sediment (sand, gravel, marine silt/clay) into the river. At the same time, erosion undermined a railway bed located part way up the bank, leaving a section of tracks about 125 m long suspended in mid-air. Photograph taken on July 27, 1996. (GSC 1998-015B)*



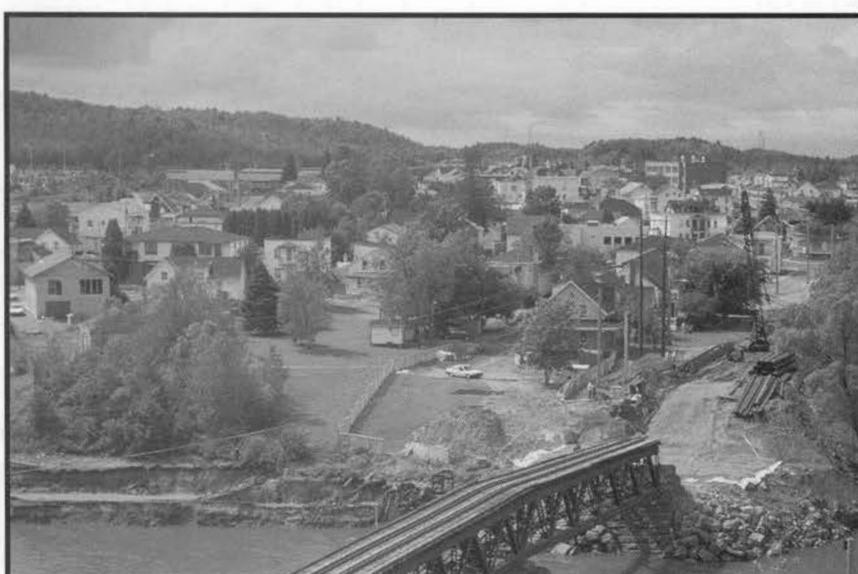


Figure 11. *Bridges commonly are damaged during major floods without necessarily being overtopped by water. Mid-channel pier supports and abutment structures that project into the flood flow create a local flow constriction that causes the current to accelerate, leading to erosion of the river bed or bank. Also, large eddies can develop in the lee of the abutments and erode the bank whereas turbulence can form immediately in front of, beside, and behind a pier support thereby eroding the river bed.*

This railway bridge along the aux Sables River was severely damaged during the flood and can be seen to be under repair in the photograph. The abutment along the left bank (far side of the channel) was eroded, damaging the left span, and the left pier support has tilted because of scouring around the foundation. Photograph taken on July 26, 1996. (GSC 1998-015C)

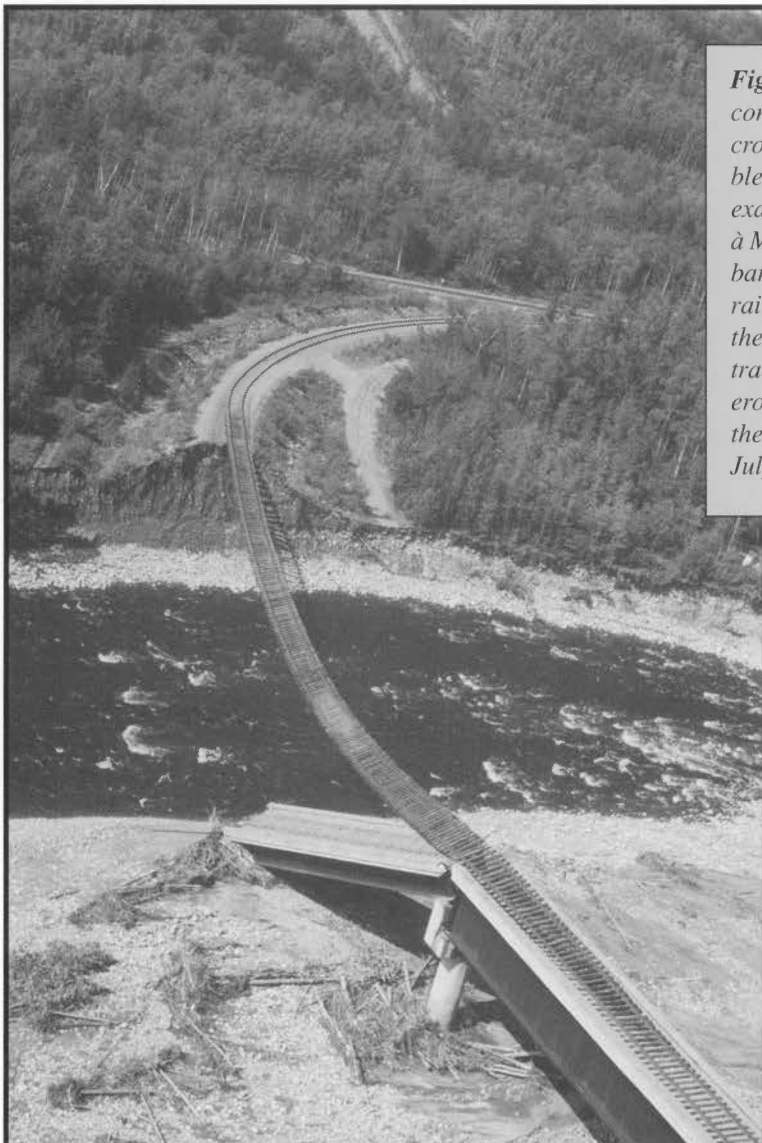


Figure 12. Bank erosion occurs naturally along the concave (or outer) bank of a river meander. Bridges crossing a river at the apex of a bend can be vulnerable to damage from concave-bank erosion. An extreme example of such damage occurred at this site along the à Mars River. During the flood, about 75 m of concave-bank erosion completely removed the left abutment of a railway bridge on the far side of the channel, causing the left span to collapse into the river. The railway tracks, undermined by the collapsed span and further erosion of the concave bank, remain suspended across the post-flood river channel. Photograph taken on July 27, 1996. (GSC 1998-015D)

Figure 13. The à Martel Falls along the du Moulin River provide another example of damage at a bridge site. Here, floodwaters spilled over a bridge that constricts a narrow reach of the river. The overflow washed out the road and severely damaged two houses next to the river. Although the bridge was damaged, its basic structure remains intact. Photograph taken on July 27, 1996. (GSC 1997-42WW)

Figure 14. When the influx of water into a reservoir exceeds the outflow, the reservoir level will rise and water may eventually overtop the dam(s) and/or dyke(s). This happens because the total outlet capacity of the dam(s) is surpassed and/or the outflow is impaired by, for example, the gates being only partly opened, malfunctioning, or being clogged with debris (Fig. 4; Jansen, 1983). The overtopping of a dam or dyke creates a very dangerous situation for areas that are immediately adjacent and downstream, especially if major erosion of the structure or an abutment ensues. During the Saguenay floods, a number of small dams were overtopped causing varying degrees and different types of damage depending upon the general setting of the dam. This photograph and those in Figures 16 to 19 all show problems at dams that impound small reservoirs.

This photograph shows a concrete dam that was overtopped causing a broad sheet of water to sweep through a residential-commercial area in downtown Chicoutimi. The resulting torrent stripped the vegetation and thin overburden from the bedrock, eroded roads, and damaged and destroyed buildings, some of which were literally washed off their foundations. A broad erosional 'channel' was created through the urban area. Sand and gravel eroded by the overflow were deposited, forming a bar in a broad pool where the flood water re-entered the river just above its mouth. The dam itself suffered only minimal visible damage from the overflow, and continued to impound water after the floodwaters had receded. Photograph taken on July 26, 1996. (GSC 1997-42S)

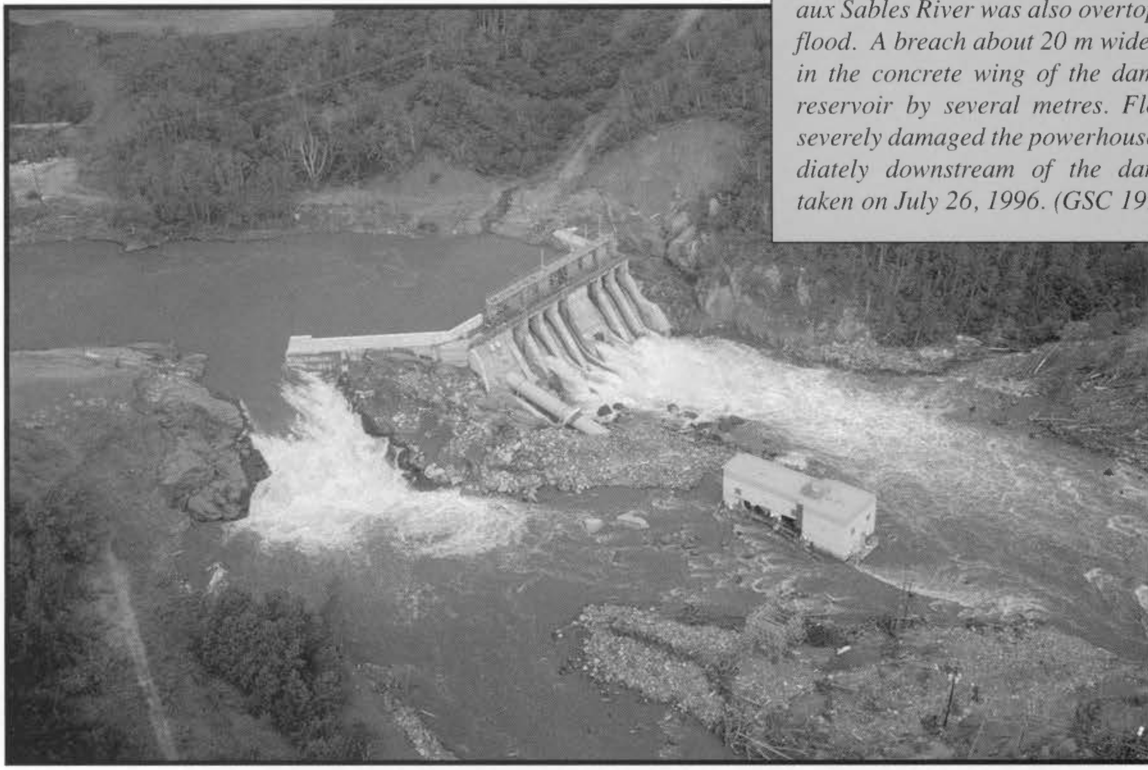


***Figure 15**. The Ville de Jonquière dam along the aux Sables River was also overtopped during the flood. A breach about 20 m wide occurred within the concrete wing of the dam, lowering the reservoir by several metres. Floodwaters also severely damaged the powerhouse located immediately downstream of the dam. Photograph taken on July 26, 1996. (GSC 1997-42L)*

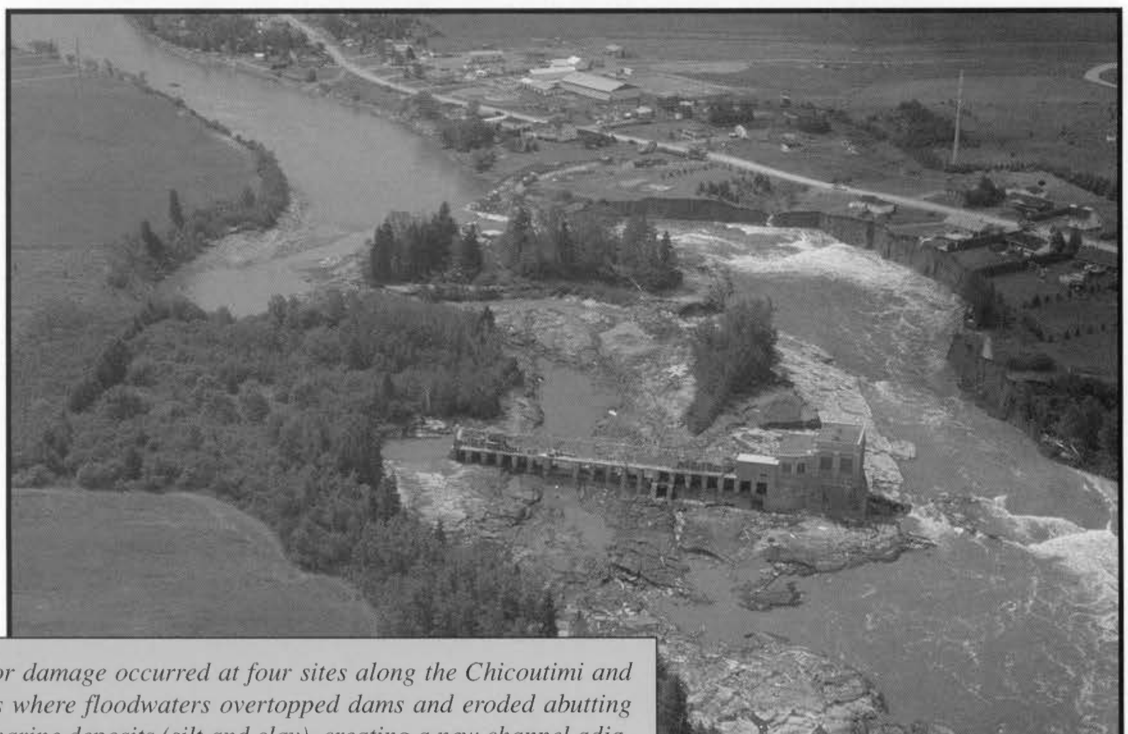
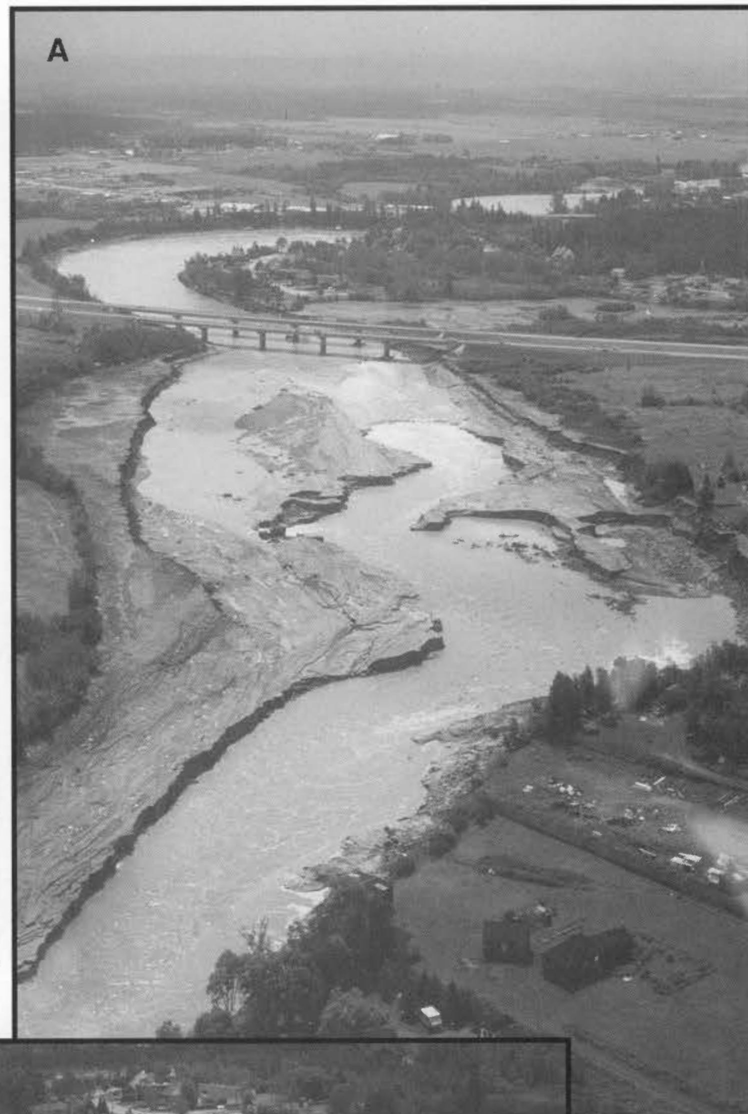


***Figure 16.** Major damage occurred at four sites along the Chicoutimi and aux Sables rivers where floodwaters overtopped dams and eroded abutting unconsolidated marine deposits (silt and clay), creating a new channel adjacent to each dam that drained the reservoir and 'captured' the entire river flow. In this photograph of the Chute-Garneau dam on the Chicoutimi River, a newly eroded channel carries the entire flow beside the dam, bypassing the penstocks and sluice gates. The dam remains intact, but is nonfunctional. Photograph taken on July 26, 1996 (GSC 1997-42N)*

Figure 17. *The overtopping of unconsolidated marine deposits abutting a dam (arrow) in downtown Jonquière resulted in the erosion of a deep gorge that carries the entire post-flood flow of the aux Sables River. At this site, the combination of lateral valleyside erosion and deep channel incision that formed the gorge undermined several apartment buildings situated above the flood level along the left (or far) side of the river, causing them to collapse. Photograph taken on July 26, 1996. (GSC 1997-42J)*



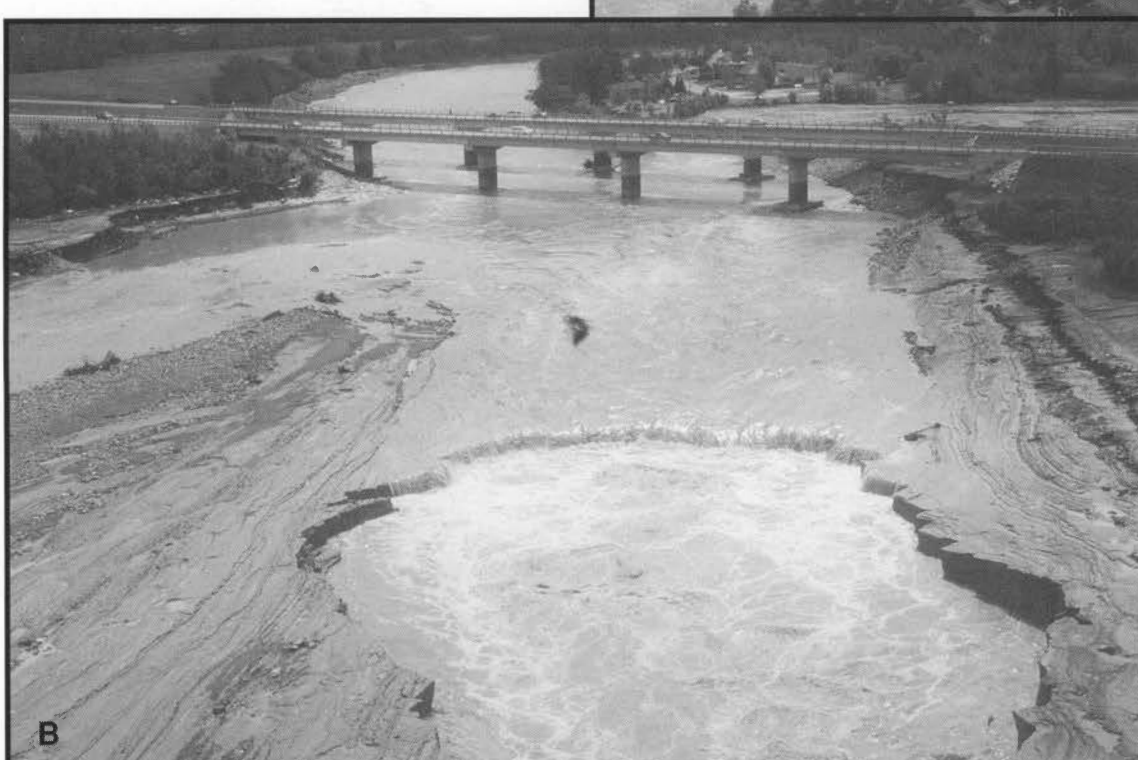


Figure 18. *The erosion of a new channel adjacent to and lower than a dam creates a drop in the local base level, which can initiate channel incision upstream into the reservoir bed. A spectacular example of this occurred along the Chicoutimi River within the area of the drained Port-Arnaud dam reservoir.* ***(A)*** *A shallow steep-sided channel 1.2 km long has been cut into marine deposits (silt and clay) of the reservoir floor (GSC 1997-42Q).* ***(B)*** *This incision is the product of 'knickpoint' retreat that occurred during the flood, whereby a 'step' forming a low waterfall 2 to 4 m high developed on the river bed (GSC 1998-015E). Turbulence and cavitation to the lee of the step scour and undermine the nearly vertical face of the marine deposits below the crest of the waterfall. This erosion causes the knickpoint to migrate upstream, extending the erosional 'gorge', while maintaining the stepped profile of the knickpoint. A waterfall still existed at the upstream end of the gorge when these photographs were taken on July 26, 1996. Most of the knickpoint retreat occurred between the time the reservoir was breached during the morning of July 21 and the morning of July 24 (INRS-Eau, 1997).*

Figure 19. *The overtopping and erosion of a dam or dyke can form a breach that progressively enlarges over time, increasing the outflow of water. The rate of erosion of the breach depends on a number of factors including the shape, height, width, length, and composition of the dam or dyke and the volume of impounded water available for drainage. Outflow will begin to decrease when the supply of water wanes as the reservoir level falls or outlet erosion slows. Breaching of a dam or dyke can result in the catastrophic release of water the discharge of which is generally directly proportional to the volume of water stored in the reservoir (*see *Costa, 1988).*

While a number of dams were breached in the Saguenay area (e.g. Fig. 13 to 16), these impounded small reservoirs and the reservoir drainage did not significantly add to the flood discharge. However, this was not the case with the Ha! Ha! Lake reservoir (surface area of 8.1 km^2*). During the rainstorm, the influx of rainfall runoff caused the waters of Ha! Ha! Lake to rise and overtop a narrow earthfill saddle dyke 162 m long and 2 to 3 m high. Subsequent erosion of the dyke and underlying surficial material resulted in the drainage of Ha! Ha! Lake. The water thus released greatly increased the storm runoff downvalley, producing a flood that was about an order-of-magnitude or more greater than the previously recorded maximum instantaneous discharge of 114* m^3s^{-1} *(Brooks et al., 1997). Drainage of the lake occurred rapidly over a period of roughly 18 hours (Commission scientifique et technique sur la gestion des barrages, 1997), but not catastrophically because of the general resistance to fluvial erosion of the silty sand diamicton underlying the saddle site. Nevertheless, the flood discharge along the Ha! Ha! River was the largest in the area relative to the size of the drainage basin. The view in this photograph is downstream into the new outlet. The subaerial lake bed and residual water surface are visible in the foreground; the arrows show the remnant margins of the dyke. The photographs in Figures 19 to 22 show selected downstream effects of the resulting deluge. Photograph taken on July 28, 1996. (GSC 1997-42B)*

Figure 20. *Although the saddle dyke was destroyed and much of Ha! Ha! Lake was drained, following the flood, the dam that had previously impounded the lake remained intact, but nonfunctional. This photograph shows the dam (arrow) with the bed of the drained lake behind it. The dam was not overtopped by lake water. Photograph taken on July 28, 1996. (GSC 1997-42D)*

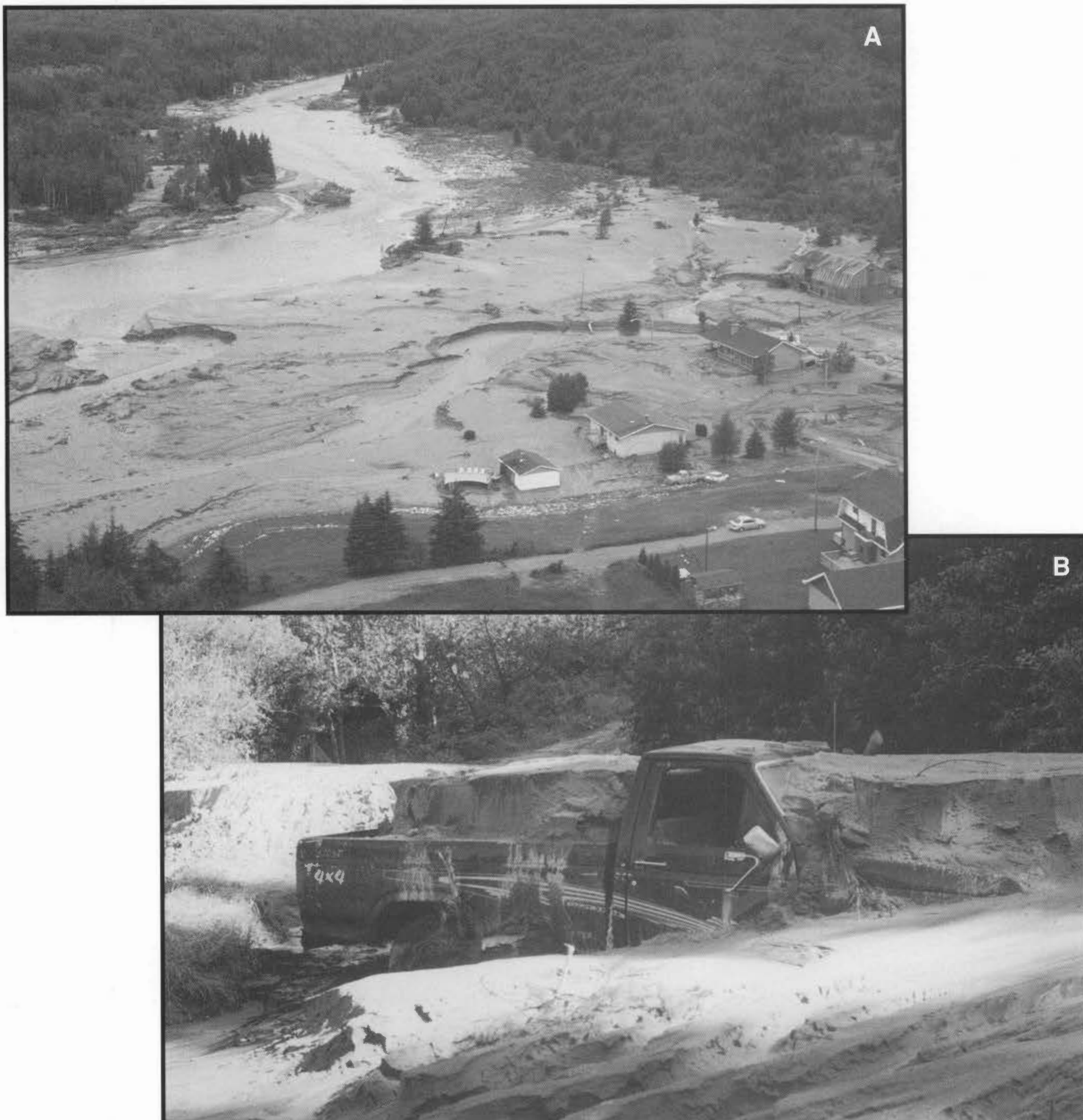


Figure 21. *Extensive aggradation occurred downstream on the Ha! Ha! River along relatively gently sloped valley reaches.* ***(A)*** *At about 10.5 km above the river mouth, aggradation occurred along a broad section of the valley bottom and several properties were covered with up to about 2 m of sand eroded from upstream (GSC 1997-42KK).* ***(B)*** *About 2 km downstream of the location shown in (A), a truck was inundated during the flood and buried in sand, literally to the roof top (GSC 1998-015F). Photographs taken on July 29, 1996.*

Figure 22. *Floodwaters eroded steeper reaches of the Ha! Ha! River. Here, channel incision and widening occurred along a narrow section of the valley bottom. The post-flood channel perimeter is formed by a bouldery lag and by diamicton and bedrock that were previously buried under river alluvium. Note the houses on the river terrace that were damaged by undermining from the lateral erosion of the right bank; some nearby houses (marked by empty driveways) collapsed into the river during the flood. Photograph taken on July 28, 1996. (GSC 1997-42NN)*

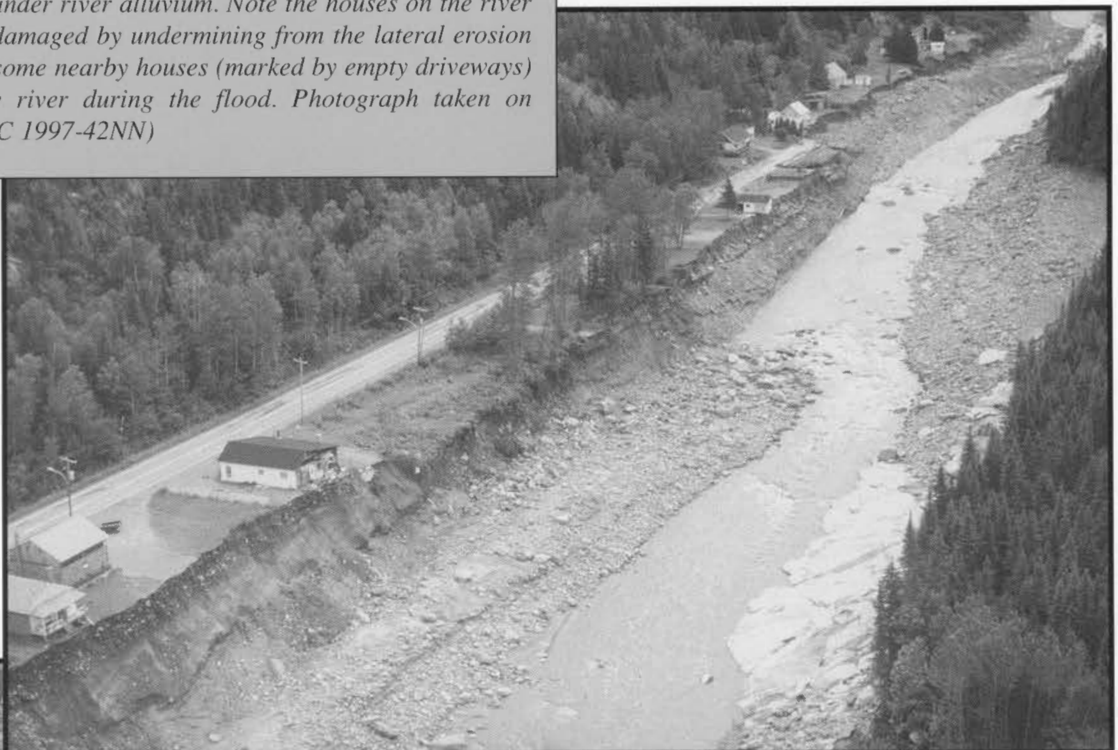


Figure 23. *At the mouth of the Ha! Ha! River, sediment and debris eroded by floodwaters upstream were carried out onto and aggraded the tidal flats (foreground), greatly increasing the subaerial extent of the flats, especially at low tide. As a striking example of the power of this flood, a bank located at the river mouth within the city of La Baie was destroyed during the flood and its 35 tonne safe was carried about 300 m out onto the tidal flats (Plan, 1996). The safe was located about three weeks later. Photograph taken on July 25, 1996. (GSC 1998-015G)*

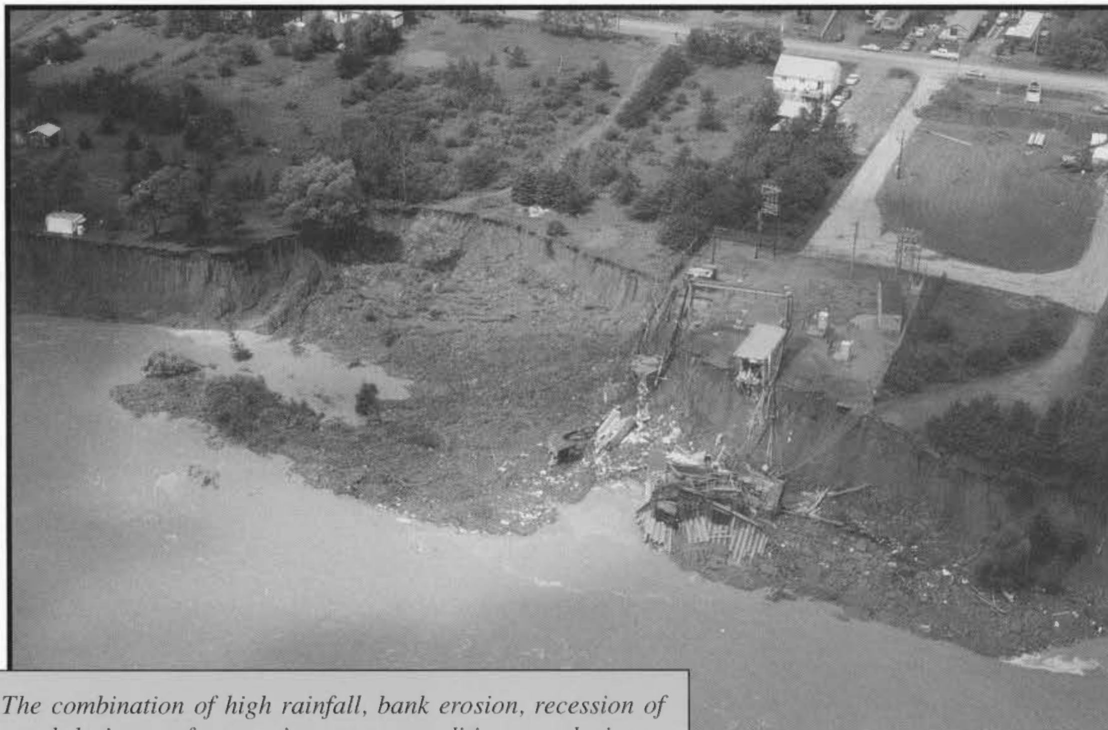


Figure 24. The combination of high rainfall, bank erosion, recession of flood levels, and drainage of reservoirs creates conditions conducive to landsliding along riverbanks. Although easily overlooked because of the widespread extent of other flood damage and geomorphic change, a number of small landslides occurred along the banks of the five rivers mentioned in this report. One of the larger failures was this retrogressive slide that occurred along the left bank of the Chicoutimi River within the reach formerly covered by the reservoir of the Pont-Arnaud dam. It occurred in fine-grained marine deposits in response to deepening of the channel bed and oversteepening of the bank by local river incision, and the drawdown of the reservoir. Photograph taken on July 26, 1996. (GSC 1997-42R)

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