William River: An outstanding example of channel widening and braiding caused by bed-load addition

Norman D. Smith
Department of Geological Sciences, University of Illinois, Chicago, Illinois 60680

Derald G. Smith
Department of Geography, University of Calgary, Calgary, Alberta T2N 1N4, Canada

ABSTRACT
The lower William River in northwestern Saskatchewan, Canada, presents an excellent and unambiguous example of rapid channel adjustment to abrupt additions of sandy bed load. A relatively narrow and deep single-channel stream as it flows northward to Lake Athabasca, the river picks up a 40-fold increase of bed load over a 27-km reach as it encounters a large dune field just south of the lake. As a result of the large infusion of eolian sand, the channel develops a thoroughly braided pattern while undergoing a 5-fold increase in width and a 10-fold increase in width/depth ratio.

INTRODUCTION
The underlying causes of stream braiding are complex; they usually involve interactions of multiple factors, including variables of flow, sediment characteristics, bank stability, channel geometry, and slope (see Church, 1972, or Cheetham, 1979, for reviews). Although most discussions of braiding presume, either implicitly or explicitly, abundant bed load to be essential, field data rarely provide unambiguous demonstrations of this. Reasons for such ambiguity include (1) the paucity of bed-load data of adequate quality for developing definitive relationships between bed-load transport and channel pattern; (2) uncertainties arising from residual or lag effects from a stream's earlier history (Schumm, 1971); and (3) the difficulty in distinguishing bed-load effects from those of other factors, especially discharge.

We describe here an example of abrupt infusion of sandy bed load being the unequivocal cause of channel widening and braiding in a medium-sized river. Although this is not a new idea, we know of no natural river where the effects of this mechanism can be demonstrated more clearly.

FIELD SETTINGS
The Athabasca Sand Dunes, located along the south shore of Lake Athabasca in northwestern Saskatchewan, comprise an area of nearly 350 km² of active and partially active dunes and deflation surfaces. Derived mainly from reworked deposits of a former high stand of Lake Athabasca (Taylor, 1960; Craig, 1963), this is the largest active dune field in continental Canada (Rowe and Hermes, 1974). The William River flows north to Lake Athabasca and intersects the dune field at its southeast margin, dividing it into west and east fields that occupy active areas of 164 and 96 km² respectively (Fig. 1). Eolian sand is fed into the river and transported northward to the lake, forming a lobate delta at the mouth. Most sand is sup-

Figure 1. Map showing location of Athabasca Sand Dunes, William River, and sample locations.

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plied by the west field where prevailing westerly winds have moved active dunes directly to the channel edge along 17 of its 27 km of contact, broken only by small stands of stabilizing spruce and willow (Fig. 2). By contrast, active dunes compose less than 0.5 km of the eastern channel edge. The abundant supply of eolian sand has caused progressive widening and braiding of the channel as it flows northward through the dunes to the lake.

The William River drainage basin is typical Canadian boreal forest—formerly glaciated terrane with low relief and abundant muskeg and lakes. The river is ice-covered from November to April, and except for the melt period in late April–early May, discharge fluctuations are generally small and subdued (Fig. 3). Stream discharge is virtually constant through the dunes to the lake, as only one small tributary with insignificant flow and sediment input joins the main channel within that stretch.

METHODS

To document the effects of eolian sand input on channel morphology, ten channel cross sections were surveyed from a point 7 km upstream from the dunes to the lake (Fig. 1). At each location, representative samples of bed material were obtained from composites of 10 to 35 bottom grabs spaced evenly across the channel. All sites comprised sandy beds.

Channel-bed sand upstream from the dunes (locs. A, B, C in Fig. 1) is medium brown, changing quickly to light tan after the river intercepts the dune field. Laboratory study showed the brown color to be due to organic coatings on the surfaces of sand grains (>99% quartz). These coatings are probably precipitates of complex compounds provided by organic-rich waters of the lake and muskeg-dominated watershed. The coverings react readily to hydrogen peroxide and occur both as dark-brown opaque blotches and tan translucent films. By comparison, eolian sands from inland dune locations show complete absence of organic coatings. Some eolian grains have reddish iron oxide stains, but these stains are easily distinguished under a microscope from the organic stains by their color and nonreactivity to hydrogen peroxide. Petrographic examination of several hundred grains from the three upstream locations (A, B, C) showed that organic-coated grains compose the following average proportions of their respective size fractions: 1 φ (0.5 mm)—98.8%; 2 φ (0.25 mm)—89.9%; 3 φ (0.125 mm)—75.0%. The higher percentages of coated grains in the coarser fractions are due to the larger surface areas on which the organic materials could form and thus were more likely to occur. No significant differences were observed between equal-size fractions of the three upstream locations; thus, we infer that the organic coatings are neither being formed nor destroyed as the sand is carried downstream to the dune field from location A. Because eolian-derived grains could be distinguished from the brown upstream-derived "fluvial" grains in bed-material mixtures (Fig. 4), we could then compute relative contributions of eolian sand to the channel sediments.

Figure 2. West dune field and William River, about midway between locations G and H. View is toward southwest.

Figure 3. William River discharge records from Water Survey of Canada gaging station 30 km upstream from dune field. A: Mean monthly discharges for years 1977–1982. B: Hydrograph for 1981, typical year showing major spring-melt peak and little discharge fluctuation thereafter.

Figure 4. Mixed population of brown organic-coated (arrows) and clear uncoated quartz grains. Organic-coated grains are supplied from upstream; clear grains are eolian and locally derived. Location E.
Downstream changes in sediment supply and channel morphology

Sediment Supply

Results of the grain-count survey show that the proportion of eolian-derived sand in the bed material steadily increases as the channel passes by the west dune field (Fig. 5A). By the time it exits the dunes, the channel has acquired a more than 40-fold increase in new (eolian) bed load over a 27-km reach. Most of the increase is shown by samples from locations E–H, representing reaches in direct contact with active margins of the west field.

Mean size of active bed material is everywhere medium sand (1–2 φ), but a slight downstream-finishing trend is present through the dunes reach (Fig. 5B), probably reflecting the increasing additions of finer grained eolian sand. Sorting shows no pronounced downstream trend; inclusive graphic standard deviations range between 0.42 and 0.57 φ, classified as "well sorted" to "moderately well sorted" by Folk (1974). Several water samples collected during moderate discharges all contained suspended-sediment concentrations of less than 18 mg/l. Although these values are probably not representative of concentrations during annual flood peaks, the nature of the source materials suggests that suspended sediment is probably a relatively minor component of total sediment load in the lower William River.

Channel Morphology

The study area consists of three successive reaches: upstream, dunes, and delta, lined by three kinds of channel-bed material: bedrock, boulders, and sand (Fig. 5C). The upstream reach, representing the unaltered channel upstream from the dune field, and the upper 16 km of the dunes reach consist of short stretches of sand bed alternating with short bedrock or boulder-lined reaches. Boulder reaches occur where the channel dissected glacial moraines, leaving the coarsest material as a lag to armor the bed and usually form rapids. Less common are bedrock reaches that, lined by horizontal outcrops of Precambrian Athabasca Sandstone, commonly contain one or more low waterfalls.

The upstream reach is straight to slightly sinuous and unbraided, contains several stabilized islands, and varies considerably in width and depth due to local controls.

The dunes reach begins 34 km upstream from the lake, where the river first encounters a small exposure of active dunes in an otherwise stabilized part of the west field. Little new sediment is immediately provided to the river (Fig. 5A, loc. D), and sandy channels initially resemble those of the upstream reach (Fig. 6A). As more sand is collected from the west field, sand-bed reaches begin to widen and braid, while boulder and bedrock channels remain unchanged. About 18 km upstream from the lake, the boulder and bedrock reaches end abruptly; channel widening and braiding then increase steadily through the rest of the dunes reach in response to ever-increasing supplies of new eolian sand (Figs. 5A, C, 6B). When the channel enters the delta reach at the northern margin of the dune field, further supply of new sand ceases; channel widening levels off (Fig. 5C), but braiding is now thoroughly developed (Fig. 6C). The channel varies little through the 6-km delta reach until it nears the lake, where wooded islands divide and direct flow in a radial distributary pattern over a broad delta platform (Fig. 6D).

The ratio of width to bankfull depth for the ten surveyed sand-bed cross sections increases progressively downstream (Fig. 7). Banks are dominantly sandy and stabilized by vegetation except where active dunes have moved to the channel edge. The very high width/depth ratios in the most disal sites (locs. I, J, Fig. 7) are in part due to low banks in the more recently constructed parts of the delta.

Figure 5. Downstream changes in William River over upstream, dunes, and delta reaches. A: Proportional addition of new eolian sediment provided to river bed load by dune fields. B: Change in mean grain size (graphic mean) and sorting (inclusive graphic standard deviation). C: Variations in channel width, bed material, and channel pattern as measured in 1-km intervals on aerial photos and checked on ground.
Braiding

Elevations of exposed bars in well-braided reaches (locs. F–J) indicate that the channel is completely submerged—i.e., nonbraided—for at most only a few days of spring runoff each year. During high and intermediate flow stages, the characteristic large-scale bedforms are solitary to quasi-repetitive lobate sand bodies bound by downstream slipface margins, usually termed "transverse" or "linguoid" bars in sedimentological literature (e.g., Collinson, 1970; Smith, 1971; Miall, 1977), but whose classification is a vexed subject (Smith, 1978). They are mobile and highly unstable features; braiding proceeds by deformation, dissection, and exposure of these bars during waning flows that follow the spring peak. Because postflood discharge variations are so gradual, and because sand is transported during even the lowest flows, resulting channel patterns present bewilderingly complex arrays of large and small, submerged and exposed, whole and dissected, regular and distorted sand bodies representing varying stages of flow and sediment-transport activity. One of the more common results of the gradually reduced flow is a variety of irregular sand bodies formed by lateral additions to downstream margins of emergent nuclei, as described by Cant and Walker (1978).

The intensity of braiding, defined by the areal proportions of exposed bed in channel cross sections, progressively increases downstream. Surveys taken during a period of intermediate but steady discharge (June 30–July 3, 1982) revealed no exposed bars in locations A–D, but with 11% exposure at E increasing to 56% at J. Of course, proportions of exposed bed vary inversely with discharge, but the downstream trend of increased braiding is characteristic of the dunes and delta reaches.

Figure 7. Downstream change in ratio of bankfull width to mean depth starting with location A upstream. Each site comprises sandy bed.
DISCUSSION

The field setting provides a clear and uncomplicated case of dramatic channel modification caused by large infusions of eolian sand. A relatively narrow and deep single-channel stream as it enters the dune field, the William River undergoes about a fivefold increase in width (Fig. 5C) and a tenfold increase in width/depth ratio (Fig. 7) and develops a thoroughly braided pattern (Fig. 6) in response to a 40-fold increase in bed load over a 27-km stretch (Fig. 5A).

The effect of increased bed load on width is shown by plotting the ratio of new (eolian) to old (upstream fluvial) sand against the ratio of channel width to initial (upstream-average) width for channel segments affected by the dunes (locs. D–J). It appears that width responds promptly to bed-load additions, increasing more or less linearly with increases in sand supply. Once the river leaves the dune field, channel widening ceases when further sand supply stops (Fig. 5C).

Other factors cited as underlying causes of similar channel changes are unimportant here—e.g., downstream variations in discharge (Leopold and Maddock, 1953; Miller and Onesti, 1979), sediment size (Schumm, 1960; Osterkamp, 1978), or bank erodability (Mackin, 1956; Brice, 1964). Width, width/depth, and braiding intensity all increase downstream independent of discharge, which remains essentially constant over the entire study reach. Highly variable or flashy discharge, sometimes cited as a condition favorable for braiding (Doeglas, 1951; Miall, 1977), is not important here; flows remain remarkably steady for weeks at a time. Average bed material is everywhere well to moderately well-sorted medium sand, and downstream changes in grain size and sorting are so slight as to play no important role in channel morphology changes. Braiding, rather than arising from bar-forming mechanisms that depend in part on coarse, poorly sorted sediment (Leopold and Wolman, 1957; Hei and Walker, 1977), results from modification and dissection of large-scale bedforms under steady or gradually reduced flows. Except for some bedrock or boulder reaches, channel banks are composed mainly of sand, and erodability varies locally according to the extent of vegetation. Present variations in bank stability undoubtedly affect channel widths locally, especially in the upstream reach. Over the long term, however, differences in bank stability are at most only minor causes of downstream channel variations in the dunes and delta reaches, and in any case are secondary effects of the predominant sand transport and deposition.

We are led to the simple conclusion, then, that all important channel modifications that occur between the upstream reach and Lake Athabasca result from the massive infusion of sandy bed load provided by the dune field.

REFERENCES CITED


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