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Planform geometry and channel migration of confined meandering rivers on the Canadian prairies

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ABSTRACT

The planform geometry and migration behaviour of confined meandering rivers at 23 locations in Alberta and British Columbia are examined. Relationships among planform geometry variables are generally consistent with those described for freely meandering rivers with small but significant differences because of the unique meander pattern of confined meanders. These exceptions are the ratio channel wavelength (l)/channel width (w) and the bend curvature (r_m/w); in these confined meanders, the ratios exceed ($l/w \approx 17$; $r_m/w = 4.1$) the free-meander norms ($l/w = 8$–14; $r_m/w = 2$–3). In general, these migrating confined meandering rivers do not develop cutoffs, and meander bends appear to migrate downstream as a coherent waveform. Migration rates vary greatly, from 0.01 to 5.8 m/y, consistent with the general distribution of published rates for freely meandering rivers. Attempts to seek correlations between migration rate and channel flow and morphometry data are modestly successful. Stream power offers the best statistical predictor of migration rate, accounting for up to 52% of variance in migration rate, greater than that provided by valley slope (34%), bankfull width (32%), and mean annual flood (30%). Overall, the findings indicate that confined meandering rivers within western Canada may be more usefully regarded as part of a continuum of a meandering river pattern rather than as a unique river planform.

1. Introduction

Freely meandering rivers have attracted a great deal of attention from river scientists and engineers over the last century. We now know a great deal more about meander-planform geometry, bend flow, bend-migration dynamics, and lateral accretion sedimentology than we understood early last century (see Ikeda and Parker, 1989; and the reviews in Leopold et al., 1964; and Knighton, 1998). That understanding has come to us in part because of carefully designed but selective laboratory and field studies of meandering so structured as to avoid the complicating vagaries of nature (the special cases). But as a result, however, we still know relatively little about one of those special cases: that of confined meanders.

Confined meanders are those that are unable to fully develop the planform geometry of free meanders because their lateral migration is constrained by the walls of the relatively narrow valleys through which they flow. Meander bends laterally migrate into the valley walls; and the potentially sinuous channel loops are truncated to form sharp right-angled bends, producing the distinctively asymmetric sawtooth array of river bends that are uniquely associated with meander confinement (Fig. 1).

This circumstance may seem like a special case but in some parts of the world, such as the Canadian prairies, some degree of confinement is normal for almost all meandering rivers. Here, many of the contemporary rivers occupy the large valleys of former glacial spillways formed and abandoned by the meltwater from retreating continental glaciers in the closing phase of the last glacial cycle. Many are classic examples of manifestly underfit streams (Dury, 1964).

The distinctive planform of confined meanders suggests that the channel geometry and migration dynamics of these river systems may be quite different from those associated with freely meandering channels. The purpose of this paper is to describe the planform geometry and migration behaviour of a set of confined meandering rivers on the Canadian prairies and to relate the channel-migration rate of these rivers to basic hydrologic and geomorphic controls. Although the new data presented here are clearly of scientific interest to those seeking to understand the dynamics of meander migration, they are also significant to practical issues such as predicting channel-migration rates for engineering and planning purposes.

1.1. Planform geometry and river migration in freely meandering rivers

The reference model for assessing the distinctiveness of confined meander morphology and behaviour is the geomorphology of freely migrating river meanders. Although the scale of river meandering varies

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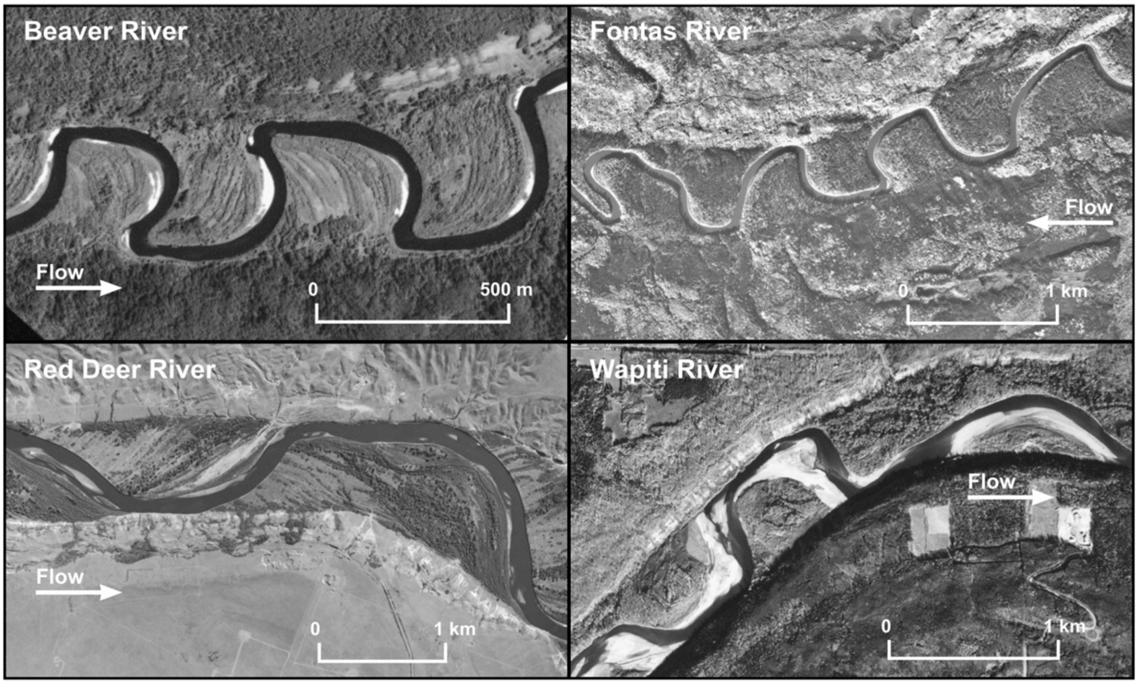

Fig. 1. Aerial photographs of the Beaver, Fontas, Red Deer, and Wapiti Rivers showing characteristic planform of confined meanders.

widely, some aspects of channel-bend geometry in freely meandering rivers are independent of scale (Leopold et al., 1964). Morphometric relationships in the form of constant scaling ratios involving bend parameters [such as meander wavelength (l), bend radius (r_m), and channel width (w) as well as discharge (Q)] have been known for some time (for example, $l / w \approx 8-14w$; $r_m / w \approx 2-3$; $l / \sqrt{Q} \approx 54$) (Knighton, 1998), although the underlying causes are still being debated. We do not know if these planform geometry relations apply also to confined meanders.

Meander migration rate depends on the force ratio: *eroding force/resisting force*. Suggested factors for the eroding force (moderated by channel curvature) include stream power (and therefore discharge and water-surface slope) and surrogate measures, such as channel width and drainage area (Hooke, 1980; Lawler, 1993); those for the resisting force include bend geometry, bank height, calibre of bank sediment, and bank vegetation (Hickin and Nanson, 1984). Some of these will be examined here in relation to confined meanders.

Statistically, stream power has been shown to exert a strong influence on migration rate (Lewin, 1983; Hickin and Nanson, 1984; Nanson and Hickin, 1986; Richard et al., 2005). Channel width has also been shown to relate strongly to migration rate (Brice, 1982; Hickin and Nanson, 1984; Nanson and Hickin, 1986; Richard et al., 2005). Using drainage area as a proxy for river scale, Hooke (1980) and Brice (1984) found that migration rate tends to increase with the square root of drainage area. For rivers in western Canada, the calibre of bank sediment was identified as being important (Nanson and Hickin, 1986). They argued that migration rate was essentially limited by the rate of entrainment and transport of bed and basal bank material. Other authors place more importance on cohesiveness of upper bank materials and vegetation cover (Beeson and Doyle, 1995; Burckhardt and Todd, 1998).

The idea that planform geometry (specifically bend curvature) controls migration rate was first suggested by Bagnold (1960). He reasoned that total resistance to flow around a meander bend depends on bend-flow hydraulics that in turn are conditioned by bend curvature (r_m/w). Nanson and Hickin (1986) found maximum migration rates of channel bends on meandering rivers in western Canada to be strongly associated with bends having a bend curvature of $2<r_m/w<3$ with a decrease in rates on either side of the optimum curvature (Hickin and Nanson, 1975; Nanson and Hickin, 1986), although they did not embrace Bagnold's explanation of this effect (Hickin, 1978). Other authors have confirmed a similar role for bend curvature in controlling channel migration (Hudson and Kesel, 2000; TRB, 2004; Hooke, 2007).

1.2. Confined meanders

Confined meanders are very common throughout much of southern Canada. Indeed, they are so pervasive here that the distinctively truncated and asymmetric planform noted above (Fig. 1) has been taken as the planform norm for the region (Carson and Lapointe, 1983). The effect of confinement on meander form has been discussed in the literature for some time with various authors noting at least one of the following: flattening of meanders where the channel impinges on valley walls, acute bends at the point of contact, and a convex downvalley asymmetry (Schattner, 1962; Yarnykh, 1978; Hooke and Harvey, 1983; Hickin, 1988). Meander migration dynamics can also be affected by confinement; downvalley translation without significant deformation has only been observed within confined meanders whose amplitude is restricted, as well as in certain bends of low curvature (Hooke, 1977; Brice, 1982; Ferguson, 1984). Lewin and Brindle (1977) recognized three degrees of confinement based on decreasing relative valley width. The first and third degrees of meander confinement are not examined here because the former involves only spatially intermittent confinement of the river so that surrounding unconfined meanders likely influence the morphodynamics of the confined bend, while the extreme confinement displayed in the latter type prevents any development of a meandering planform. The confined meandering rivers examined here display second-degree confinement, where every outside bend contacts the confining medium; the potential amplitude of the meander is greater than the width of its valley, and alluvial deposits are discontinuous. Unlike the case of entrenched or incised meanders, however, an alluvial plain forms the valley bottom allowing the confined stream to migrate. Those properties intrinsic to confined meanders, such as planform distortion, are the most pronounced with second-degree confinement.

Although little research exists on migration dynamics of confined meanders, they have been the focus of research on the development of concave-bank benches consisting of counterpoint deposits associated with the sharp meander bends found on second-degree confined