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Canadian Journal of Earth Sciences

Réimpression de la
Revue canadienne des sciences de la Terre

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Volume 35 • Number 4 • 1998

Pages 453–466

Canada

# The 1870s avulsion of the Saskatchewan River

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**Abstract:** Several major avulsions of the Saskatchewan River have occurred in the Cumberland Marshes (east-central Saskatchewan) during the past few thousand years. The most recent avulsion occurred in about the 1870s, converting over 500 $km^2$ of floodplain into a belt of anastomosing channels, splay complexes, and small lakes, a region that is still evolving today. The avulsion began near the tip of a large meander bend by following a small outflowing creek (Sturgeon River) which in turn followed an abandoned former channel of the Saskatchewan River. Flow began to permanently divert out of the Saskatchewan when a narrow strip of floodplain separating the Sturgeon River from the nearby Torch River became breached. Diversion into the connected Sturgeon–Torch began to increase sometime in the 1870s and probably culminated around 1882. The triggering event for the avulsion may have been a chute cutoff of the meander bend, shown by numerical modeling experiments to have significantly raised water-surface elevations at the avulsion site. Increasing flow diversion soon overwhelmed the smaller Sturgeon–Torch channel (now known as the New Channel), and several crevasse splays formed to help accommodate avulsive discharge. Sixteen kilometres downstream, most of the avulsive flow spilled out of the New Channel to form a shallow (~1 m), marshy floodplain lake which flowed eastward down the regional floodplain gradient to the basin presently occupied by Cumberland Lake. Since its inception, the avulsion-generated lake has become gradually infilled by prograding splay complexes fed by networks of anastomosing channels to characterize most of the present-day avulsion belt.

**Résumé** : Durant les quelque derniers mille ans, plusieurs détournements de chenal importants de la rivière Saskatchewan se sont produits dans les marais de Cumberland (région est-centrale de la Saskatchewan). Le plus récent détournement de chenal est apparu vers les années 1870, convertissant une plaine d'inondation de plus de 500 $km^2$ en une aire de chenaux anastomosés, de systèmes complexes de crues, et de petits lacs, et même aujourd'hui cette région continue d'évoluer. Ce détournement de chenal fut amorcé à proximité de l'étranglement d'un méandre érodé par l'écoulement d'un petit affluent (rivière Sturgeon), et celui-ci à son tour s'est déversé dans un ancien chenal abandonné de la rivière Saskatchewan. La fuite ininterrompue de l'écoulement de la rivière Saskatchewan a commencé lorsqu'une brèche s'est développée au travers une bande de terre étroite de la plaine d'inondation qui séparait la rivière Sturgeon de la rivière Torch voisine. Le détournement dans les rivières Sturgeon–Torch connectées, s'est amplifié durant les années 1870 et a culminé probablement vers 1882. L'événement qui a fait démarrer le détournement de chenal est peut-être un recoupement transversal d'un lobe méandrique, car on démontre par des expériences de modélisation numérique qu'il y a eu des remontées importantes des niveaux de la surface des eaux au site de ce détournement. L'écoulement dérivé croissant a rapidement submergé le petit chenal Sturgeon–Torch (nommé aujourd'hui New Channel), créant plusieurs crevasses de crue qui facilitèrent la décharge de l'eau issue du détournement de chenal. À 16 km en aval, la majeure partie de l'écoulement dû au détournement de chenal a débordé du Nouveau Chenal pour former un lac peu profond (~1 m) dans une plaine d'inondation marécageuse, qui s'évacuait en direction est le long du gradient régional de la plaine d'inondation, vers le bassin occupé actuellement par le lac Cumberland. Depuis le début de sa formation, le lac créé par le détournement se remplit graduellement de sédiments transportés par les crues progradantes, alimentées par les réseaux de chenaux anastomosés caractérisant la majeure partie de la zone actuelle de détournement de chenal.

[Traduit par la rédaction]

## Introduction

It is widely recognized that aggrading river systems, especially those forming extensive alluvial floodplains, periodically divert their flow away from an existing dominant channel to form one or more new channels, a process known as avulsion. Avulsion is an inevitable result of river aggradation and is therefore a key mechanism in the generation of laterally extensive alluvial deposits, either as contemporary floodplains or ancient stratigraphic sequences, from what are essentially linear transport systems. Despite its importance, however, avulsion remains a poorly understood process. Avulsions are infrequent, rarely observed, and, except perhaps for coarse-bedload rivers with relatively low noncohesive banks (e.g., Bryant et al. 1995; Leddy et al. 1993), are not readily amenable for experimental investigation. Most avulsions appear to result from a gradient advantage created by superelevation of a channel above its flanking floodplain, normally presumed to result from differential aggradation. Otherwise, little is known of the necessary and sufficient conditions for avulsion, nor the particular antecedent conditions which

Received April 30, 1997. Accepted November 18, 1997.

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govern its timing, location, or subsequent evolution toward development of a new channel.

In the area of the Cumberland Marshes, the Saskatchewan River has undergone repeated avulsions during the past several thousand years, following the withdrawal of glacial Lake Agassiz (Morozova et al. 1996). The region is sometimes referred to as the Saskatchewan Delta (Kuiper 1960; Dirschl 1972), although it does not behave as a delta in the conventional sense. Historically, the Saskatchewan River has long served as a travelway and locus of gathering centers for aboriginal peoples (Meyer and Thistle 1995), as well as a major transport route for later European exploration, fur trade, and other commerce. Over a century ago, the east-flowing Saskatchewan underwent its most recent avulsion, diverting its flow and sediment load northward and initiating a series of events which would bring profound changes to a large area of the river floodplain. One of the immediate consequences was an early demise of commercial steamboat traffic which was forced to reroute, often unsuccessfully, through shallow and unpredictable channel networks as the newly inundated floodplain attempted to adjust to the redirected flow (Peel 1972). The avulsion caused rapid and widespread sedimentation on the floodplain, producing a series of deposits (Smith et al. 1989; Smith and Pérez-Arlucea 1994) whose recognition and character bear on present models of floodplain evolution and interpretations of ancient alluvial sequences (Aslan and Kraus 1993; Kraus 1996; Jorgensen and Fielding 1996). Avulsive deposition in Cumberland Lake and subsequent changes in lake water levels have created ongoing problems for local residents (Prairie Farm Rehabilitation Administration 1977; Underwood McLellan Ltd. 1983), and the northward diversion of flow has created water supply problems for the marshes south of the former channel (known as the Old Channel) (Northwest Hydraulics Consultants Ltd. 1976) in which lie major wildfowl management and muskrat trapping areas.

Despite the magnitude and effects of this major avulsion, the details of its origin are poorly understood, and subsequent accounts of the event are often confusing and contradictory. In this report, we attempt to address the questions of when, how, and why the avulsion took place, as well as some of its immediate effects, by combining historical accounts of the river with more recent field observations. Our main purpose is to contribute toward a better understanding of avulsions and their geologic and geomorphologic consequences for river systems, a subject that is receiving much current attention (e.g., Törnqvist 1994; Mackey and Bridge 1995; Heller and Paola 1996; Kraus 1996; Schumm et al. 1996).

## Location

The Cumberland Marshes lie at the western margin of the glacial Lake Agassiz lacustrine plain in east-central Saskatchewan and west-central Manitoba, comprising some 8000 km$^2$ of shallow lakes, active and abandoned river channels, and assorted wetland environments (Fig. 1). Former channels of the Saskatchewan River now stand as forested alluvial ridges elevated slightly above the surrounding floodplains. Prior to the 1870s, the Saskatchewan occupied a single, well-developed, eastward-flowing meandering channel, bypassing Cumberland Lake, which lay slightly to the north. Shortly thereafter, at a point about 50 km southwest of Cumberland Lake, the river began to avulse northward from near the tip of a large meander bend known as Mosquito Point by rivermen at that time (Fig. 2). Through a network of newly created and preexisting channels, the avulsed flow eventually entered Cumberland Lake, later rejoining the Saskatchewan River through three outlets of Cumberland Lake: the Bigstone and Tearing rivers and the Bigstone Cutoff (Fig. 1). The effects of the avulsion continue today. Excluding Cumberland Lake, which has shallowed considerably due to avulsive sedimentation (Willard et al. 1978), the avulsion has so far modified over 500 km$^2$ of former floodplain, now characterized by a complex system of anastomosing channels, splays, small shallow lakes, lacustrine deltas, and interchannel wetlands, a region known locally as the breakout area. In recent times, increasing amounts of discharge are being taken up by fewer and larger channels, notably the New Channel, Centre Angling Channel, and Mossy River (Fig. 1). At present, approximately 90–95% of the annual Saskatchewan River discharge diverts into the breakout area, the remainder being carried by the nearly abandoned Old Channel, mostly during high-flow periods.

## The avulsion: historical evidence

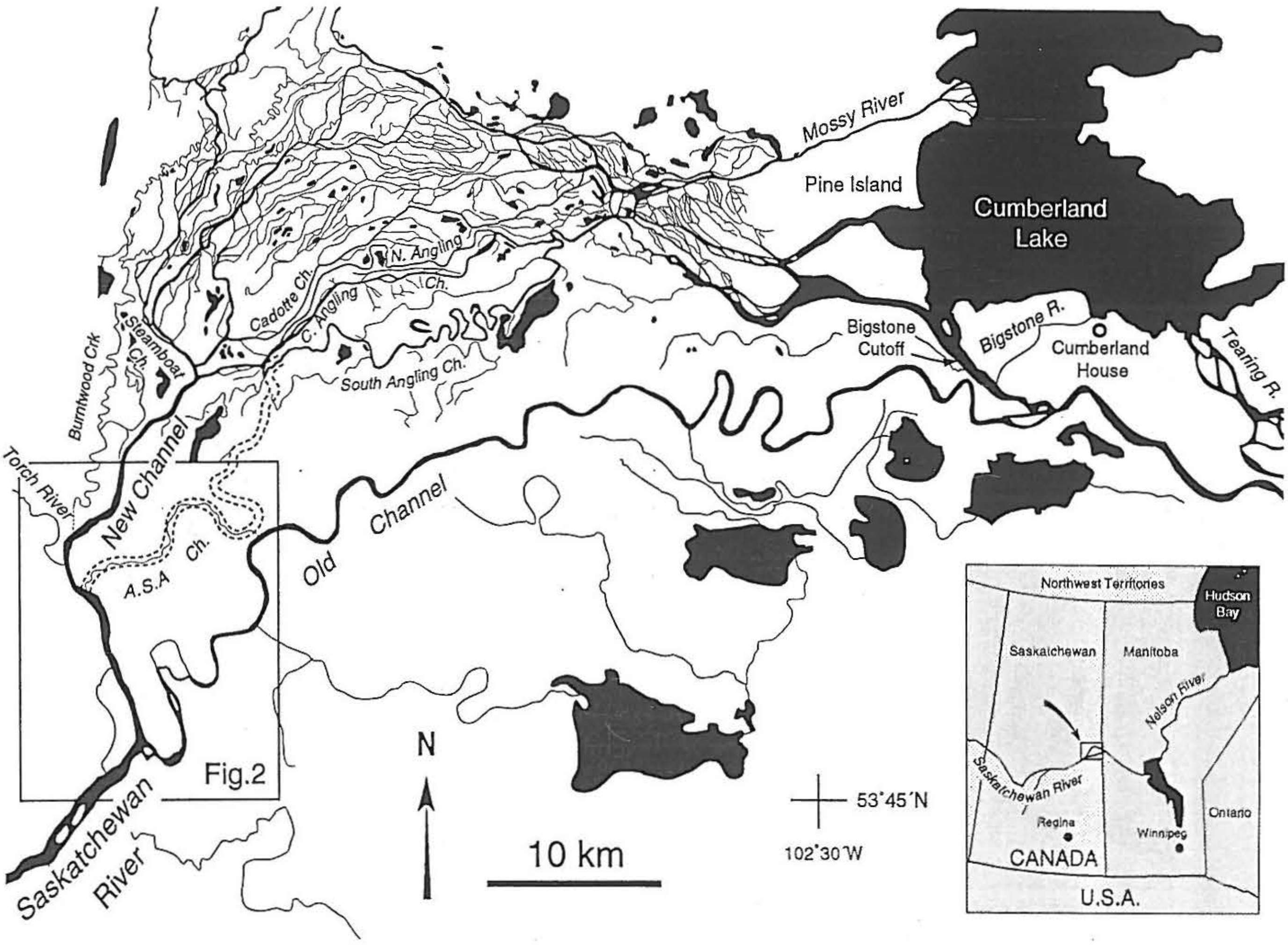
### Time of occurrence

Evidence for the date of initial avulsion is elusive; nevertheless, this has not prevented specific and seemingly precise dates from being cited in various published and unpublished reports of the region. The most commonly cited dates are 1873 (Willard et al. 1978; Reed 1959; Smith et al. 1989), 1875 (Kuiper 1953; Northwest Hydraulics Consultants Ltd. 1976. 1986; Prairie Farm Rehabilitation Administration 1977; Carson 1990), and 1882 (Peel 1972; Smith 1983). Less precise dates have also been offered, e.g., "about 1870" (Dirschl 1972), "early 1870's" (Dirschl and Coupland 1972), and "first half of the 1870's" (Meyer et al. 1992). This surprisingly large range of presumed avulsion dates probably stems in part from loose interpretations of second-hand accounts by William McInnes and Otto Klotz, both of which were published and therefore widely accessible. McInnes, a geologist, visited the region in 1910 and wrote the following account of the avulsion (our comments in brackets):

> About forty years ago.....the river broke through the 2 mile wide barrier of low land separating it on the North from the channel of Candle [formerly Sturgeon, now Torch] river...and flowing...into Cumberland Lake. The break occurred during the period of the spring flood, the water following the course of an old canoe portage leading from one of the sharp northerly bends of the Saskatchewan [i.e., Mosquito Point] to a southerly elbow of Candle [Torch] river.

Virtually identical versions of the above account were published twice (McInnes 1911, p. 169; 1913, p. 102), but only the 1913 publication was widely distributed, and if the "About forty years ago..." phrase were taken literally, it could explain the origin of the 1873 avulsion date. Despite describing an event which had happened several decades earlier, McInnes gave no source of his information. His statement that the avulsion followed an old canoe portage between the Saskatchewan and Candle (Torch) rivers is often repeated in subsequent literature. The 1875 date, on the other hand, appears to derive

**Fig. 1.** Map showing western portion of the Cumberland Marshes where the most recent avulsion of the Saskatchewan River took place (New Channel and associated anastomosed channels north of the Old Channel). Most of the smaller channels depicted in the avulsion belt are now inactive but contain water during high seasonal flows. Map based mainly on 1953 airphotos.




from a misinterpretation of the term cutoff for, at around the same time that the avulsion began, the Mosquito Point meander bend was cut off by a new chute channel across the base of the point bar (Fig. 2). In 1884, 26 years before McInnes' visit, Otto Klotz, a surveyor for the Canadian government, passed through the area and gave this description (Klotz 1885, p. 16):

> From the low nature of the land, the river in high water cuts new channels, and sands up old ones, continually changing the geography. A conspicuous instance of this is the Cut Off...across Mosquito Point. The water, after passing through the Cut Off, flows up its old bed, and the bulk thereof passes through another channel, about seven miles long, into the Sturgeon [Torch] River and thence into Pine Island, or Cumberland Lake, from which it again joins the main Saskatchewan. In low water this route is now used by steamboats. It is about nine years since the Cut Off was made...

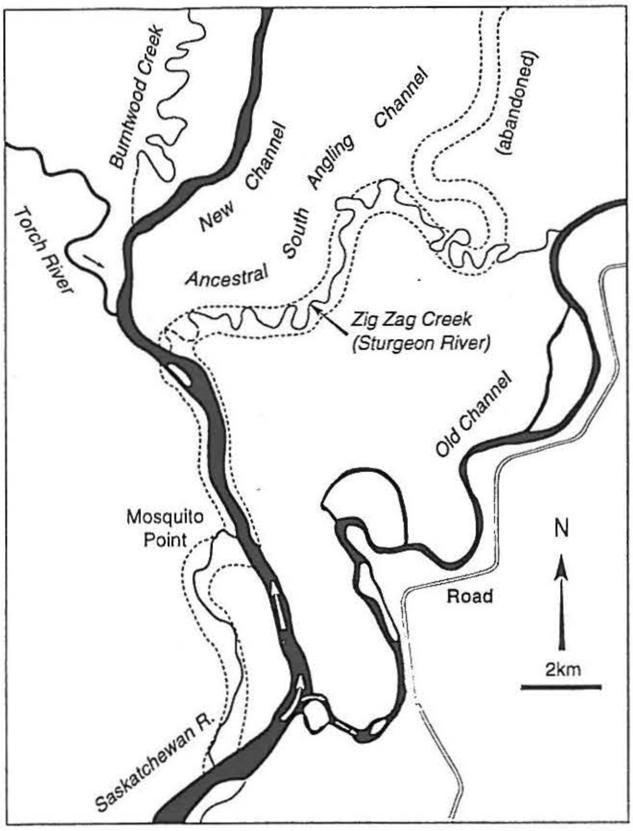
From this account, two points are clear: (*i*) the cutoff of the Mosquito Point bend had apparently occurred in 1875, and (*ii*) the avulsion was well underway by 1884. Klotz makes no mention of an initial avulsion date. In the June 11 entry of his unpublished diary (Klotz 1884, p. 13), he states,

> After leaving the Cut-Off we lose part of the water again which flows thro' a cutoff to the Sturgeon [Torch] River and in consequence have a shallow channel full of sandbars, islands, and channels.

This entry describes conditions in the Old Channel immediately after leaving the Mosquito Point "Cut-Off," but note that Klotz also refers to the initial avulsion route as a cutoff. In both contemporaneous and later reports of that area, the intended meaning of the term cutoff is commonly ambiguous. For example, a map prepared by Captain A. Russell in 1882 (see Peel 1972, p. 106), entitled The Cut-Off on the Saskatchewan River, does not identify what the cutoff refers to, i.e., the chute cutoff of Mosquito Point or the new connection to the Torch River, but the map clearly was intended to highlight the new avulsion-generated route for steamboat traffic. It is likely, therefore, that the 1875 date, originally identifying the time of the Mosquito Point chute cutoff, became mistakenly identified with the avulsion in some subsequent accounts.

Peel (1972) considered 1882 to have been the date of avulsion because that was the first year that Saskatchewan River steamboats began to abandon the Old Channel in search of a new route through the marshlands north of Mosquito Point. He

**Fig. 2.** Map showing area near the site of avulsion (see Fig. 1 for location). A large northward meander bend of the preavulsive Saskatchewan River (Mosquito Point) intersected a former channel of the Saskatchewan (Ancestral South Angling Channel) which, prior to the avulsion, was occupied by the small ouflowing Zig Zag Creek. Avulsion occurred sometime after a connection was formed between Zig Zag Creek and the Torch River. See text for details.




gives no documentation, however, that the avulsion actually began in 1882. Circumstantial evidence that the avulsion began earlier can be drawn from an account by Jean D'Artigue (1882, p. 156), who, in passing through the area in 1880 without a guide, received the following instructions for negotiating the Mosquito Point cutoff area:

> On leaving this place [D'Artigue's party was traveling downstream, to the east], always keep along the right bank; for a few miles farther, at Mosquito Point, the river divides into two principal branches, of which the one on the left [i.e., north] would take you into the Sturgeon [Torch] River, and from there into Lake Cumberland where you would inevitably lose yourselves.

The recognition of "two principal branches" implies that the avulsion was well underway by 1880. The possibility that some diversion of flow began even earlier than 1880 is suggested by repeated complaints of low water in what is now the Old Channel, recorded through the late 1870s in journals of the Hudson's Bay Company at Cumberland House (Cumberland House Journal 1877–1880). However, because steamboats continued to use the Old Channel through the middle and late 1870s (Peel 1972), it is not likely that the avulsion was fully developed in that period.

From the above accounts, we infer that (*i*) none of the commonly cited dates (1873, 1875, 1882) properly identifies the time of initial avulsion; (*ii*) the avulsion was well developed by 1882, but it likely began earlier; and (*iii*) the avulsion probably began inconspicuously in the early or mid-1870s, then enlarged gradually to cause little alarm or "news," which may be why it was so poorly documented.

## Cause

Although McInnes' account (see quote above) gives the impression that the avulsion carved a whole new channel between Mosquito Point and the Torch River after initially following a canoe portage, there is strong historical evidence that a small creek existed where the avulsive flow eventually broke out of the Saskatchewan River. The creek is clearly indicated in an 1828 map by George Taylor (Fig. 3), and it is also mentioned in earlier accounts by explorer Peter Fidler in 1792 and fur trader Alexander Henry in 1808, both of whom refer to it as the Sturgeon River. Traveling the Old Channel and heading upstream from Cumberland House, Fidler (1792, p. 88) states the following in his September 12 journal entry:

> ...came to the Lower end of the Sturgeon River, on the North side about 15 yards wide, pretty deep, & easy current.

He is here referring to the mouth of the present Zig Zag Creek (Fig. 2), now virtually abandoned. Later the same day at the Mosquito Point bend (which Fidler misidentified):

> ...then...the head of Sturgeon River on the North side, sometimes pass thro it in canoes, but is farther about than to keep the Saskatchewan. it [i.e., Sturgeon] is partly supplied by this river [i.e., Saskatchewan] — & two small rivulets that fall into it from the North a little below here.

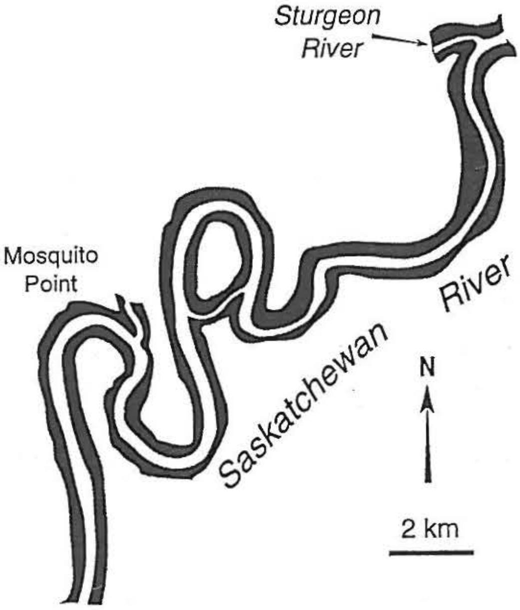
Fidler is clearly saying that the "Sturgeon River" flows out of the Saskatchewan River and shortly rejoins it again at the "lower end," which he encountered earlier the same day. This is supported by Alexander Henry's 1808 (August 27, 28) account of the same reach, also while traveling upstream (Coues 1897). After camping at the mouth of the "lower entrance of Sturgeon River" (i.e., Zig Zag Creek) on August 27, the next day his party

> ...were soon among some islands, at the upper end of which we passed the upper end of Sturgeon River, which is nothing more than an arm of the N. side [of the Saskatchewan River], forming an island about 3 leagues in length. This N. channel has obtained the name of a river, being at high water navigable for canoes.

Thus, the "Sturgeon River" in these early accounts was a small creek flowing northward from Mosquito Point and turning eastward to rejoin the Saskatchewan as the present-day Zig Zag Creek (Fig. 2). This assessment is closely similar to that given by Meyer et al.(1992).

Note that the "Sturgeon River" here is not the same Sturgeon River as referred to in later reports (= Torch River), which has its own drainage basin and flowed directly into Cumberland Lake well before the avulsion. From the accounts of Fidler and Henry, the two preavulsive channels (Torch and Sturgeon) at that time were apparently separated by a narrow neck of floodplain (Fig. 2). Sometime later, but at least by 1870, however, the neck separating the two channels had become breached, allowing water to pass directly from the

**Fig. 3.** Segment of Taylor's (1828) map of the Saskatchewan River showing a small channel at Mosquito Point which later became the initial conduit for the avulsion. Although this channel was not identified by Taylor, it is evidently continuous with the lower (northeast) portion of the "Sturgeon River" (which he did identify) according to earlier accounts by Peter Fidler (Fidler 1792) and Alexander Henry (in Coues 1897). Scale and north arrow are approximate.




Saskatchewan into the Torch by way of the Sturgeon channel. This is confirmed in the following account by Henry Budd (August 30, 1870) who was travelling upriver from Manitoba to Nipawin, Saskatchewan (upriver from Mosquito Point), but planned to visit Cumberland House on his way back downriver (Pettipas 1974, p. 38):

> I take the route by the Saskatchewan [today the Old Channel] all the way, being the straightest: and see Cumb(berlan)d on my way back by the Sturgeon River

Thus, an alternative route to Cumberland House (situated on Cumberland Lake, Fig. 1) from Mosquito Point by way of Sturgeon – Torch – Cumberland Lake was available by then. We do not know when the link between the Sturgeon – Zig Zag and Torch channels was formed, and it is even possible that a tenuous connection existed at the time of Fidler's 1792 observations (e.g., see Fidler's above comment concerning "two small rivulets"). In any case, available historical documents provide little doubt that the avulsion took place by enlarging the small creek (Zig Zag or upper "Sturgeon River" of early reports) flowing out of the Saskatchewan at Mosquito Point, joining the Torch River ("Sturgeon River" of later reports) through the narrow floodplain barrier, and finally overwhelming the Torch as the avulsion developed complex channel systems en route to Cumberland Lake. This scenario is succinctly summarized in a description by John Cadenhead, an assistant to Otto Klotz, in a letter to his hometown newspaper (Cadenhead 1884, p. 456):

> When the water passes through the cut-off [referring to the chute channel across the base of the Mosquito Point bend], most of the water flows up its old bed, and has forced its way through a small creek into the Sturgeon River which flows into Pine Island [Cumberland] lake...

In subsequent derivative accounts of the avulsion, the triggering event is commonly attributed to high water forced by an ice jam (e.g., Dirschl and Coupland 1972; Northwest Hydraulics Consultants Ltd. 1986; Prairie Farm Rehabilitation Administration 1977; Kuiper 1953; Smith et al. 1989), but details of the event do not appear to have been recorded. Again, there may be confusion arising from what the term cut-off refers to. In his diary, Klotz (1884, June 10 entry, p. 13), after reaching the Mosquito Point cutoff, states,

> The whole country is low and in a spring freshet when ice is coming down a new channel may be broken through almost in any place.

No indication, however, is given that an ice jam actually caused either the meander-bend cutoff or the avulsion. Cadenhead (1884, p. 456) is more specific, however:

> A short distance farther on we run through the cut-off, a new channel forced by the ice through heavy forest, which cuts off a long bend of the river...

But here again, the event being discussed is the meander-bend cutoff, not the avulsion, though a careless reading of this account might lead one to conclude that an ice jam caused the avulsion. In any case, it is not clear how this ice-jam interpretation was reached 9 years after the fact. Tree damage? Their guides? Local lore?

### Discussion of historical accounts

Despite the dramatic effect the avulsion had on the Saskatchewan River and anyone who traveled it, the details of its initiation and early development are sketchy, sometimes contradictory, and mostly unrecorded. It likely did not originate as a catastrophic short-term event, but rather evolved gradually and intermittently over several years, perhaps culminating in 1882 when steamboats could no longer safely negotiate the Old Channel. We estimate that most of the flow had probably diverted from the Mosquito Point bend within about 4–8 years after initial enlargement of the "Sturgeon River" outflow channel. The triggering mechanism for this initial enlargement is not clear, despite the persistent mention of ice jamming or high spring flooding in subsequent accounts. Although the avulsion is still not "complete" inasmuch as a small percentage of annual flow is still carried by the Old Channel, the rate of increasing flow diversion probably leveled off soon after 1882. In 1884, Klotz (1885) and Cadenhead (1884) both noted that most of the flow was by then going down the New Channel. As such, the avulsion was neither unusually abrupt nor unusually gradual. By comparison, the 1855 avulsion of the Yellow River (China) required only 1 day to complete (Qian 1990), and the Thomson River avulsion (Australia) was mostly accomplished by a single large flood (Brizga and Finlayson 1990). On the other hand, avulsions of the Mississippi River may have required several centuries to complete (Autin et al. 1991; Saucier 1994). The reasons for such wide time ranges are poorly understood, but it seems likely that two factors, erodability of substrate and gradient between the avulsed channel and its floodplain, are particularly critical in determining the rate at which avulsion proceeds. This question deserves further study (but see below).

Contrary to later derivative accounts that depict the Saskatchewan River as bursting through its banks and immediately creating new channels, the avulsion began by enlarging a small existing branch channel, then appropriating a somewhat larger nearby channel (Torch) which directed the flow northward and eastward toward Cumberland Lake. It was probably not an obviously spectacular event and, as a result, apparently not very newsworthy until commercial steamboat traffic had to be rerouted.

## The avulsion: underlying causes

The following question can now be posed: Why did the avulsion occur where it did? As a necessary precondition, it can be assumed that the levee crests of the preavulsive channel (present Old Channel) stood well above the level of the adjacent floodplain, otherwise there would be no gradient advantage to cause flow to permanently divert away from the channel. Levee crests of several former dominant channels in the Cumberland Marshes, including the Old Channel, generally stand about 3–4 m higher than their contiguous floodplains (Kuiper 1960, his Fig. 3), reflecting a condition of net aggradation in the Cumberland marsh region for the past several thousand years (Morozova et al. 1996).

That the avulsion should initiate at the outer bank of Mosquito Point is not surprising, as partial or complete avulsions of other meandering channels are commonly observed to originate in bends (Fisk 1952; Russell 1954; Speight 1965; Smith et al. 1997). Although we have insufficient data to say whether bends are actually preferred locations for initiating avulsions, at least three reasons suggest this may be the case: (*i*) water-surface superelevation and higher velocities at the concave banks of bends are better able to test and exploit weaknesses in the levee as potential avulsion conduits; (*ii*) during floods, inertia tends to direct overbank flow at high angles to and directly away from the channel at bend apices, i.e., toward the adjacent floodbasin; and (*iii*) the process of bend migration in a meandering channel tends to narrow levees at the outer bend and thus steepen gradients between the channel and floodbasin. Furthermore, once a levee is breached and a new crevasse channel initiated, its location in the outer bank of a meander bend resists rapid closure. Any or all of these processes may have conspired to help set the stage for the avulsion at Mosquito Point.

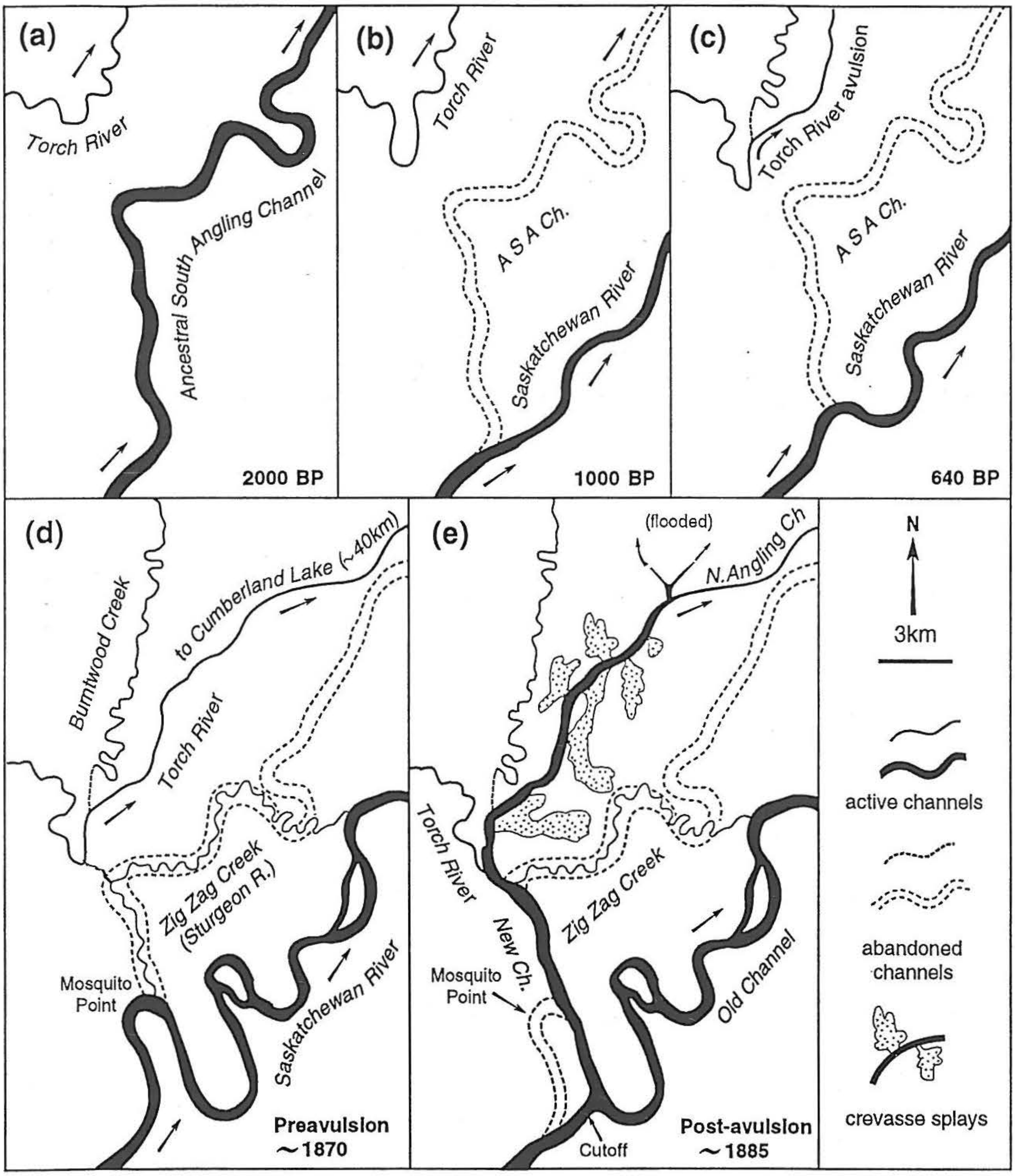
The principal reason the avulsion occurred at the Mosquito Point bend, however, appears to lie in the character and configuration of the adjacent floodplain as determined by prior alluvial history. One of several principal channels formerly occupied by the Saskatchewan River during Holocene time intersects the present New Channel about 1 km south of the present-day Torch – New Channel junction. We term this former channel the Ancestral South Angling (ASA) channel because part of its lower reach is now reoccupied by the modern South Angling Channel (Fig. 1). Distances between levees of the abandoned ASA channel average about 300 m, indicating former channel widths comparable to those of the present New Channel and the Saskatchewan River downstream from the Bigstone – Old Channel junction. The upper reach of the ASA channel belt, i.e., that portion intersected by and lying directly east of the New Channel, is currently occupied by Zig Zag Creek (Fig. 2), and evidence from airphotos (e.g., channel remnants and vegetation patterns) indicates that the ASA had also occupied that portion of the New Channel between Mosquito Point and Zig Zag Creek. Thus, the small preavulsive Sturgeon River described by Peter Fidler and Alexander Henry and indicated in George Taylor's map (Fig. 3) merely followed the old course of the ASA channel, first northward away from Mosquito Point for about 4 km, then abruptly eastward, diverting out of the ASA channel belt at a sharp northward bend to rejoin the Saskatchewan (Old Channel) about 1 km to the east (Fig. 2).

A chronology of events leading up to the avulsion (Fig. 4) can be reconstructed from $^{14}C$ dates of organic-rich sediments exposed in channel cutbanks and recovered from auger boreholes. Peat and organic-rich clay layers are commonly interlayered with floodplain alluvium throughout the Cumberland Marshes, reflecting changing locations of fluvial activity due to avulsions. Focusing on levees and using a sampling strategy similar to that of Törnqvist (1994), we assumed that the age of the top of a peat layer directly underlying fine-grained levee sediment marks the beginning of activity for the associated channel. Similarly, the age of the base of a peat layer that overlies the levee of an abandoned channel gives the time of abandonment of all fluvial activity in that area. In the ASA channel belt 7 km north of Zig Zag Creek, peat layers directly below and above the levee yielded dates of 4190 ± 70 and 1730 ± 45 BP, respectively. The Torch near its present junction with the New Channel yielded a sublevee age of 2300 ± 70 BP, suggesting the Torch channel was locally emplaced by avulsion or channel migration shortly before the ASA channel became abandoned. Thus, about 2000 BP, both channels were active, with the Torch bending sharply northward as it approached the ASA channel from the east (Fig. 4*a*). Several sublevee peat ages indicate that the Old Channel originated about 1000–1200 BP, by which time the ASA channel had become abandoned (Fig. 4*b*). A single sublevee peat age in the New Channel north of the Torch River junction yielded an age of 640 ± 40 BP, which is inferred to represent the minimum time that the Torch avulsed into a lower area between the ASA channel and its own channel belt (now Burntwood Creek; Fig. 4*c*). Based on $^{14}C$ dates elsewhere, an initial Torch avulsion date of about 900 BP is likely. This avulsion brought the southernmost bend of the Torch to within 1 km of the ASA channel belt. Around this time or somewhat later, perhaps in conjunction with northward migration of the Mosquito Point meander bend, Zig Zag Creek began to flow out of and shortly rejoin the Saskatchewan by way of the reoccupied ASA channel belt. At some later but unknown time, a small channel formed through the neck separating the Torch and Zig Zag channels, leading to a floodplain configuration immediately preceding the avulsion of the Saskatchewan (Fig. 4*d*). The avulsion then needed only to widen and deepen this ready-made initial conduit to form an efficient connected channelway for drawing away the flow from the Saskatchewan (Fig. 4*e*).

## The cutoff versus the avulsion

We have suggested above that the avulsion was probably a gradual event that culminated around 1882 when steamboats

**Fig. 4.** Chronology of events leading up to and immediately following the Saskatchewan River avulsion. (*a*) Ancestral South Angling (ASA) Channel, a former course of the Saskatchewan, is nearing inactive stage as main flow is directed to southern region of the marshes (off map); smaller Torch channel has moved to appoximate position of today. (*b*) Saskatchewan River (present Old Channel) becomes emplaced approximately 1000–1200 BP; ASA Channel is now abandoned. (*c*) Torch has avulsed by 640 BP, forming a new channel between its own alluvial ridge (Burntwood Creek) and that of the ASA channel. (*d*) Configuration several years before the avulsion and chute cutoff of Mosquito Point meander bend. Zig Zag Creek (Sturgeon River) occupies former ASA channel belt leading away from Saskatchewan River near tip of Mosquito Point bend and also has made a narrow connection to the Torch River. (*e*) Avulsion accelerated by enlarging the linked Torch – Zig Zag conduit, diverting flow into the Torch channel; undersized Torch could not accommodate full discharge, forming levee breaches and crevasse splays along the New Channel (splays are depicted as approximate present sizes, though they are inactive today). At junction of North Angling Channel (a former continuation of the Torch), most flow diverted out of the New Channel, flooding lowlands to the north and beginning formation of the main anastomosed channel belt; this position approximately corresponds to the Cadotte – Steamboat – Centre Angling junction in Fig. 1.



began to abandon the Old Channel for lack of sufficient flow. Technically, the avulsion actually began at some undetermined date when the Sturgeon – Zig Zag channel initially linked with the Torch River 5 km north of Mosquito Point (Fig. 4*d*). This linkage was probably in place by 1870, but apparently involved only a small amount of diverted flow from the Saskatchewan River, as suggested by the following quote from Klotz (1885, p. 16) during his 1884 survey:

> .....14 years ago [~1870] there was not enough of water in the Sturgeon River (that part between the lake proper [Cumberland Lake] and river proper [Saskatchewan River] for York boats to carry the Hudson's Bay Company's supplies to their post at the junction of the Sturgeon and Saskatchewan channels.

It seems, therefore, that the avulsion began as a relative trickle and maintained that state for at least several years, possibly much longer, until flow diversions began to increase significantly in the mid to late 1870s.

Because the cutoff of the Mosquito Point meander bend apparently occurred in 1875 (Klotz 1885), i.e., near or at the time the Saskatchewan began to avulse in earnest, it is tempting to think that the two events may have been related. The geometry of the affected cutoff channels (Fig. 2) is such that a portion of the flow passing through the chute channel (northeastward) would be expected to deflect up the abandoned channel (north-northwestward), causing the water surface to rise and thus enhance conditions for avulsion. Accordingly, we devised a numerical modeling experiment to test the effects of the Mosquito Point cutoff on river stage at the avulsion site. The hypothesis to be tested was that the cutoff increased stage at the avulsion site, thereby initiating or contributing to the avulsion.

### Methodology

Two numerical experiments were conducted using CIRC, a coastal ocean circulation model which solves the three-dimensional primitive equations for fluid motion in Cartesian coordinates on a rotating earth. For details of the model, see Keen and Slingerland (1993, 1995) or Slingerland et al. (1996). The advantage of CIRC over typical river models is that it computes the momentum equations using a state of the art turbulence closure scheme (Leendertse and Liu 1995, 1997). The model is solved on a staggered finite-difference grid using a central difference scheme for both time and space. A 100 × 100 m grid was laid over an airphoto tracing of the bend to discretize the Saskatchewan channel into wet and dry computation nodes (Fig. 5*a*). At each wet node, the water column was divided into two layers to allow for vertical variations in flow velocity. Dependent variables were computed in each of the layers by solving the primitive equations subject to the condition that the fluid shear stress at the interface is a complex function of the local relative velocities in the two layers. Manning's $n$ for the bottom layer at all wet nodes was everywhere set at 0.04, a value consistent with the dune-dominated medium sand bed of the modern channel. Boundary conditions were temporally invariant water-surface elevations of 1 m above still-water level at the upstream entrance to the computation reach and 0 m at the downstream exit. These values were chosen through trial and error to produce a flow equal to the mean annual discharge of 530 $m^3/s$ (Carson 1990). The model was spun up to steady state, after which time computed water-surface elevations and velocities were analyzed. The experiment consisted of two simulations, one with the geometry of the channel as it existed prior to the cutoff, and the other simulating flow after the cutoff. The chute channel was assumed to have the same width and depth as the regular channel. In neither case was any Saskatchewan water allowed to overflow banks or escape down the incipient avulsion channel. The latter is not a serious oversimplification because of the probably small size of the Sturgeon – Zig Zag channel.

### Results

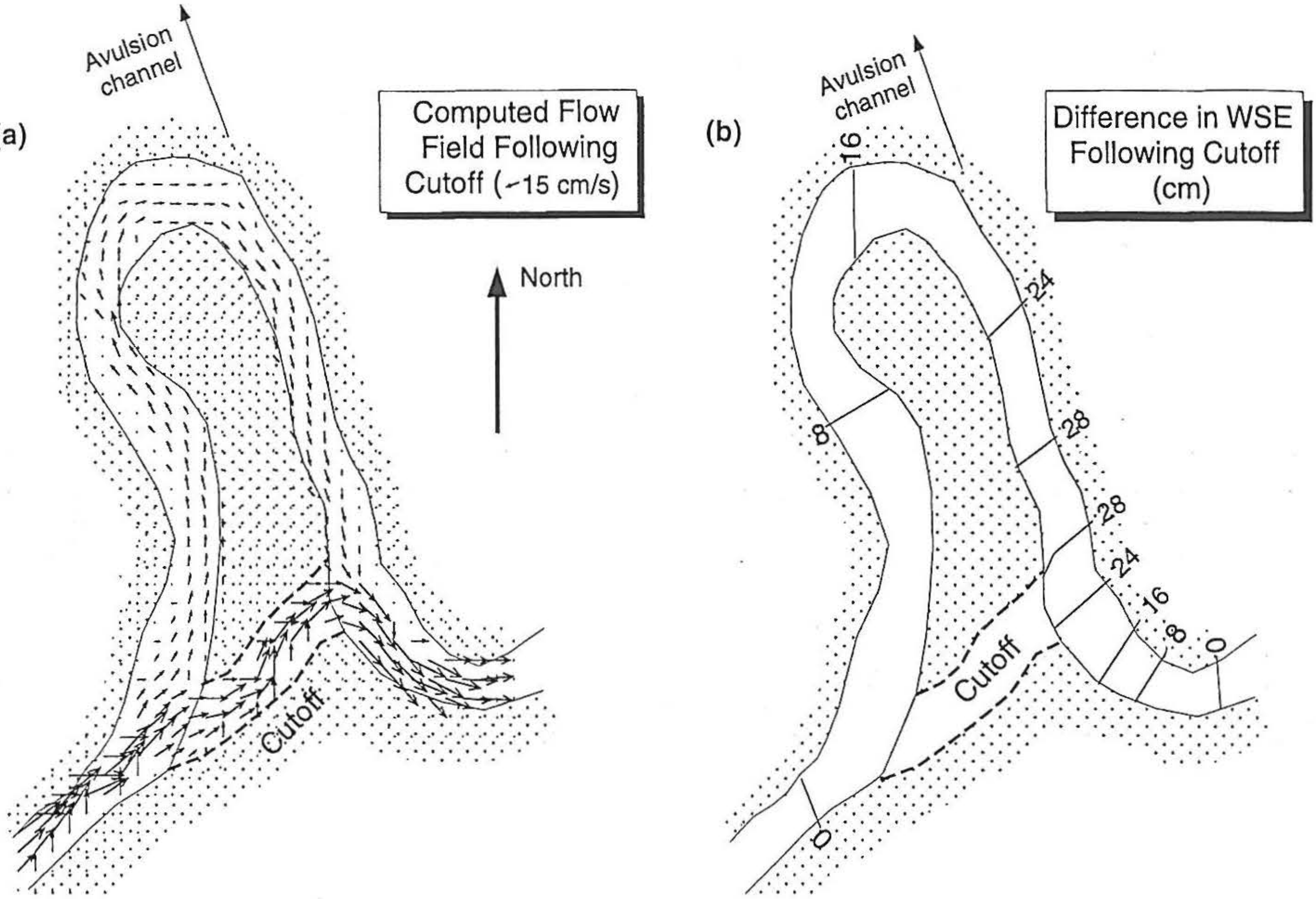
After the cutoff, water continues to flow around the meander bend, but at a reduced rate (Fig. 5*a*). Most importantly, the water surface adjusts to the new geometry (Fig. 5*b*) by increasing elevation throughout the cutoff bend to a maximum of 30 cm near the downstream end of the chute channel. At the avulsion site, the water-surface elevation is about 18 cm higher after the cutoff than before. Therefore, the results support the hypothesis that the cutoff increased water-surface elevations at the avulsion site. The increase in stage arises from the momentum flux of discharge at the downstream end of the chute channel. That momentum is directed upstream (north-northwestward) towards the avulsion channel. At steady state, this momentum flux must be balanced by a net pressure force arising from the head drop between the avulsion channel and the lower end of the chute channel. That head drop can only arise if the water-surface elevation at the avulsion channel is greater after the cutoff compared with before.

The actual stage increase at the avulsion site depends on the details of the flood hydrograph at the time. If the mean annual discharge is doubled, the computed difference in water-surface elevation at the avulsion site increases to 40 cm, or a little more than double the rise at mean annual discharge. Furthermore, the increase in stage could have been substantially higher as sediment scoured from the chute was deposited downstream from the cutoff, raising the bed elevation there. We conclude, therefore, that the cutoff led to a flow configuration capable of sustaining higher than normal water levels at the avulsion site during all discharge stages prior to avulsion. Although we cannot demonstrate that the cutoff indeed forced the avulsion, we suggest that this may have been a contributing, even critical, factor in initiating enlargement of the Sturgeon – Zig Zag channel which then led to permanent diversion of the Saskatchewan flow.

## The aftermath

The drainage basin area and discharge of the Torch River are both less than 5% that of the Saskatchewan River (Underwood McLellan Ltd. 1983), hence its channel was much too small to fully accommodate the diverted Saskatchewan discharge. Widening of the captured Torch channel (now the New Channel) could not keep pace with increasing discharge, so several large crevasse-splay systems broke out of the New Channel to accommodate excess flow (Fig. 4*e*). Channel widening was likely inhibited by cohesive silt–clay and peat-rich floodplain sediments into which the Torch had entrenched following its diversion from (present-day) Burntwood Creek (Figs. 6*a*, 6*b*). On the other hand, widening of the reoccupied ASA channel

Fig. 5. Computed flow variables in the Mosquito Point meander bend and the 1875 cutoff channel. (*a*) Computed vertically averaged horizontal velocity vectors in the upper 3 m after the cutoff for mean annual discharge of 530 $m^3/s$; dots and bases of arrows define computation nodes. (*b*) Contours of water-surface elevations (WSE) before cutoff subtracted from elevations after cutoff. Note that the water-surface elevations rise in the cutoff meander bend.

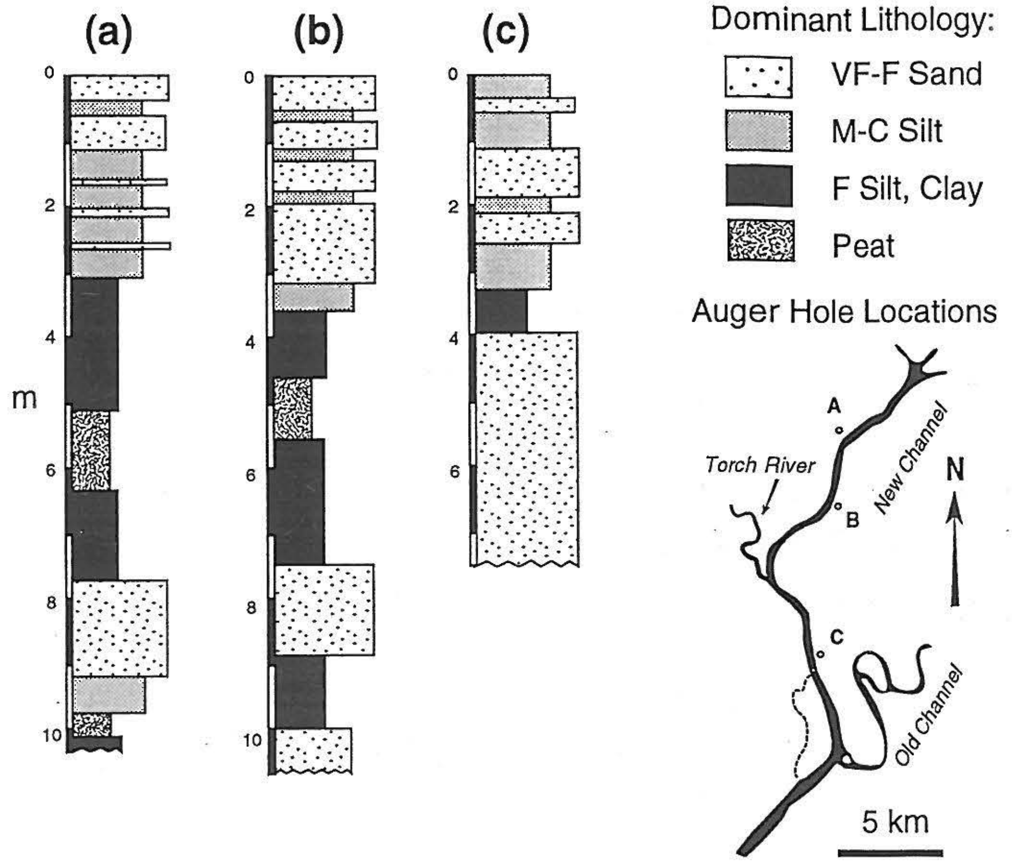



immediately north of Mosquito Point proceeded more easily because, as a former channel of the Saskatchewan, it was already wide and most likely filled in part with noncohesive sand (Fig. 6*c*). The difference in bank erodability of the proximal and distal segments of the New Channel is still manifested today as distinctly different width to depth (*W/D*) ratios (Fig. 7): the proximal segment (former ASA) is consistently wider and shallower (avg. $W/D = 61.7$, $\sigma = 3.1$, $n = 6$) than the distal segment (former Torch) (avg. $W/D = 40.8$, $\sigma = 7.4$, $n = 12$).

Prior to the avulsion, the Torch was connected with the present North Angling Channel which flowed eastward into Cumberland Lake (Fig. 1). Following the avulsion, the Torch channel, though overwhelmed by the captured Saskatchewan flow, was able to maintain its integrity as a single well-defined channel as far downstream as the approximate area where the present Steamboat, Centre Angling, and Cadotte channels diverge, about 16 km downstream from Mosquito Point (Fig. 1). There, most of the remaining flow broke out of the Torch, flooding the low-lying terrain to the north and east to begin a complex development of progradational sedimentation and anastomosed channels which characterize most of the breakout area today. The avulsively flooded terrain drained eastward into what is today regarded as Cumberland Lake, although early postavulsion maps of the area (McInnes 1913; Voligny 1917) considered this flooded area to be a western extension of Cumberland Lake (Fig. 8). The water surface of the inundated floodplain, however, undoubtedly stood higher than the surface of Cumberland Lake proper, and the flooded region was initially most likely a wide (max. 12 km), shallow (approx. 1–2 m deep), eastward-flowing water mass interrupted by locally higher floodplain areas and contiguous with, but sloping into, Cumberland Lake. In the years following the avulsion and continuing today, this avulsively inundated region, comprising most of the breakout area, has gradually become filled with alluvial sediment, resulting predominantly from progradation of splay complexes fed by concurrently developed networks of anastomosed channels. Detailed accounts of the sedimentology and geomorphology of the alluvial fill are given elsewhere (Smith et al.1989; Smith and Pérez-Arlucea 1994).

Today, active sedimentation is mainly concentrated in two areas: (*i*) the delta at the mouth of the Mossy River where it enters Cumberland Lake, and (*ii*) the region immediately west of Cumberland Lake near the Bigstone Cutoff (Fig. 1). The Mossy River delta began to form around 1940 when the last remnants of the avulsively flooded upstream basin (called Sturgeon Fisheries Lake while it existed) became sufficiently

**Fig. 6.** Lithologies of three auger boreholes in the New Channel levee. Sections *a* and *b*, relatively rich in cohesive silt–clay and peat, represent mainly floodplain material enclosing the reoccupied Torch channel, whereas section *c*, predominantly noncohesive sand, represents the reoccupied Ancestral South Angling portion of the New Channel (cf. Fig. 7). VF–F, very fine to fine; M–C, medium to coarse.



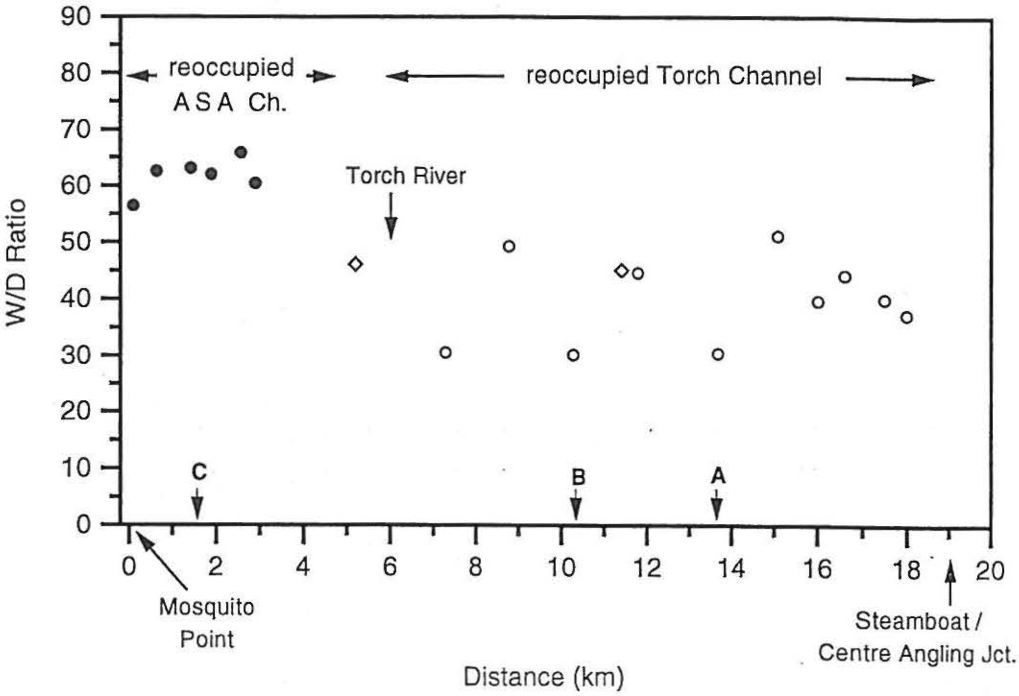

infilled to allow the Mossy channel to transport bedload directly to Cumberland Lake. The delta has since grown to its present area of approximately 17 km$^2$. Active sedimentation in the area directly west and northwest of the Bigstone Cutoff, representing the easternmost extent of the breakout area, is manifested as numerous recently formed islands and sand bars in channel reaches and rapidly encroaching marsh vegetation in aggrading interchannel areas. The older, more proximal portions of the breakout area are becoming increasingly inactive. Virtually all levees and splays are now densely vegetated, and the majority of small anastomosed channels are either completely abandoned or active only during high discharges. The anastomosed channel network of the avulsion belt is rapidly evolving into a single main channel; at present, the contiguous New Channel – Centre Angling Channel dominates flow in the upper two-thirds of the system. This development toward fewer and larger channels represents part of the long-term tendency of the avulsion belt to evolve toward a single new meander belt for the Saskatchewan River, similar to those which have preceded it in the past (Smith et al. 1989).

## Summary and discussion

We have seen that the Saskatchewan River avulsion probably initiated at the Mosquito Point meander bend because the Ancestral South Angling (ASA) channel was intersected at that point, providing an easily enlarged conduit for drawing flow away from the main channel. The intersection of such buried or inactive channels may be an important cause of avulsion in floodplains characterized by actively migrating channels. This mechanism has been suggested as the underlying reason for the incipient avulsion of the Mississippi River into the Atchafalaya basin (Fisk 1952; Aslan et al. 1995), now prevented by artificial structures. Similarly, during the extensive flooding of the upper Mississippi valley in 1993, four levee breaks along a tributary channel (Fountain Creek) occurred where the channel intersected segments of older buried channels (Chrzastowski et al. 1994), presumably due to erodability of the sand-filled paleochannels which caused the overlying levees to weaken and collapse.

In addition to being partly filled with easily eroded sand, the ASA channel was occupied by a small outflowing creek which became the initial path of diversion. This creek (Sturgeon River in old reports) was present at least 80 years prior to the avulsion, so it did not exist as a quickly developed "opportunity" for avulsion. Rather, that opportunity probably depended more on successful breaching of the small floodplain divide separating the creek from the northward-flowing Torch River. We have no information as to how or precisely when this breach took place, but the abrupt eastward bend of the creek 4 km north of Mosquito Point (Fig. 2) likely resulted in overbank flows directed northward toward the Torch during previous flood periods. A new connecting channel would then have formed by a combination of upstream incision at the outflow point and downstream incision where the overbank flow joined the Torch (cf. Schumann 1989; Schumm et al. 1996).

**Fig. 7.** Width to depth ratios (*W/D*) in New Channel north of Mosquito Point. Values in the reoccupied ASA (Ancestral South Angling) portion of the New Channel (solid circles) are consistently higher than those in the reoccupied Torch portion (open symbols). See text for discussion. Circles (open and solid) represent channel cross sections surveyed by the Prairie Farm Rehabilitation Administration in the 1950s (personal communication); open diamonds represent cross sections surveyed in this study. A, B, C show locations of auger holes *a*, *b*, and *c*, respectively, in Fig. 6.




Once this connection was made, the stage was set for major avulsion, viz., (*i*) an aggrading trunk channel elevated above its flanking floodplain, and (*ii*) an initial pathway leading away from the trunk channel to the low-lying northern floodplain. All that remained was the need for a threshold or "trigger" event to initiate the avulsion by enlarging the three integrated channel segments to form the New Channel. We suggest that this trigger may have been provided by the chute cutoff of the Mosquito Point bend, which caused higher than normal water-surface elevations at the avulsion site. This is turn may have initiated widening and deepening of the Sturgeon – Zig Zag channel by creating higher water-surface slopes for the outflow. Once started, the proximal segment of the outflow channel (abandoned ASA channel) widened readily, whereas the Torch and its short connecting channel, encased in cohesive floodplain sediment, enlarged more reluctantly, a situation which is still evident today (Fig. 7).

The main portion of the breakout area, i.e., the region showing complex anastomosed channel networks on contemporary maps (Fig. 1), became extensively flooded soon after the avulsion began, as the undersized Torch channel was unable to enlarge fast enough to accomodate the full Saskatchewan River discharge. The ensuing progradational style of deposition, supplied by the New Channel and characterized by metre-scale (commonly 1–3 m thick) sequences of alluvial sediment ranging from clay to medium sand (Smith et al. 1989; Smith and Pérez-Arlucea 1994), has gradually aggraded the avulsed floodplain, so only small remnant bodies of standing water exist today amid a complexly varied alluvial terrain. The overall picture of the affected floodplain, then, is a two-part system consisting of a well-defined proximal channel (New Channel) whose position was governed by preexisting channels, and a shallowly inundated distal floodplain which has served as a sediment-receiving basin since the onset of avulsion approximately 120 years ago. Eventually, the newly aggraded floodplain will again be dominated by a single-thread meandering channel set within slightly older avulsion-generated sediments, an evolutionary trend that is already well underway.

## Conclusions

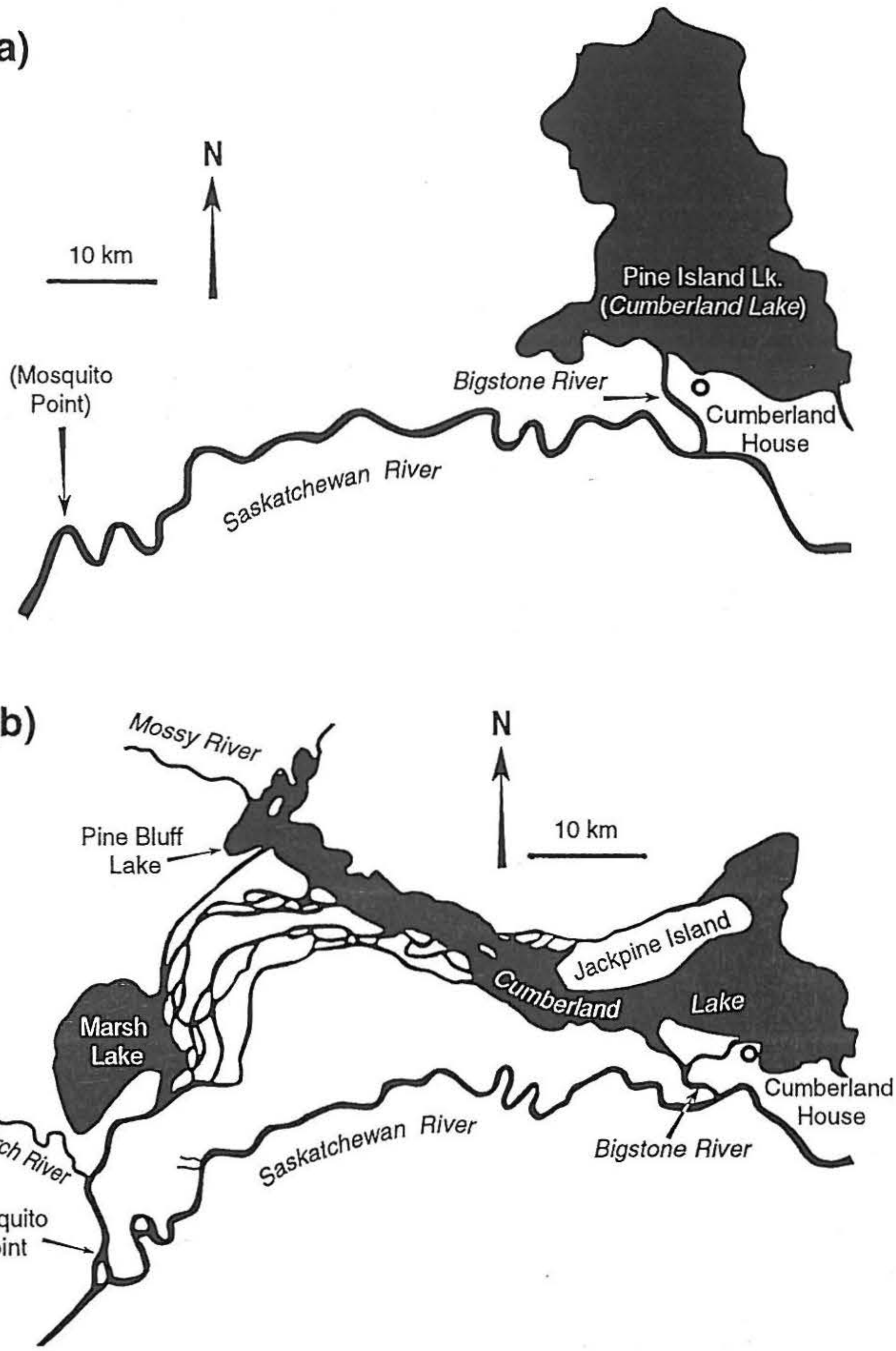
(1) In the Cumberland Marshes, the Saskatchewan River has avulsed repeatedly in the past few thousand years. The most recent avulsion cannot be dated precisely, but it probably occurred gradually over several years, culminating around 1882.

(2) The avulsion began at Mosquito Point, a large northward meander bend. The flow diversion initially followed a small outflowing creek (Sturgeon River – Zig Zag Creek) which in turn followed the course of the abandoned Ancestral South Angling (ASA) channel, a former channel of the Saskatchewan River.

(3) Sometime following the breach of a narrow (1 km wide) strip of floodplain separating the Sturgeon River from the north-flowing Torch River, the Torch channel captured the diverted flow and, together with the Sturgeon segment, formed the New Channel, which carries most of the Saskatchewan River discharge today.

(4) A cutoff of the Mosquito Point meander bend occurred about 1875, approximately the time that increasing amounts of discharge began to divert from the Saskatchewan channel. Numerical flow modeling of the Mosquito Point bend before

**Fig. 8.** Preavulsion and postavulsion maps of Cumberland Lake and breakout area. (*a*) The 1858 map of Henry Hind (in Kuiper 1953). The Saskatchewan River is drawn fairly accurately, but outline of Cumberland Lake (Pine Island Lk.) is crude and shown as being much too large. Mosquito Point identified for orientation. (*b*) McInnes' 1913 map shows avulsion well in progress. Although mapped as part of Cumberland Lake, extension of the lake west of Jackpine Island (= Pine Island today, Fig.1) is actually inundated floodplain flowing eastward. The northern border of this westward "lake extension" is defined by preavulsive Mossy River. Anastomosed channel network southwest of lake extension, though not accurately mapped, indicates approximate extent of floodplain aggradation since the onset of avulsion. This extension of "Cumberland Lake," Pine Bluff Lake, and Marsh Lake do not exist today (cf. Fig. 1).




and after the cutoff indicates that water-surface elevations were raised significantly at the avulsion site following cutoff. The cutoff event may thus have triggered the avulsion.

(5) The upper segment of the New Channel (former ASA channel) easily enlarged to accommodate the avulsion, but the Torch segment, encased in resistant floodplain sediment, was overwhelmed by the added flow, leading to formation of crevasse splays along the New Channel and regional inundation of the distal floodplain.

(6) Subsequent sedimentation in the avulsively flooded floodplain led to the development of splay complexes and anastomosed channel networks which characterize the

"breakout area" today. Current sedimentation is mostly confined to the mouth of the Mossy River and to the area near the Bigstone Cutoff directly west of Cumberland Lake.

(7) The avulsion belt, i.e., the floodplain area affected by the avulsion, is presently reverting to fewer and larger channels which will inevitably result in the reestablishment of a single dominant meandering channel for the Saskatchewan River.

## Acknowledgments

We are grateful to Judith Beattie (Hudson's Bay Company Archives, Winnipeg), and Diane Duguay and Carole Séguin (National Archives of Canada, Ottawa) for their assistance in locating historical documents relating to the Saskatchewan River avulsion. Dale Russell (Western Heritage Services, Inc., Saskatoon) brought the D'Artigue and Pettipas references to our attention. Unpublished channel cross sections upon which Fig. 7 is based were generously provided by Barry Jacobs of the Prairie Farm Rehabilitation Administration (PFRA) office in Winnipeg. We thank David Meyer, University of Saskatchewan, for numerous tips and useful discussions regarding the area. $^{14}C$ dates were provided by S. Valastro, University of Texas Radiocarbon Laboratory, Austin. We thank Gary Carriere and Morley Hoksbergen of Cumberland House for their assistance in the field. The manuscript benefitted from comments by journal reviewers Peter Ashmore and Michael Church; their efforts are much appreciated. Supported by National Science Foundation grants EAR-9304104 (Smith) and EAR-9303851 (Slingerland).

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