Rapid rates of channel migration in a Pacific island river

James P Terry and Ray A Kostaschuk

Abstract

The Wainimala River is a major tributary of the Rewa River, the largest fluvial system on Fiji's main island, Viti Levu. The mountainous rainforested landscape has a wet tropical climate due to the predominant moist south-east trade winds and orographic effects. The fluvial regime frequently experiences large floods owing to the average biennial occurrence of tropical cyclones. Unrestricted sections of the lower Wainimala channel display a meandering pattern across alluvial terraced floodplains. Air photograph records over the last c.50 years show significant changes in meander position and geometry. In a selected study reach, maximum rates of meander bend movement are in the order of 15 m/yr, a high rate of channel migration compared to other environments. Locally, channel shifting is a problem for some rural Fijian communities because rivers demarcate traditional land boundaries on floodplains between adjacent clans. As a result of channel movement, the village of Waidracia has lost valuable river-marginal farmland needed for growing subsistence crops and for cattle pasturing. Documenting recent historical rates of river channel adjustment in the tropical Pacific islands in relation to large flood events is important, because cyclone frequency or intensity may increase in the Pacific region with global warming, as some climate change models now predict.

Keywords
Fiji, river channel movement, tropical cyclones, floods

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Introduction and aims

Fluvial systems in the humid tropics can be highly dynamic, particularly where high rainfall, climatic seasonality and intense storms influence hydrological behaviour, sediment transport and channel geomorphology (Gupta 1993). This includes those rivers on tropical Pacific islands, where channel patterns and floodplain morphology change most notably in large flood events caused by tropical storms and cyclones. River banks are undercut and collapse, meander bends are cut off and abandoned, river beds scour and fill, and floodplains erode or aggrade. Consequently, alluvial rivers in the wet tropics often exhibit large changes in their channels through time, especially in terms of meander geometry and position.

Since the seminal work on river meanders by Leopold and Wolman (1960), much effort has focused on characterising and explaining adjustments to the channel pattern of meandering rivers (e.g. Hooke 1984; Ikeda & Parker 1989; Howard & Hemberger 1991; Knighton 1998). Progress has been made in relation to temperate rivers (e.g. Hooke 1995), but this may not be easily transferred to the humid tropics. It is unfortunate that little information exists on rates of channel movement for tropical rivers, especially considering the implications of channel instability for human occupation and activities on river floodplains.

The aim of this paper is to describe the total cumulative adjustment and average migration rates of several meander bends over the last c.50 years on the main island of Fiji in the south-west Pacific, in a river where rapid changes in channel position are causing problems for floodplain land use by the local rural population. Examination of aerial photographs forms the basis of a survey of historical and recent channel movement, which builds upon important earlier work in the area by Rodda (1990). Supporting evidence is provided by field measurement and from oral history of the local people. Observed rates of channel migration are discussed in relation to climate and the occurrence of large magnitude flood events. Comparison is also made with recorded rates of meander movement for rivers in other environments. We do not attempt to examine episodic movements caused by individual floods, nor describe the geomorphic processes responsible for channel shifting. These more complex problems will be the focus of future investigations.

Study area, climate and fluvial geomorphology

The study area lies in the lower valley of the Wainimala River on the eastern side of the mountainous volcanic island of Viti Levu (figure 1). The confluence of the Wainimala and Wainibuka tributaries forms the major Rewa River 5 km downstream of the study area. The Rewa is the largest fluvial system in Fiji draining an area of 2900 km^2, or approximately one third of the island.

The climate of eastern Viti Levu island is dominated by the moist south-east trade winds and orographic lifting effects of the mountainous terrain. Annual rainfall is approximately 2500 mm for the capital Suva on the south-east coast, but increases with elevation to >5000 mm in the volcanic highlands that rise to over 1300 m in the north-western part of the Rewa basin. The precipitation pattern is distinctly seasonal. The wet season from November to April receives 67% of the annual rainfall total, while the May to November dry season receives the remaining 33%. The wet season is the time when intense tropical storms occur, often bringing heavy precipitation and causing river floods (Kostaschuk, Terry & Raj 2001).

The present channel study forms part of a wider investigation of fluvial geomorphology, carried out by a collaborative research team from Fiji and Canada. The umbrella programme runs over a five-year period from 1998 to 2003 and examines the effects of tropical cyclones on river flows, morphology and sedimentation in Fiji. The project focuses on the Rewa River basin for a number of reasons. First, parts of this large basin are regionally important for both subsistence and commercial agriculture on the floodplains. Second, there is a history of major floods that have affected the rural population occupying the floodplains. Third, there are current problems of siltation in the Rewa estuary, which needs to be dredged at an annual cost of over F$1 million (MAFF 1995–1997). Estuarine siltation is thought to be the product of high rates of erosion, both on the catchment slopes and in river channels that exhibit rapid rates of channel shifting.

The individual section ('channel reach') of the Wainimala River chosen for studying meander behaviour is approximately 5 km in length, lying between the villages of Serea and Vunidawa (figure 1). The landowners of Waidracia village, located on the south bank of the river, indicated this reach as one experiencing rapid channel movement. On several previous trips to

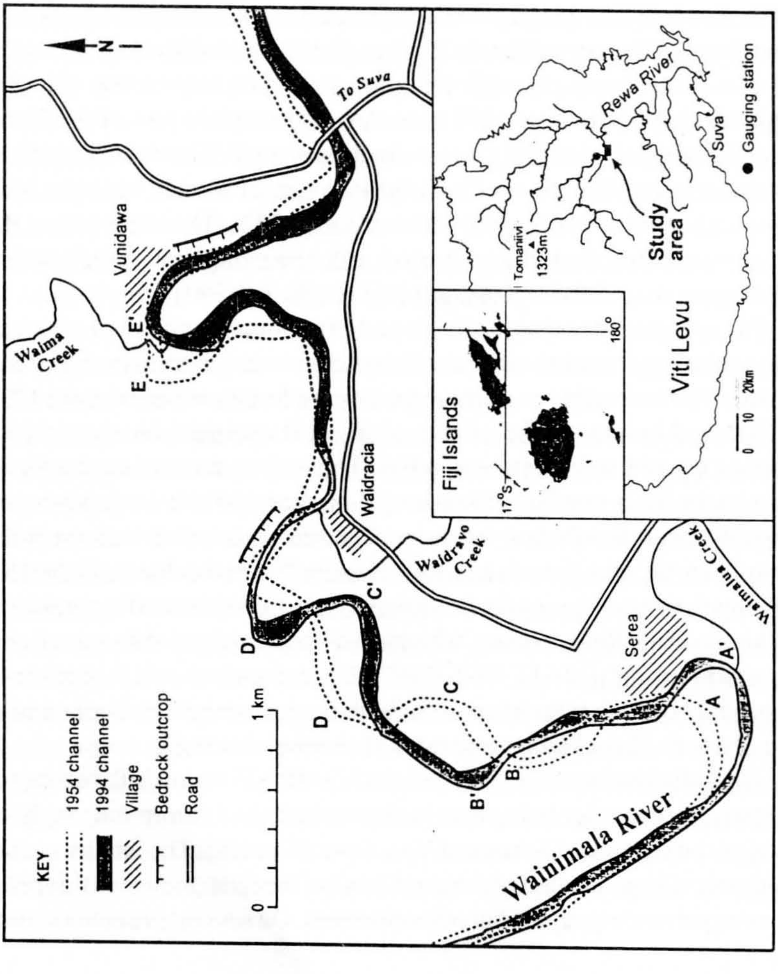

Figure 1 Study region in South-east Viti Levu Island, Fiji and position of the Wainimala river channel in 1954 and 1994

the area by the authors, the Fijian chief of Waidracia lamented the continuing loss of river-marginal farmland because of river bank erosion and channel migration towards their village. In rural Fiji, rivers are used to demarcate the boundaries of native land ownership between adjacent clans. Shifting of the Wainimala River over recent decades has reportedly diminished the area of floodplain available to the Waidracia people to grow their staple food crops and for cattle pasture. One purpose of this study therefore was to provide evidence of historical channel movement for the people of Waidracia, in support of their claim to the Fiji government for assistance.

The valley in the study area is oriented in a west to east direction, and the valley floor varies from 1 to 2.5 km wide. The alluvial floodplain geomorphology is characterised by several terrace heights, surveyed with a global positioning system (GPS) at 9–12 m above sea level (Terry, Garimella & Kostaschuk 2002). Floodplain deposits predominantly comprise fine-grained materials, although thin (c.2 cm) layers of gravels occur in isolated exposures in some riverbanks. These occasional gravels are believed to have been laid down by extreme overbank floods. The natural vegetation on the valley slopes is dense tropical rainforest, but in valley bottoms this has been replaced by rough pasture for cattle grazing and subsistence agriculture of root crops such as taro and cassava. The catchment of the study reach drains a 810 km^2 area of rugged volcanic terrain rising to over 1300 m at the Tomaniivi watershed in the north west (figure 1). Reliable precipitation and river discharge records are available from a hydrometeorological station operated by the Hydrology Section of the Fiji Public Works Department at Nairukuruku village a few kilometres up the valley. Average baseflow there is 50–100 m^3/s and bankfull discharge estimated by surveying is approximately 1200 m^3/s.

Channel pattern analysis and results

Aerial photographs covering the Wainimala River are available for 1954 and 1994 from the Fiji Lands and Survey Department. A Geographic Information System (GIS) was used to digitise the channel positions on the two sets of aerial photographs to produce the map given in figure 1. Since the aerial photos were taken at altitudes of 20,000 feet and 27,000 feet, necessary scale adjustments were made by georeferencing several fixed points on the photographs, such as buildings and road junctions. Over the four decades between 1954 and 1994 there was significant channel movement, although individual meander bends behaved differently in their amount and type of adjustment. Meander adjustment was assessed by observing planform geometry changes and measuring the amount of displacement of meander bend apexes between 1954 and 1994. With this method, for open-type meanders with long gentle curvature it can be somewhat difficult to designate precise locations for bend apexes. For this reason, the results presented in table 1 are recorded to the nearest 50 m only, to avoid giving a misleading impression of greater measurement accuracy. Meander geometry changes are described according to the system shown in figure 2, which is based on the principles of Hooke (1977).

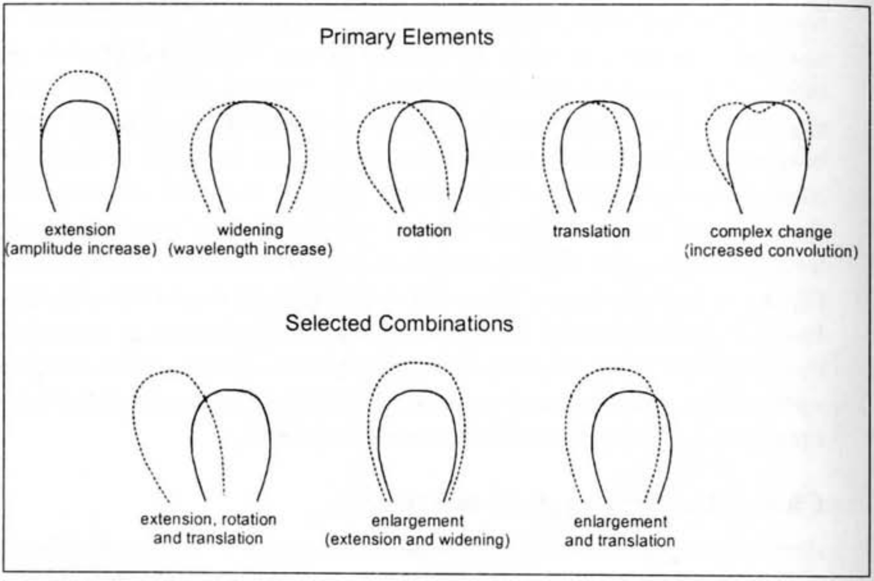

Figure 2 Types of river channel meander bend adjustment, based on Hooke (1977).

Rodda (1990) reported that a 1928 Native Lands Commission map showed a relatively straight river channel in the vicinity of Waidracia village. However, by 1954 a meandering pattern was well developed (Rodda 1990 and figure 1). Meander bend A near Serea village is the largest individual loop examined. The apex of this bend did not migrate down the valley, but extended considerably in amplitude, by almost 250 m. The apexes of meanders B, C, D and E all exhibited translation (that is, migrated in a down-valley direction) by approximately 200 m, 600 m, 550 m and 300 m respectively. Meander B shows an increase in wavelength and became a more open bend, whereas meanders C and D grew in amplitude but shortened in wavelength, thus becoming 'tighter' loops over the study period. Meander E near Vunidawa generally retained its amplitude and wavelength, but rotated a small amount and also developed a more convoluted geometry.

Table 1 Migration of individual meander bends in the Wainimala River between Serea and Vunidawa from 1954 to 1994

Meander bend[1]	Total migration[2] m	Average[3] migration rate m/yr
A	250	5
B	200	6
C	600	15
D	550	14
E	300	8

[1] See figure 1 for bend locations.
[2] Measurements to nearest 50 m.
[3] Measurements to nearest 1 m/yr.

Over the four decades between 1954 and 1994, the calculated average migration rate for the five meander loops investigated ranges from 5 to 15 m/yr (table 1). Meander C was the fastest moving section of channel. As a consequence of migration, the position of the bend apex C' was in close proximity to the Waidravo creek by 1994. Subsequent field surveying in June 1998 indicated that less that 20 m of floodplain separated the Wainimala River from cutting into the channel of this small tributary. We predicted that if this occurred there was a strong possibility for the abandonment of bend D' by the Wainimala in preference for the occupation and enlargement of the Waidravo creek channel. According to our prediction, the Wainimala River eventually cut into the channel of the Waidravo creek during the wet season of 2000. This fluvial process, where a river with a rapidly shifting channel eventually erodes into and then occupies the channel of another river, is called *channel piracy*. The consequence for Waidracia village of this piracy was that the farmland enclosed by meander bend D', approximately 13 hectares in area, was effectively 'lost' from their ownership to the opposite side of the new main Wainimala river channel (figure 3).

Discussion

Table 2 allows comparison of our measured rates of channel migration in the Wainimala River with various other rivers in contrasting environments. It is clear that our channel pattern shows relatively fast adjustment compared to meandering rivers outside the humid tropics. In order to explain the rapid channel shifting of the Wainimala River, it is necessary to consider the frequency of large and erosive flood discharges. Large floods are the hydrological response to the occurrence of tropical cyclones in Fiji. From 1970 to 2000, 40 cyclones traversed Fiji island waters. These often produced extreme rainfall events. During cyclone Gavin (4–11 March 1997) for example, which was the most severe cyclone to strike Fiji in recent years, the Rewa basin experienced a deluge due to orographic lifting of the storm's spiralling rain bands. In the upper Wainimala catchment, the highest weather station (at an elevation of 760 m) received a torrential 610 mm of rainfall in 24 hours on 7 March, with maximum rainfall intensities calculated over 10 minutes from automatic rain gauge charts exceeding 150 mm/hr (Terry & Raj 1999).

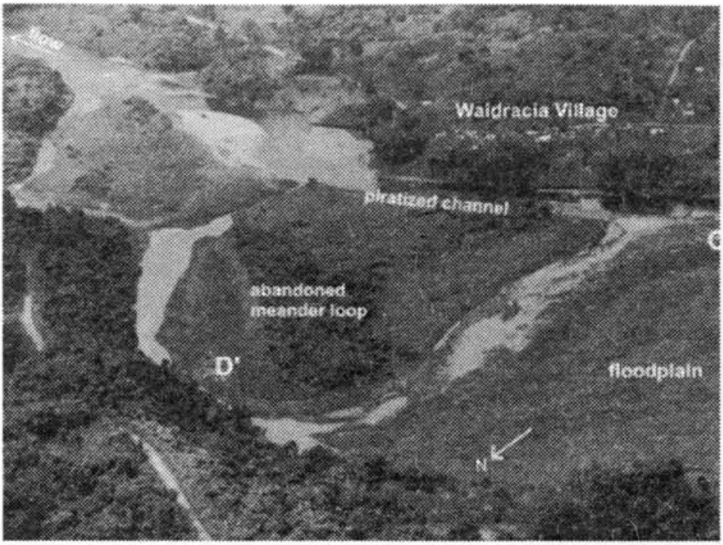

Figure 3 Low level aerial view in July 2001 of the Wainimala River adjacent to Waidracia village. Flow is from right to left. Prior to early 2001 the river followed the meander loop in the centre of the photo. Down-valley migration of this bend led to piracy of a tributary channel adjacent to the village, causing abandonment of the bend in preference for the present straight course. The area of floodplain farmland enclosed by the cut off loop is now effectively 'lost' from Waidracia village ownership.

Table 2 Comparison of observed rates of channel migration in various regions

River	Location	Environment	Channel migration rate[1] (m/yr)	Authors
White River	Indiana, USA	warm temperate	0.67	Brice 1973
Hernad	Czechoslovakia	"	5–10	Laczay 1977
various	Devon, England	"	0–1.79	Hooke 1980
South Esk	Scotland	"	0.5	Bridge & Jarvis 1982
various	Wales	"	0.1–5	Lewin 1987
Ob	Russia	sub-polar	0–15	Kulemina 1973
various	British Columbia, Canada	"	0.57–7.26	Nanson & Hickin 1986
Wainimala	Viti Levu Island, Fiji	tropical wet	5–15	Rodda (1990) and this Study

[1] Published values include both meander bend migration and bank erosion rates.

Rainfall events of this magnitude cause extreme discharges in the Wainimala and other rivers of the Rewa basin. Over the 20 year period of record (1978–1997) for the river gauging station at Nairukuruku, bankfull and overbank floods occurred with an average return period of two years. Nine floods were caused by tropical cyclones and one other by a wet season depression. The hydrological response to cyclone Gavin rainfall is shown in figure 4. It is seen that river discharge increased rapidly from 50 to 6300 m^3/s, which is five times the bankfull flow. This is a huge discharge of water considering the 810 km^2 area of the catchment. When the authors visited the study location one month after this event, Waidracia villagers indicated sites at meander C' where severe outer bank collapse had taken place during the flood (figure 5). According to local oral history, such extreme flood events are highly erosive and are responsible for the most significant amounts of riverbank retreat and channel movement. Such is a recognisable characteristic of many tropical rivers, where most of the work is accomplished during high-magnitude events (Gupta 1993).

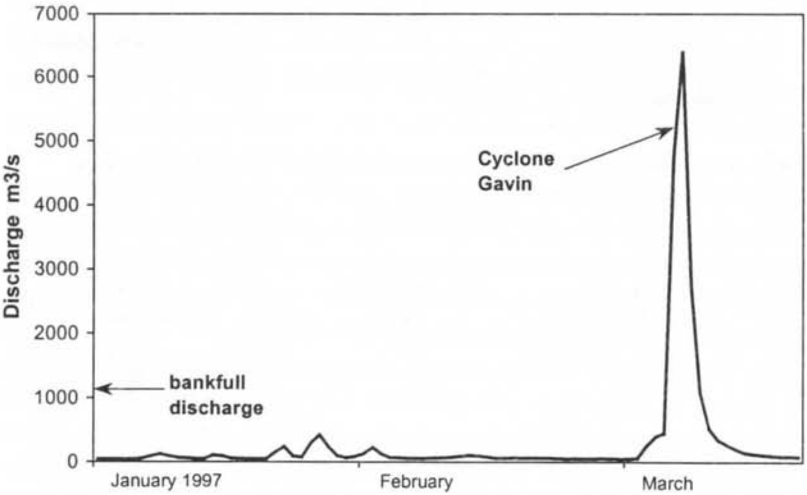

Figure 4 Hydrograph of the Wainimala River at Nairukuruku gauging station in the early months of 1997. Note the extreme flood discharge generated by tropical cyclone Gavin in March.

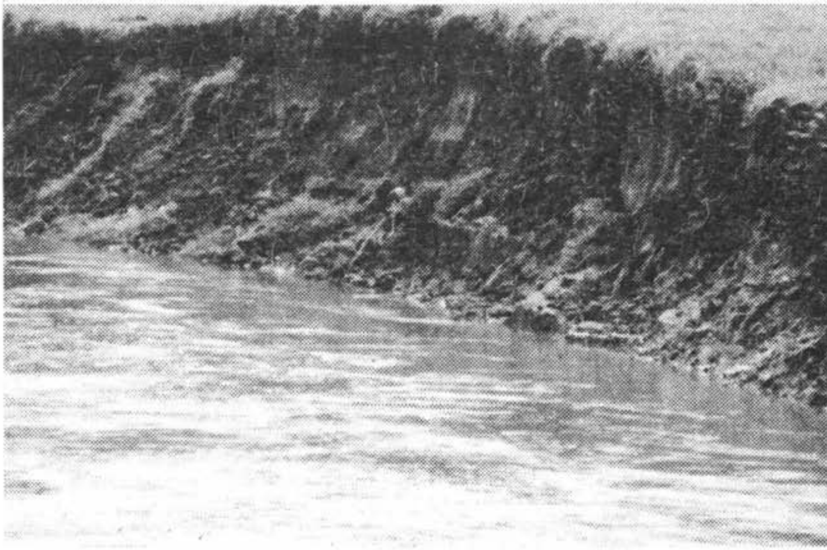

Figure 5 Severe riverbank erosion along meander bend C' caused by the extreme discharge during tropical cyclone Gavin in March 1997. For scale, note the woman fishing in the centre of the photograph.

Conclusions

Most studies of river channel behaviour in response to major floods have focused on rivers in humid temperate climates (Newson 1994), even though large floods are probably more frequent and significant in the humid tropics (Gupta 1988; Rajaguru *et al.* 1995), especially in regions affected by tropical cyclones. On many Pacific islands, tropical cyclones are identified as a major cause of river flood events, to which river channel morphology and pattern must adjust. For the alluvial Wainimala River in Fiji, an important geomorphic response to the biennial frequency of large floods is adjustment in channel planform geometry. Several types of adjustment in meander bend shape were recorded. These are amplitude extension, wavelength change (both increase and decrease) and meander translation down-valley. Over a period of 40 years, average individual meander bend migration rates ranged from 5 to 15 m/year. In one instance near the village of Waidracia, meander shifting led to piracy by the Wainimala River of a tributary river channel, with the consequent loss of access for the villagers to an important area of valley farmland. The observed rapid rates of channel movement in Fiji may increase further if tropical cyclones become more frequent or intense because of climate change in the South Pacific, as some climate models now predict.

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