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Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta

Stewart B. Rood, John M. Mahoney, David E. Reid, and Leslie Zilm

Abstract: Completed in 1951, the St. Mary Dam enables water storage and diversion for irrigation; river flows downstream are consequently dramatically reduced during summer months. To assess historical changes in the abundance of riparian cottonwoods (*Populus balsamifera*, *Populus angustifolia*, and a few *Populus deltoides*), airphoto analyses were conducted for 40-km river reaches upstream and downstream from the dam and along adjacent dammed and undammed rivers. Cottonwoods along the lower St. Mary River are confined by steep-walled canyons to narrow bands and consequently analyses of the lineal river distance associated with cottonwoods were conducted. These revealed a 68% decline from 1951 to 1985. The decline was progressive, with 28.9, 27.6, 15.1, and 7.6% of the reach associated with cottonwoods in 1951, 1961, 1981, and 1985, respectively. Ground surveys from 1985 to 1994 indicated further decline after 1985 and an absence of cottonwood seedlings and saplings. Cottonwood stands upstream from the St. Mary Dam and along adjacent rivers are more extensive and analyses of the areal extent of stands were consequently appropriate. These indicated minor change along the upper St. Mary (−0.5%), the upper (+1.9%) and lower Waterton (+3.5%), and the upper Belly (−9.1%) rivers, and an increase in forest abundance along the lower Belly River (+52.2%), between 1951 and 1985. Thus, the decline of cottonwoods along the lower St. Mary River was not symptomatic of a general pattern of decline in the region. Analyses of historical stream flows indicated that the cottonwood mortality was drought induced as a result of insufficient flows during the hot, dry summer periods and abrupt flow reductions following the high-flow period in the late spring. The riparian water table was determined to be closely coordinated with river stage, as changes in river elevation were followed by quantitatively similar changes in water table depth. Along the St. Mary River, reduced sedimentation downstream from the dam was not considered to be responsible for the cottonwood decline. The historically sparse cottonwood abundance along the lower St. Mary River may have reflected environmental conditions that were naturally only marginally suitable, and those groves may have been particularly vulnerable to the impacts of river flow regulation.

Key words: *Populus*, cottonwoods, instream flows, mortality, riparian vegetation.

Résumé : Complété en 1951, le barrage St-Mary peut accumuler l'eau et servir de diversion pour l'irrigation; l'écoulement de l'eau en aval est conséquemment fortement réduit pendant les mois d'été. Pour évaluer les changements historiques de l'abondance des peupliers ripariens (*Populus balsamifera*, *Populus angustifolia* et quelques *Populus deltoides*), les auteurs ont analysé les photos aériennes des 40 km de rivière en amont et en aval du barrage ainsi que le long de rivières adjacentes portant ou non des barrages. Le long de la partie inférieure de la rivière St-Mary les peupliers sont confinés, par des falaises escarpées, à d'étroites bandes et, conséquemment, les auteurs ont étudié la ligne équidistante de la rivière où se trouvent les peupliers. On y observe un déclin de 68% entre 1951 et 1985. Le déclin est progressif avec 28,9, 27,6, 15,1 et 7,6% de l'étendue associée aux peupliers respectivement en 1951, 1961, 1981 et 1985. Des suivis au sol de 1985 à 1994 indiquent que le déclin s'est poursuivi après 1985 et que les semis et plantules de peupliers sont totalement absents. Les peuplements de peupliers en amont du barrage St-Mary et le long des rivières adjacentes sont plus étendus et il convenait d'effectuer l'analyse des surfaces. Ces analyses montrent des changements mineurs en amont sur la rivière St-Mary (−0,5%), en amont (+1,9%) et en aval (+3,5%) sur la rivière Waterton, ainsi qu'en amont (−9,1%) sur la rivière Belly, et une augmentation de l'abondance de la forêt (52,2%) sur

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S.B. Rood.[1] Department of Biological Sciences, The University of Lethbridge, Lethbridge, AB T1K 3M4, Canada.
J.M. Mahoney. Alberta Environmental Protection, Oldman Dam, Pincher Creek, AB T0K 1W0, Canada.
D.E. Reid and L. Zilm. HBT AGRA Ltd., 221-18 St. SE, Calgary, AB T2E 6J5, Canada.

[1] Author to whom all correspondence should be addressed.

l'aval de la rivière Belly, entre 1951 et 1985. Ainsi, le déclin des peupliers le long de la rivière St-Mary ne constitue pas un patron général de ce déclin dans la région. Les analyses historiques des cours d'eau indiquent que la mortalité des peupliers est induite par la sécheresse causée par l'écoulement insuffisant pendant les périodes chaudes et sèches de l'été et les brusques réductions de l'écoulement suivant les forts écoulements de la fin du printemps. On a constaté que la nappe phréatique riparienne est étoitement reliée avec la hauteur de la rivière, puisque des changements dans l'élévation de la rivière sont suivis de changements quantitativement similaires dans la profondeur de la nappe phréatique. Le long de la rivière St-Mary, on ne peut considérer qu'une réduction de la sédimentation à partir du barrage pourrait être responsable du déclin des peupliers. La faible présence historique des peupliers le long de la rivière St-Mary pourrait refléter des conditions environnementales qui étaient naturellement marginales pour ces espéces et ces canyons étaient probablement vulnérables aux impacts de l'écoulement de l'eau.

Mots clés : *Populus*, les peupliers, l'écoulement, la mortalité, la végétation riparienne.
[Traduit par la rédaction]

Introduction

Riparian (river flood plain) cottonwood forests provide environmental, aesthetic, and recreational relief in many otherwise treeless regions of North America's western prairies and Rocky Mountain foothills. Riparian woodlands often comprise the regions' richest wildlife habitats, offering forage, cover, and reproduction sites for numerous birds and mammals (reviewed in Finch and Ruggiero 1993). Generally less than 2 km wide, the cottonwood forests can extend for tens or hundreds of kilometres in length and link the prairie, foothills, and mountain ecosystems, enabling wildlife and plant movements.

As well as being particularly valuable, riparian cottonwood forests are also particularly vulnerable. Riparian areas offer desirable sites for crop or livestock production, domestic settlement, transportation corridors, and other uses that involve forest clearing and (or) lead to a failure of cottonwood recruitment. River damming and water diversion, principally for irrigation, are common in the semiarid regions of western North America, and such damming has led to downstream forest decline along numerous rivers (reviewed in Rood and Mahoney 1990, 1993). It is very likely that the downstream impacts of damming are primarily dependent on the patterns of river flow management and consequently an understanding of the relationships between river flow patterns and the responses of riparian cottonwoods are important. Such understanding may be achieved by analyses of river flows and riparian cottonwoods along various dammed and undammed rivers.

The abrupt decline of riparian cottonwoods downstream from the St. Mary Dam was previously introduced and possible causes for decline have been proposed (Rood and Heinze-Milne 1989). The present study continued investigations of the cottonwoods along the St. Mary and adjacent rivers with two objectives: (*i*) to assess the pattern of decline over time, and (*ii*) to clarify the causes of the forest mortality. Particular attention was directed towards the relationships between river flow and cottonwood condition, since these relationships are crucial for the sustenance of phreatophytic riparian woodlands (Hughes 1994; Mahoney and Rood 1991*b*, 1992; Rood and Heinze-Milne 1989; Scott et al. 1993; Stromberg and Patten 1991, 1992).

Materials and methods

Background: the St. Mary River

The St. Mary River originates in alpine tundra in the Lewis Range of the Rocky Mountains in Glacier Park, Montana (maps showing the study region are included in Rood and Heinze-Milne 1989 and Rood et al. 1995). Numerous alpine streams flow into Upper St. Mary Lake, from which the St. Mary River flows to Lower St. Mary Lake and then northward from Montana into Alberta. A diversion weir is situated near the outflow of Lower St. Mary Lake and diverts some water to the Milk River for its return through Alberta back to Montana.

In Alberta, the largest tributaries of the St. Mary River are Lee Creek, a free-flowing tributary that originates from the eastern border regions of Glacier and Waterton parks, and Pothole Creek, which flows into the St. Mary River near the confluence with the Oldman River. Pothole Creek delivers irrigation return flows during the summer months and is situated upstream from the lower St. Mary River hydrometric gauging station. During the summer months, up to one-half of the flow of the lower St. Mary River results from this contribution and, consequently, the summer discharge data presented in the figures of the present paper are sometimes considerably higher than the flows through the river reach along which cottonwoods were studied. Higher flows are proportionally less influenced by Pothole Creek, and thus the peak flow patterns are representative of flows through the principal cottonwood study reach along the lower St. Mary River.

Analyses of historical cottonwood abundances

Analyses of historical cottonwood (primarily balsam poplars, *Populus balsamifera* subsp. *balsamifera*, and narrowleaf cottonwoods, *Populus angustifolia*, with a few prairie cottonwoods, *Populus deltoides*, and various interspecific hybrids; Greenaway et al. 1991; Rood et al. 1986) abundances along the St. Mary River involved a lineal ticking method described previously (Rood and Heinze-Milne 1989), using two sets of black and white airphotos: July 1951 (scale 1 : 40 000) and June 1985 (1 : 30 000). This lineal analysis involved tracing of the rivers on transparencies, marking the river maps at 1-mm intervals and determining whether cottonwood groves occurred on either bank for each 1-mm segment. This method determines the proportion of river length associated with riparian cottonwoods and is thus a one-dimensional simplification of cottonwood abundance. This approach is appropriate for the lower St. Mary River, since those cottonwoods are restricted to narrow bands along a flood plain that is confined by steep coulees and sandstone cliffs.

Two-dimensional areal analyses of historical cottonwood abundances in 1951 and 1985 were conducted for the St. Mary River and for the adjacent Belly River, upstream and downstream of the Belly River weir, and for the Waterton River, upstream and downstream of the Waterton Dam. For areal analyses, photographic enlargements were made from 1951 and 1985 airphotos to produce 1 : 15 000 photomosaics. Cottonwood stands were outlined, and areas were determined by computerized digitization.

For both lineal and areal analyses, complete river reaches were assessed, extending 40 km upstream and downstream from reservoirs or the Belly River weir. Thus, all forest stands along these reaches were quantified rather than applying an experimental design involving subsampling and the subsequent extrapolation to a larger population and corresponding statistical evaluation.

Field inventories

About 100 visits to the St. Mary River were made from 1983 to 1994, including three low-altitude (150 m) flyovers, and field visits by vehicle and canoe. Field visits particularly investigated the occurrence of young seedlings or saplings, the apparent health of mature trees, and the occurrence of sand and silt bars along meander lobe point bars or along lateral bars.

Analyses of historical stream flow

Historical stream-flow data for the St. Mary River had been collected by the Water Survey of Canada from hydrometric gauging stations 05AE027, at the International Boundary, and 05AE006, at the bridge between Lethbridge and Standoff. Daily mean hydrographs were compared for upstream versus downstream survey stations for each year from 1951 through 1993, with particular consideration for abrupt reductions of flow and extended periods of minimum flows during the summer months. Maximum daily mean discharges were analyzed by flood-recurrence analyses for the period from 1960 to 1990 using the following formula:

$$[1] \quad T = \frac{n + 1}{m}$$

where T is the return interval in years, n is the total number of years considered, and m is the order of flow events, beginning with the largest event as 1.

Analyses of riparian water table level

In June 1993, transects with six piezometer tubes (wells), each consisting of a 4 m long × 4 cm internal diameter slotted PVC pipe, were installed at each of two sites along the lower St. Mary River. The Welling Ford site is situated 39 km downstream from the St. Mary Dam at a broad meander lobe that supported a dense cottonwood grove in 1950 and still supports about 15 trees, principally balsam poplars and narrowleaf cottonwoods. The Russell Farm site is located 86 km downstream from the St. Mary Dam and is downstream from the inflow of Pothole Creek. A grove of narrowleaf cottonwoods and balsam poplars continues to survive at the Russell Farm site. Transects extended perpendicular from the river's edge and were positioned near the centre of meander lobes that sloped gradually from the river's edge. These meander lobes would be considered prime zones for cottonwood seedling replenishment. The piezometer tubes were installed with a drill truck that augered a 20 cm diameter hole 5 m deep. A hollow centre in the auger shaft permitted positioning of the piezometer tube, after which the auger was reversed for withdrawal. Water table depth measurements were made by dropping a weighted string to the water surface and string measurement after withdrawal. Repeated measurements indicated that this procedure provided readings that were precise to about 2 mm. Measurements of water table depth along the two transects were made weekly during July and August 1993 and from May through September 1994.

Analyses of proposed future operating plans

In conjunction with analyses of the proposed operations plans for the Oldman River Dam (Mahoney and Rood 1993), hydrological modelling was conducted for all rivers in the Oldman River Basin (Alberta Environment 1989*a*, 1989*b*). The modelling generated (*i*) naturalized weekly mean flows that would have occurred if no dams or diversion occurred, and (*ii*) projected flows that would follow the commissioning of the Oldman River Dam and increased diversion for irrigation and other uses up to a level recommended by present provincial policies. This proposed operations strategy was identified as ODO5 (Oldman Dam Operations 5). The modelled hydrographs were generated for stream inflow conditions that actually occurred for each of the years from 1967 to 1986 and were compared to actual historical hydrographs, averaged on a weekly time-step for comparison. Thus, three hydrographs were compared for each year, representing (*i*) modelled free flow conditions that would have occurred with no damming or diversion; (*ii*) modelled proposed flow patterns that would accompany the implementation of the strategy that is presently being applied to the South Saskatchewan River Basin; and (*iii*) actual flow patterns that occurred with the historical levels of damming, diversion, and other flow alterations.

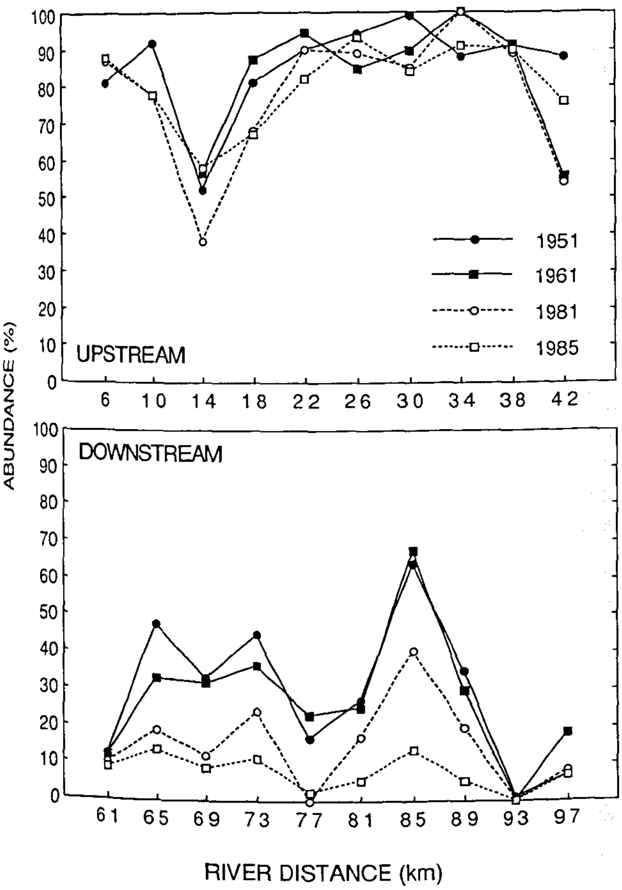
Results and discussion

Analyses of historical cottonwood abundances

Analyses of the abundance of cottonwoods along the reach downstream from the St. Mary Dam confirmed and extended the pattern previously reported (Rood and Heinze-Milne 1989). The abundances of riparian cottonwoods were consistently and progressively reduced in 8 of the 10, 4-km river reaches from 1951 to 1985 (Fig. 1). In the other 2 reaches (Fig. 1, 77 and 93 km), cottonwoods were already sparse or absent in 1951 and unchanged thereafter. Field surveys from 1985 through 1990 indicated continuing decline, and by 1990 most of the river reaches were almost void of cottonwoods.

The decline of cottonwoods progressed relatively steadily

Fig. 1. Riparian cottonwood forest abundance along ten 4-km river segments upstream and downstream from the St. Mary River Dam. These values represent the percentage of reach length associated with riparian forests on either river bank and were determined from airphotos taken in the years indicated. The values for 1961 and 1981 are reproduced from Rood et al. (1989, Fig. 2), but river distances are from the Canada – United States border rather than the St. Mary Reservoir.



between 1951 and 1985 (Fig. 2), although mortality may have been accelerated over time and particularly after 1981. This possible acceleration of mortality might reflect cumulative physiological stress, although increases in water withdrawals for irrigation also occurred between 1951 and 1981. The progressive mortality suggests that the stresses were cumulative over time and that cottonwood mortality does not include a specific lethal stress threshold that is uniform across trees and and forest groves. This conclusion is consistent with the observed progressive decline of riparian cottonwoods along various North American rivers during the severe natural drought of the 1930s (Albertson and Weaver 1945). The cumulative and progressive nature of the decline of cottonwoods along the lower St. Mary River argues that simple instream flow needs (IFN) assessments that attempt to assign a single minimum flow standard are misguided. Riparian cottonwoods may survive insufficient flows for a few years but cumulative stresses would be expected to lead to gradual mortality.

The apparent rate of cottonwood decline along the lower St. Mary River between 1951 and 1985 was about 1% per

Fig. 2. Riparian cottonwood forest abundances vs. year for four 8-km river segments downstream from the St. Mary River Dam. These values were determined from Fig. 1, with two adjacent river segments combined for each 8-km segment shown here.

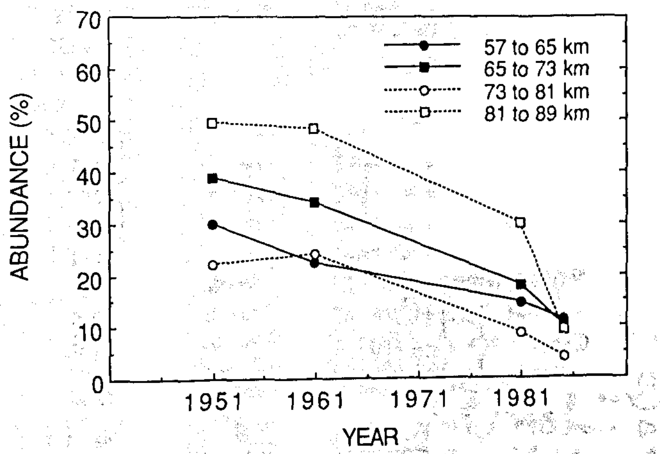
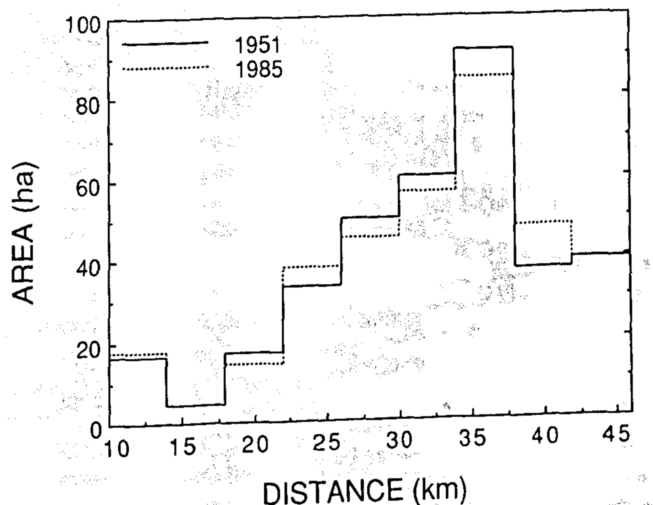


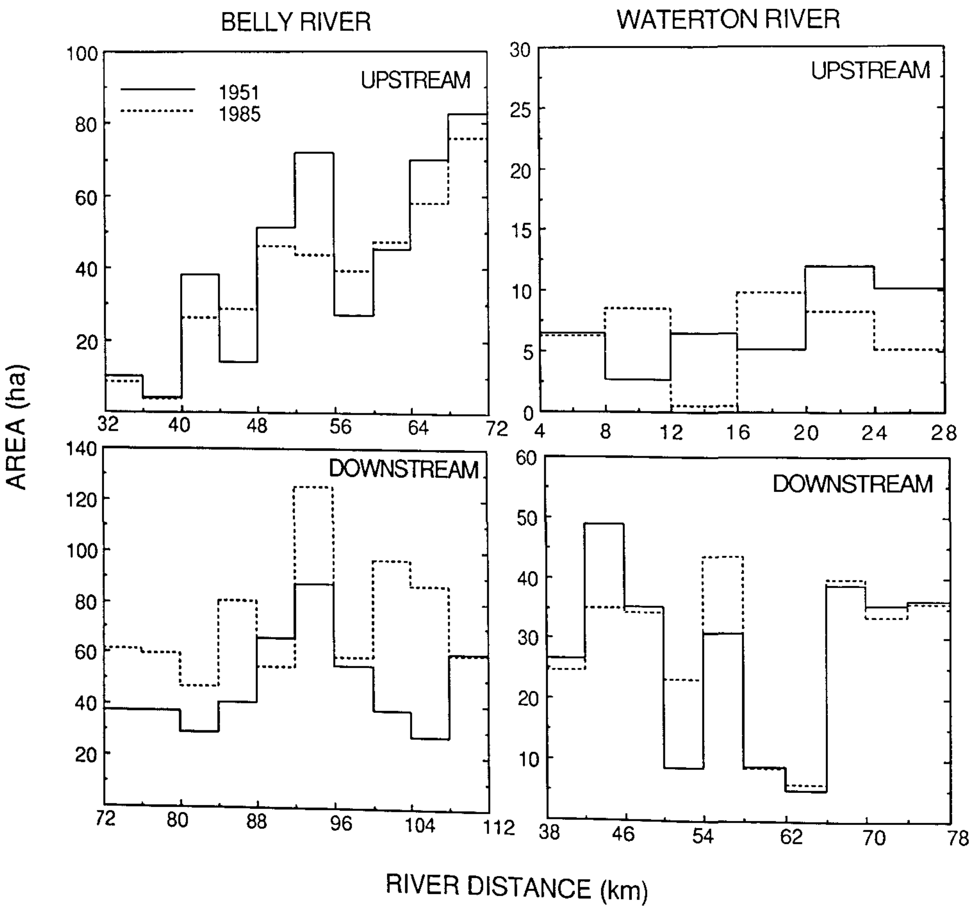
Fig. 3. Areas of riparian cottonwood forests along nine 4-km river segments upstream from the St. Mary River Dam as determined from airphotos taken in 1951 and 1985. River distances are from the Canada – United States border.



year (on an absolute basis). This is of similar magnitude but slightly slower than the 2% decline per year that Snyder and Miller (1991) reported for the Arkansas River downstream of the Colorado border. Either rate of decline is abrupt relative to the life-span of cottonwoods, which is typically about a century but may extend up to 250 years in southwestern Alberta (Shaw 1976). This rapid rate of decline would very probably not be caused solely by a failure of cottonwood replenishment and a decline of mature trees through normal aging and mortality. Instead, the abrupt decline probably represents artificially accelerated mortality between 1951 and 1985.

In contrast to the severe decline along the lower St. Mary River, lineal analyses of the St. Mary River upstream of the St. Mary Dam demonstrated little change in the abundance of riparian cottonwoods from 1951 to 1985 (Fig. 1). This apparent lack of change in forest abundance as determined by

Fig. 4. Areas of riparian cottonwood forests along 4-km segments of the Belly or Waterton rivers as determined from airphotos taken in 1951 and 1985. All distances are from the Waterton National Park boundary, with the upstream reaches being in the free-flowing sections upstream from the Belly River weir or Waterton River Dam and the downstream reaches being downstream from those control structures. Note that *y*-axis scales vary across the graphs.



the lineal analysis is consistent with the pattern previously reported for 1961 versus 1981 (Rood and Heinze-Milne 1989) (Fig. 1).

However, the assessment of lineal distance associated with cottonwoods is somewhat inappropriate for most segments of the upper St. Mary River, where broad cottonwood stands occupy the broad flood plain. Lineal assessment is applicable to segments such as Coal Canyon (Fig. 1, km 14), where like much of the lower St. Mary River, cottonwoods are limited by steep-walled canyons to narrow bands. For these upstream canyons, lineal analysis revealed little change in the distribution of cottonwoods, indicating that cottonwood decline did not occur for all narrow cottonwood groves along the St. Mary River between 1951 and 1981. This further indicates the localized loss of cottonwoods downstream from the St. Mary Dam.

Since the cottonwood stands along the upper St. Mary River generally involve large groves, historical analyses of areal extent are more appropriate than lineal analyses. The areal extent of cottonwoods was almost unchanged between 1951 and 1985 (overall decline of 0.5%), as the apparently slight increases and decreases were balanced over the 9, 4-km segments (Fig. 3). Although somewhat inappropriate, analyses of changes in areal extent were also performed for the narrow cottonwood bands downstream from the St. Mary Dam and suggested a 61% decline, a value that was quantitatively similar to that of the lineal analysis. Thus, two quantitative analyses were performed and compared. Both analyses resulted in similar conclusions regarding the St. Mary River, indicating little change upstream from the dam but major decline downstream. This indicates that the cottonwood decline downstream from the St. Mary Dam was not part of a widespread cottonwood decline such as occurred during the extensive natural drought of the 1930s (Albertson and Weaver 1945).

To further investigate possible regional patterns, historical cottonwood abundances along the adjacent Belly and Waterton rivers were conducted using 1951 and 1985 airphotos and both lineal and areal analyses. Although some localized changes occurred, total areas occupied by cottonwoods along the upper Belly River (9.1% decrease) and upper (1.9% increase) and lower (3.5% increase) Waterton River were very similar in 1951 and 1985 (Fig. 4). The relatively unchanged area of cottonwoods along the lower Waterton River contrasts slightly from an apparent decline that was observed by lineal distance analyses of airphotos taken in 1961 and 1981 (Rood and Heinze-Milne 1989). A separate lineal distance analysis conducted in the present study also indicated a slight decline of about 9% from 1951 versus 1985 airphotos. Thus, certain groves along the lower

Waterton River probably lost cottonwoods between 1951 and 1985, but changes in areal abundance were minor and compensated by increases in abundance in other groves (Fig. 4). Cottonwood groves are substantial along the lower Waterton River and consequently the areal analysis is more appropriate than the lineal distance assessment. In contrast to the St. Mary River situation, the lineal and areal analyses produced slightly different results for the lower Waterton River, emphasizing the need to select an assessment method that is suited to the riparian situation under study.

Although the areal analyses indicated little change in cottonwood abundance along the lower Waterton River between 1951 and 1985, field surveys in 1988 through 1991 revealed considerable branch and crown dieback and numerous decrepit cottonwood groves. Thus, the riparian cottonwoods are not thriving downstream from the Waterton Dam, but their overall abundance has not been substantially reduced yet.

Along the lower Belly River, cottonwood forests increased substantially between 1951 and 1985 (Fig. 4). This supports the pattern previously based on lineal distance analysis (Rood and Heinze-Milne 1989). The lower Belly River is adjacent to the lower St. Mary River, and the difference in the recent fate of the stands along these two streams further indicates that the decline along the St. Mary River is due to localized impacts, a conclusion that supports the proposal that the decline is at least partly caused by the operation of the St. Mary Dam. However, the increase in cottonwood abundance along the downstream, but not upstream, reaches of the Belly River also indicates that stream-specific and even reach-specific patterns occur with respect to cottonwood population dynamics. This localized variation complicates interpretation based solely on historical abundance and emphasizes the need to supplement airphoto inventories with field studies and physiological investigations.

Influence of changes to sedimentation patterns

The decline of riparian cottonwoods along the lower St. Mary River suggests a negative impact from some physical alteration caused by the operation of the St. Mary Dam. Two principal physical impacts have been proposed to be responsible for forest decline downstream from other dams: changes to sedimentation patterns, and alterations to patterns of stream flow (Rood and Mahoney 1990, 1993).

Changes to sedimentation patterns result from the settling out of suspended material in the slow-moving reservoir and the resultant impoverishment of the silt load downstream. This impact has been referred to as the silt shadow, cannot be easily mitigated, and is thus of particular concern with respect to river resource management. In the earlier report regarding cottonwood decline downstream from the St. Mary Dam, the lack of recovery of cottonwoods over distance downstream from the St. Mary Dam was interpreted as evidence opposing a major role of the silt shadow in the observed decline (Rood and Heinze-Milne 1989). Impacts due to the silt shadow would be most severe near the dam and would progressively attenuate downstream as the silt load recovered. In contrast, the loss of cottonwoods was consistently observed along the study segments that extended 40 km downstream (Fig. 2). Five other lines of evidence support this interpretation, further indicating that the silt-shadow effect is not responsible for the riparian cottonwood decline downstream from the St. Mary Dam.

First, the observed cottonwood decline probably involved an accelerated mortality of cottonwoods rather than being caused by a lack of cottonwood replenishment. Airphoto analyses would only assess large trees, and consequently the observed decline involved a loss of mature trees. In contrast it would be principally a failure of seedling recruitment that would be impacted by changes in downstream sedimentation patterns. However, having reached this conclusion, field surveys revealed very few seedlings and saplings along the lower St. Mary River, and consequently a failure of replenishment is occurring in addition to accelerated mortality of established trees. The failure of recruitment was probably at least partly due to drought stress: flow conditions that would lead to mortality of mature trees would even more certainly lead to mortality of vulnerable seedlings that rely on much smaller root systems.

Second, the recovery of suspended silt probably occurs rapidly downstream from the St. Mary Dam. The lower St. Mary River is relatively steep in gradient and flows swiftly past actively slumping coulees and numerous banks with thick layers of sands and silts. Field visits revealed frequently turbid waters downstream from the dam due to the abundance of suspended material. Consistent with these observations, abundant freshly deposited sand and silt bars were regularly observed after high flow periods.

Third, although the prairie cottonwood, *P. deltoides*, may prefer or require fine sand or silt substrates, the narrowleaf cottonwood, *P. angustifolia*, and the balsam poplars, *P. balsamifera*, thrive along rivers in the Rocky Mountain foothills which have very coarse substrates. These trout streams are generally clear flowing, since they are naturally impoverished of suspended sediment. Extensive balsam poplar groves exist along headwater streams in southern Alberta that flow over substrates of coarse gravel and cobbles. Balsam poplars and narrowleaf cottonwoods are the predominant species along the St. Mary River, and these species are well adapted to coarse substrates.

Fourth, natural lakes will act in the same capacity as artificial reservoirs in slowing the downstream flow and allowing suspended sand and silt to settle. Balsam poplars and narrowleaf cottonwoods occur immediately downstream of natural lakes in southwestern Alberta and northern Montana. For example, these trees thrive at the outflow of Upper St. Mary Lake, where the stream bed and banks consist of coarse gravel and cobble and the river is seldom turbid.

Finally, the impacts of river damming on downstream cottonwoods are not universal. Riparian vegetation has increased downstream from some dams (Johnson 1994; Williams and Wolman 1984) while cottonwood decline is observed downstream from others (reviewed in Rood and Mahoney 1990, 1993). The present study indicates that the St. Mary and Waterton dams have had different impacts, at least in terms of the immediacy of decline downstream.

Analyses of historical stream flows

The second type of physical impacts downstream from dams involves alterations to the patterns of stream flow. Most researchers have concluded that these impacts are directly or indirectly responsible for cottonwood decline downstream

Fig. 5. Peak flow recurrence (return) intervals for the St. Mary River upstream (●) and downstream (○) of the St. Mary River Dam, based on maximum daily mean discharges from 1952 to 1990, excluding 1961. Approximate fit lines are plotted to reflect a two-component function.

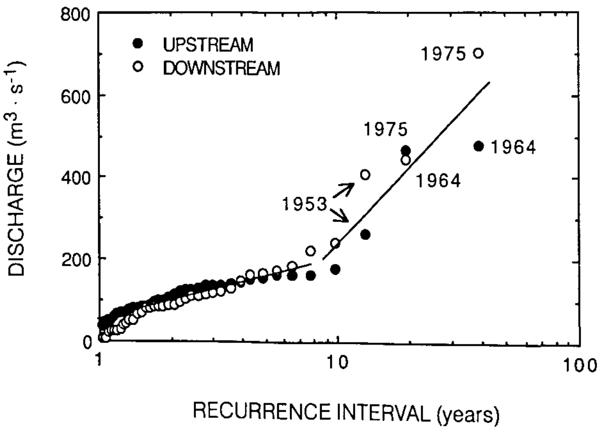
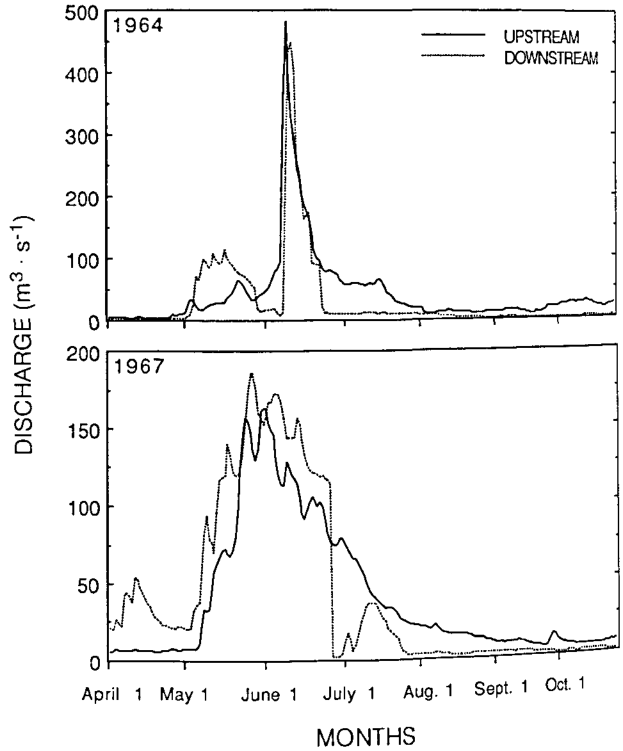


Fig. 6. Hydrographs showing daily mean discharges for the St. Mary River upstream and downstream of the St. Mary River Dam for the period of April 1 to October 31 of 1964 and 1967, extremely high and very high (recurrence interval of 6.5 years) flow years, respectively.



(reviewed in Rood and Mahoney 1990, 1993; Auble et al. 1994; Bradley and Smith 1986; Snyder and Miller 1991; Stromberg and Patten 1991, 1992). Regulation of the dam gates deliberately influences downstream flow patterns and can reduce or increase flows at specific times. The patterns of regulated flows downstream are dependent on the management objective for the dam, with two principal categories of patterns occurring for dams in the western prairies or Rocky Mountain foothills.

The first category of flow patterns typically involves flood-control or hydroelectric-generation dams. These dams are operated to attenuate seasonal flow patterns by trapping water during the high-flow periods and augmenting downstream flows during low-inflow periods. Downstream flow patterns are thus artificially stabilized.

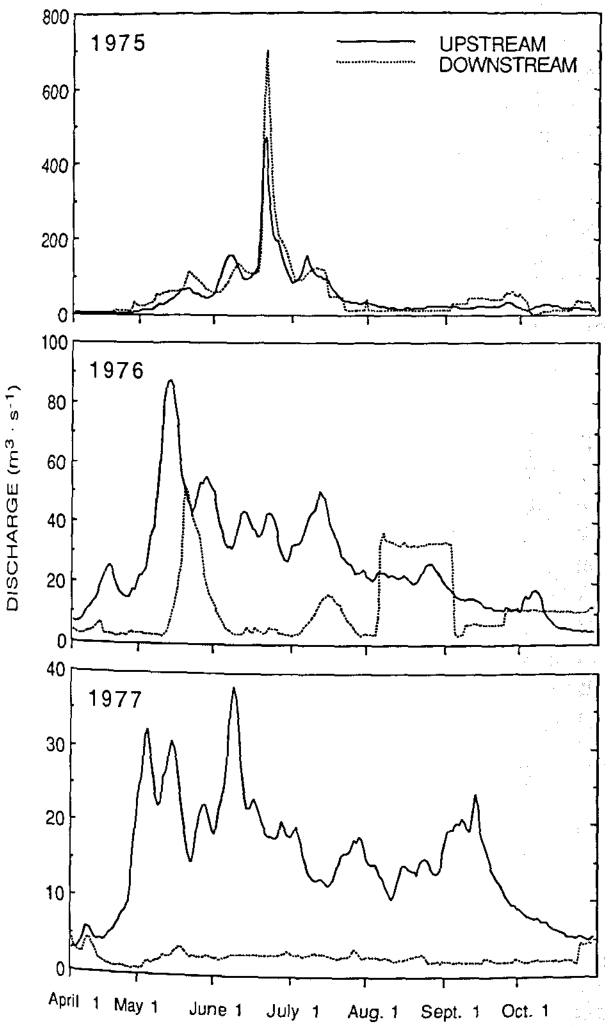
The attenuation of flood flows will particularly impact seedling recruitment in downstream cottonwood forests (reviewed in Rood and Mahoney 1990, 1993; Scott et al. 1993; Stromberg et al. 1991). Flood flows are required for the dynamic stream erosion and deposition that underlies the active meandering of the stream channel and the creation of new, barren gravel, sand, and silt bars that are suitable for seedling establishment. In addition to the impact on the fluvial geomorphology, the high-flow period is essential to saturate the recruitment zones and subsequent gradually declining flows expose saturated recruitment sites and also provide moisture for the young seedlings. Attenuated flooding will thus reduce opportunities for cottonwood seedling recruitment.

Analyses of the historical flows of the lower St. Mary River demonstrate that flood flows are not dramatically altered. During the four decades following damming, major flood flows occurred in 1964 and 1975 and persisted downstream of the dam (Fig. 5). The timing of those flood flows may have been delayed by one or more days, and the specific pattern of the flood flows was slightly modified by the presence of the reservoir and by the artificial regulation of the dam's control gates. However, these changes were relatively minor and the magnitudes of major peak flows were generally similar upstream and downstream of the St. Mary Dam (Figs. 6 and 7).

Although the peak flows in flood years were relatively unaltered by the St. Mary Dam, the subsequent declining (falling limb) flows were often dramatically modified. Following the high-flow period in 1964, a relatively natural decline occurred until the flow dropped below about 100 $m^3 \cdot s^{-1}$ (Fig. 6). At that point, the control gates were closed and only a minimal flow was permitted downstream. Thus, the flood flow was followed by abrupt flow reduction and then a sustained period of minimal flow through the summer. This abrupt flow reduction would be accompanied by rapid water table decline that would be lethal for seedlings and might also be stressful for old cottonwoods (Mahoney and Rood 1991*a*, 1992; Segelquist et al. 1993). This pattern of abrupt flow reduction has been a common feature of river flow management along the St. Mary River following damming (Fig. 6).

In contrast to the flood year of 1964, the flow pattern of 1975 was relatively similar upstream and downstream from the St. Mary Dam (Fig. 7). Downstream flow reduction was slightly more rapid, but the alteration was less severe than in 1964, 1967, or other years with above-average peak flows. The flow pattern of 1975 may have been sufficient for initial seedling recruitment and would probably have been favorable to established trees. However, average and low flow years followed 1975, and the downstream flows during the summers of those years were minimal (Fig. 7). Successful recruitment and maintenance of established cottonwoods is a progressive response to long-term moisture patterns. Thus, although stream flows of 1975 would have been sufficient, flows in subsequent years would have been stressful.

Fig. 7. Hydrographs showing daily mean discharges for the St. Mary River upstream and downstream of the St. Mary River Dam for the period of April 1 to October 31 of 1975, an extremely high flow year, and the two following years.

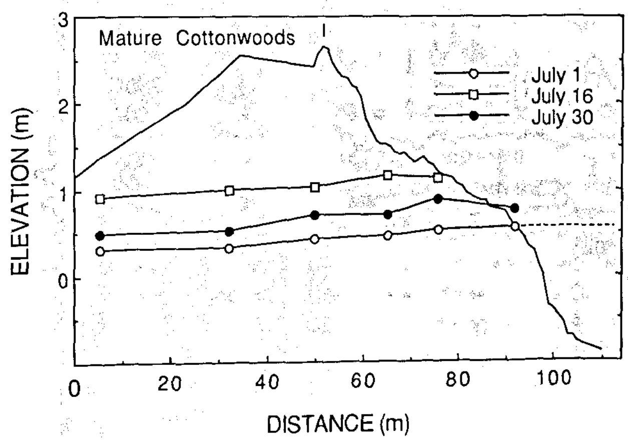


Analyses of riparian water table levels

A close relationship between river stage (elevation) and water table depth is assumed for southwestern Alberta, since the riparian substrates consist largely of mixtures of sand, gravel, and cobble. Such mixtures would be relatively freely permeable (Mahoney and Rood 1992), enabling rapid water infiltration from or drainage to the river. High hydraulic conductivity is also indicated by observations of cutoff stream channels, abandoned gravel pits, and other ponds that continue to rise and fall in apparently close association with the rise and fall of the adjacent river.

The close linkage between river stage and riparian water table depth was confirmed in the present study through measurements of water levels in piezometers (test wells) positioned along transects in the riparian zone of the St. Mary River (Fig. 8). Water tables were measured weekly through the summer and generally demonstrated the pattern shown in Fig. 8, with a gradual decline in water table level extending away from the river's edge. For example, the water table sloped away at 31.5, 32.8, and 41.6 cm per

Fig. 8. Water table levels in six test wells positioned along a transect extending perpendicular to the St. Mary River at the Welling Ford, southern Alberta. Water table elevations are plotted for three dates in July 1993, and in each case the river stage was similar in elevation to the elevation in the well closest to the river edge. Elevations are scaled above a reference 0 m, which represents the river stage elevation at a flow of 6 $m^3 \cdot s^{-1}$, which would be a very low natural late summer flow. The broken line represents the river surface on July 1, 1993. Distance is from a reference balsam poplar tree that anchored the transect. Note that the elevation scale is greatly expanded relative to the distance scale.

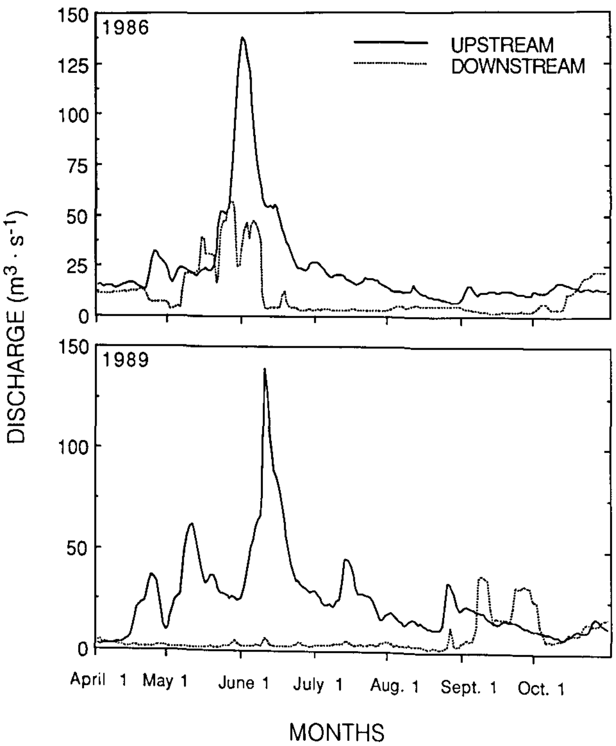


100 m on July 1, 16, and 30, respectively, and similar slopes were observed at most other dates. Exceptions consistently occurred immediately following changes in river stage when a lag in infiltration or drainage resulted in the water table sloping farther downwards or upwards, respectively, away from the river.

The piezometer study confirms that the riparian water table rises and falls in coordination with changes in the river stage and also indicates that the riparian water table is recharged by the river, providing an influent stream – water table situation. This situation would be consistent with the conclusion that these cottonwoods are reliant on water from the adjacent river (Busch et al. 1992) and also that reduced river flows downstream from the St. Mary Dam would create additional drought stress of the adjacent riparian cottonwoods.

These analyses reveal three features of the regulated flows along the lower St. Mary River. First, flood flows are relatively unaltered, and consequently a change to flooding patterns was not the cause of the decline of established trees or the failure of replenishment through new trees. Second, downstream flow reductions were frequently abrupt and these would probably be particularly stressful for cottonwoods (Mahoney and Rood 1991*a*, 1992). Third, prolonged periods of minimal flows occurred during the hot, dry periods of summer when evapotranspirational demand would have been highest. These minimal flows would have resulted in deeper riparian water tables, reducing water availability for the cottonwoods. Xylem water potentials of the three riparian cottonwood species in southern Alberta are naturally close to the threshold that results in xylem cavitation (Tyree et al. 1994). Further water stress imposed by insufficient stream flows would probably create further stress and possi-

Fig. 9. Hydrographs showing daily mean discharges for the St. Mary River upstream and downstream of the St. Mary River Dam for the period of April 1 to October 31 of fairly high flow years, 1986 (recurrence interval RI of 2.8 years) and 1989 (RI of 3.3 years).



bly catastrophic cavitation. The result would be branch and crown dieback and, eventually, complete shoot die-off, the patterns that were observed in field surveys downstream of the St. Mary Dam.

Over the four decades following the completion of the St. Mary Dam, there has been a continual expansion of irrigation agriculture in southern Alberta. Increases in irrigation acreage, expansion of canals to permit increased diversion flows and other changes have resulted in progressive increases in the amounts of water diverted from each of the rivers in the Oldman Basin. Consequently, although periods with high, average, or low stream flows have accompanied natural variations in regional precipitation (primarily variation in winter snow accumulation in the Rocky Mountain watersheds), the artificial hydrological impacts along the lower St. Mary River have generally increased over the past four decades. Thus, flows in the 1980s were particularly impacted, even during the higher inflow years of 1986 and 1989 (Fig. 9). The extensive commitment to irrigation in southern Alberta provides little opportunity for recovery of river flows along the lower St. Mary River which would be required for restoration of the riparian cottonwoods.

The present study confirms the previous observation of abrupt decline of riparian cottonwoods downstream from the St. Mary Dam (Rood and Heinze-Milne 1989) and demonstrates progressive loss over time. In contrast to the previous report, however, the present study indicates that cottonwood abundance downstream from the newer Waterton Dam has been relatively unchanged over the past three decades. The collapse of the cottonwood forests along the lower St. Mary River may be partly due to the more severe pattern of flow alteration and partly due to the natural suitability of the lower St. Mary River for riparian cottonwoods. In contrast to the lower Waterton River, cottonwoods were historically sparse along the lower St. Mary River, even prior to damming and water diversion for irrigation (Dawson 1885). The cottonwood abundance along the lower St. Mary River has consequently declined from sparse to almost absent.

It is likely that sparse cottonwood groves are particularly vulnerable to artificial impacts. The naturally sparse occurrence indicates that the local environment is only marginally suitable, and thus the existing trees would be functioning near the limit of their physiological range of adaptation. Consistent with this interpretation, there are almost no large, and consequently very old, cottonwoods along the lower St. Mary River. The lack of old trees also suggests that the environment is marginal, since (*i*) low-flow periods that would naturally occur at irregular intervals would lead to mortality preventing cottonwood survival for long periods, and (*ii*) old trees are probably particularly prone to stress-induced mortality (Albertson and Weaver 1945) and would thus be unable to survive marginal conditions. Following these lines of reasoning, the lower St. Mary River valley was apparently naturally only marginally suitable for cottonwoods, and consequently further stress imposed by artificial river flow reductions would be expected to have abrupt and severe impacts.

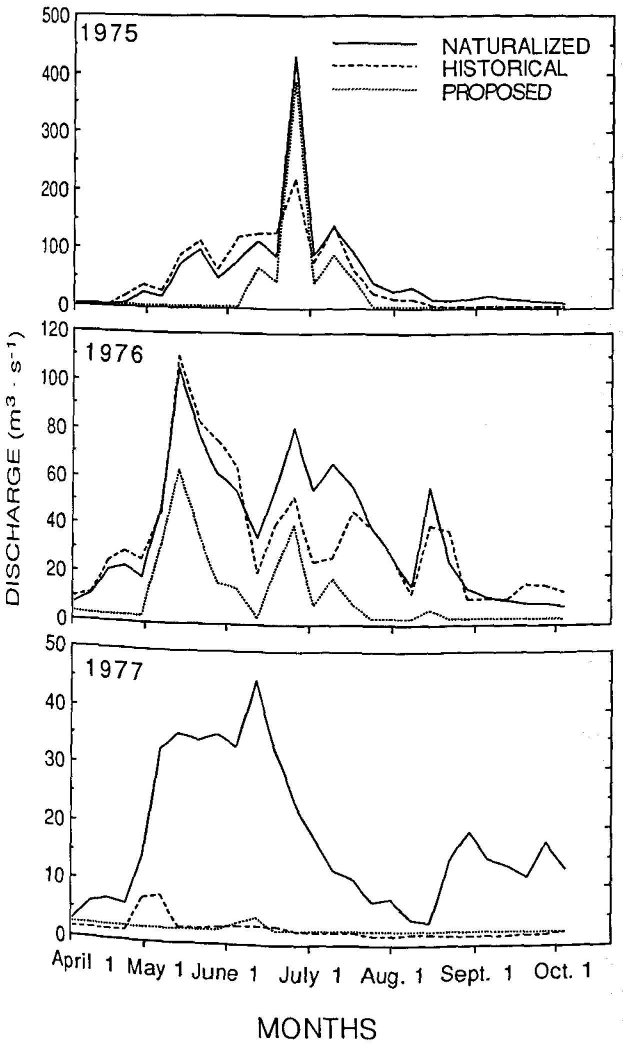
Future considerations

Subsequent to the previous report relating river damming and riparian cottonwood decline in southern Alberta (Rood and Heinze-Milne 1989), there have been a number of changes in the patterns of operation of the St. Mary and other dams in the Oldman River Basin. Allowable minimum flows were increased, in the case of the St. Mary River, from 0.93 to 2.75 $m^3 \cdot s^{-1}$. This increase will favor survival of established riparian vegetation but is probably still quite suboptimal for established trees and insufficient for seedling recruitment.

In recent years, the St. Mary Dam has been operated somewhat differently, allowing more gradual flow reductions following the high-flow period in late spring. The possible benefits of this operational adjustment are presently unclear, since the summers of 1992 and 1993 were exceptionally wet, confounding studies of the impacts from changes in dam operations. Providing some optimism, field surveys in 1992, 1993, and 1994 revealed additional saplings of narrowleaf cottonwoods and balsam poplars which probably resulted from clonal recruitment by root suckering. Clonal replenishment is common in southern Alberta (Rood et al. 1994) and may be particularly responsive to the recovery of stream flows, since root systems apparently remain viable even following severe shoot dieback (Stromberg and Patten 1989).

Although these recent changes provide encouragement for the preservation of some riparian cottonwoods in southern Alberta, the presently proposed operations plans for the rivers of the Oldman River Basin (Alberta Environment 1989*a*, 1989*b*) do not provide promise for recovery of the St. Mary cottonwoods (Mahoney and Rood 1993). There is little hope for substantial recovery of flows of the St. Mary River

Fig. 10. Hydrographs showing weekly mean discharges that would occur for the period of April 1 to Sept. 30 for the Waterton River for an extremely high flow year, 1975, and the two following years. Three lines are plotted, representing (*i*) naturalized flows, i.e., the estimated flows that would have occurred if no dams or water diversion existed; (*ii*) historical flows, i.e., the actual flows that did occur with the existing Waterton River Dam and actual historical levels of diversion in place at those times; and (*iii*) proposed flows, i.e., those that would be predicted to occur in a year with similar weather conditions to the years 1975 through 1977, but with the Oldman River Dam commissioned and consumptive uses increasing to the level approved by present provincial policies. Note that *y*-axis scales vary across the graphs.



in dry years when stream flows are low and irrigation demands are high. Without the commitment of increased flows during the dry periods it is unlikely that the cottonwood saplings that have emerged in the past 3 years will survive.

The presently proposed operations plan (Alberta Environment 1989*a*, 1989*b*) also raises concerns for the Waterton River cottonwoods. The present study suggests that those cottonwoods are still relatively abundant, although stressed. Proposed flow patterns for the lower Waterton River would become similar to the historical flow patterns of the lower St. Mary River (Fig. 10). Thus, there would be prolonged minimal flows during dry years, with stream inflows similar to those of 1977. Flows during average years similar to 1976 would be considerably reduced, and even in wet years with flows similar to 1975, flows would be reduced (Fig. 10). It is predicted that the combined impacts of these flow reductions would be accelerated mortality and reduced replenishment of the downstream riparian cottonwoods. It is consequently predicted that the forest groves would decline as the existing trees age and die.

In conclusion, the present study confirms the previous observation of abrupt decline of riparian cottonwood forests downstream from the St. Mary Dam. The observed 68% decline in the 35-year period between 1951 and 1985 is abrupt relative to the life-span of cottonwood trees and the decline was progressive over time. The decline is probably at least partly due to drought-induced mortality resulting from abrupt flow reductions and insufficient summer flows. Reduced river flows are accompanied by deeper riparian water tables, and this probably compounds natural drought stress leading to reduced xylem water potentials and consequent cavitation that underlies shoot dieback (Tyree et al. 1994). The current prognosis remains bleak for recovery of the cottonwoods along the lower St. Mary River, and proposed river management plans are also likely to impose further stresses on the cottonwoods along the neighboring Waterton River.

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