Pacific Science (1999), vol. 53, no. 3: 257–272

Island Environment and Landscape Responses to 1997 Tropical Cyclones in Fiji[1]

JAMES P. TERRY[2] AND RISHI RAJ[3]

ABSTRACT: Principal responses of the physical environment of the Fiji Islands to tropical cyclones Gavin and June in 1997 were investigated. These cyclones, which entered Fiji waters in March and May 1997, respectively, were the first severe tropical depressions to traverse Fiji since 1993. Northern and western islands were the most severely affected. Hurricane-force winds, intense rainfall, and temporary storm surge caused damaging effects, including widespread flooding, landslides, and coastal degradation. Different tropical cyclones produce contrasting patterns of landscape change on Pacific islands, depending on strength and duration of the storms, proximity of the storm tracks to land, rainfall totals and maximum intensities, hydrological behavior of the vegetation and soils, and many other factors influencing the environmental susceptibility of the islands concerned. Spatial patterns in the environmental responses of Fiji to cyclones Gavin and June were assessed using satellite images of the storms' movements and data on rainfall, river rises, landslide occurrence, and coastal inundation. Field observations at some of the worst affected areas demonstrate the magnitude of these effects.

IN EARLY 1997 two tropical cyclones struck the Fiji Islands in 2 months, bringing high winds, heavy rainfall, and storm surges. As a result, the physical environment of the islands suffered damage, including flooding, landslides, and coastal degradation.

Cyclone Gavin was the first tropical storm to affect Fiji in the 1997 wet season, lasting from 4 to 11 March (Fiji Meteorological Service 1997a), and was the most severe storm to affect the islands since Cyclone Kina in January 1993. The depression developed north of Fiji waters and west of Tuvalu, achieving cyclone status with storm force winds 48–63 knots (89–117 km/hr) at approximately 10° S, 173° E. (Wind speeds refer to sustained winds over 10-min averaging times.) By the evening of 5 March, Gavin intensified to a "hurricane" (with sustained winds over 63 knots [118 km/hr] and gusts to 130 knots [240 km/hr]). Gavin approached the island of Vanua Levu from the north during 6 March, but shortly after midnight on 7 March it altered course to the southwest (Figure 1). The hurricane continued on this track, passing over the Yasawa and Mamanuca Islands offshore to the northwest of Viti Levu. After 7 March, Gavin progressed on a southerly track away from the main Fiji group, but remained at hurricane strength until well after leaving Fiji waters.

The second depression developed closer to the main Fiji Islands, being officially named Cyclone June at a location of 14° S, 174° E early on 3 May 1997. During most of its relatively short 3-day life, June strengthened to only gale force (34–47 knot winds), except for approximately 24 hr from the early morning of 4 May when it intensified into the storm force category. Although Gavin traveled fairly rapidly through Fiji waters, Cyclone June displayed more erratic behavior, making sudden changes in both direction and speed. This made prediction of its move-

[1] Financial support provided by the University of the South Pacific. Manuscript accepted 17 November 1998.
[2] Department of Geography, University of the South Pacific, P.O. Box 1168, Suva, Fiji (fax: +679 301487; E-mail: Terry_J@usp.ac.fj).
[3] Hydrology Section, Public Works Department, P.O. Box 3740, Samabula, Fiji (fax: +679 320313).

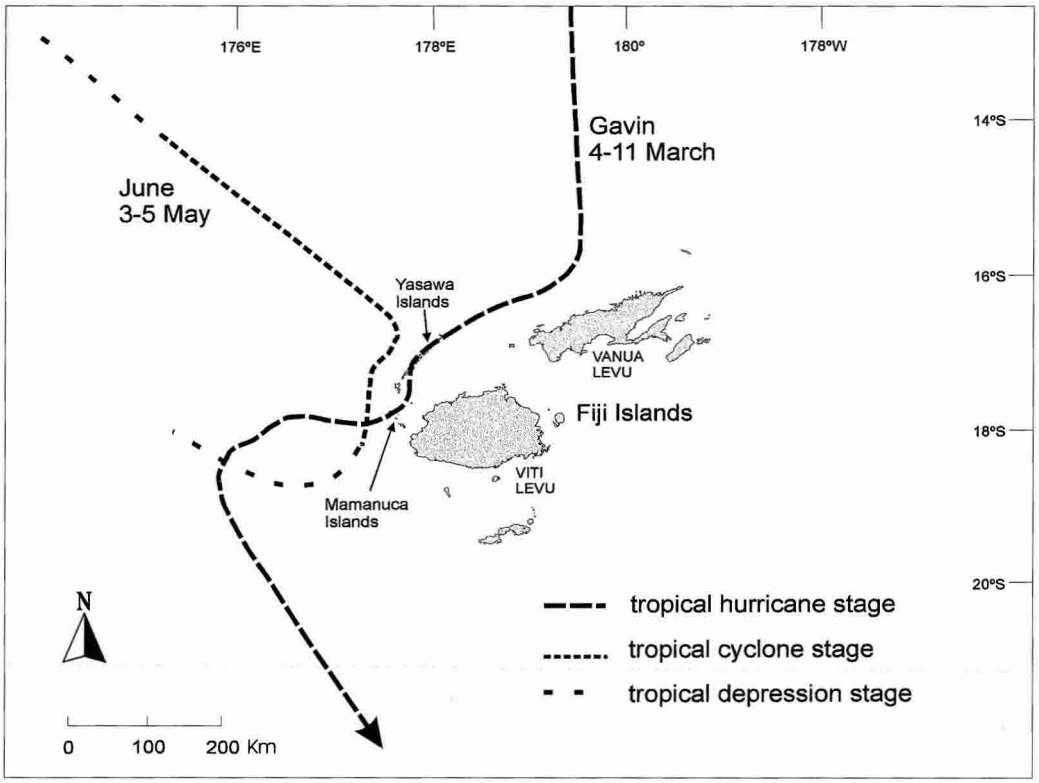

FIGURE 1. Tropical cyclone tracks and intensities through Fiji waters in 1997.

TABLE 1

COMPARISON OF THE BEHAVIOR OF TROPICAL CYCLONES GAVIN AND JUNE

CYCLONE GAVIN, 4–11 MARCH 1997	CYCLONE JUNE, 3–5 MAY 1997
Developed away from Fiji: latitude 10° S	Developed close to Fiji: latitude 13.5° S
Large storm	"Midget" storm
Traveled quickly: average 20 km/hr	Traveled slowly: average 13 km/hr
No erratic change in speed	Showed erratic acceleration and deceleration
No erratic change in direction	Showed erratic changes in direction
Intensified to hurricane intensity (>63 knots)	Remained mostly at gale intensity (34–47 knots)
Long life span: 7 days	Short life span: 3 days
Long track: left Fiji waters as a cyclone	Short track: decayed in Fiji waters

ments by Fiji weather forecasters a difficult task. In particular, after moving slowly but steadily on a southeast course toward the Yasawa Islands during 4 May, Cyclone June then decelerated and remained almost stationary to the northwest of the Yasawas the next day, before taking an unexpectedly sharp turn southward (Figure 1). Unlike Gavin, which left Fiji waters as an active cyclone with no signs of decay, June began to lose structure, weaken, and then die out near the Fiji Islands, moving slowly northwestward away from the coast of Viti Levu. The main differences between cyclones Gavin and June are shown in Table 1.

According to historical data since 1840,

TABLE 2

COASTAL PRECIPITATION TOTALS FOR CYCLONES GAVIN AND JUNE

	RAINFALL (mm)	
CLIMATE STATION	CYCLONE GAVIN	CYCLONE JUNE
Nadi	396	123
Suva	222	184
Labasa	372	312

Tropical Cyclone June has the distinction of being only the fourth cyclone to threaten Fiji outside the normal cyclone season between the months of November and April (Fiji Meteorological Service 1997b). The life and behavior of this depression are distinct in several ways from those of Cyclone Gavin 2 months earlier, which is a reflection of June's development at an unusually late time of the season, when sea temperatures and climatic conditions are not as conducive to sustaining a tropical cyclonic storm as earlier in the wet season. The Fiji Meteorological Service (1997c: 1) reported that "June was a midget cyclone that never really formed a visible eye due to an insufficiently favourable environment."

Rainfall Patterns

Examination of the weather records for Fiji's 22 synoptic climate stations showed that cyclones Gavin and June produced widely differing rainfall patterns over the Fiji group. Cyclone Gavin produced higher overall rainfall totals than Cyclone June, mainly because it had a 4-day longer life span (Table 2). Although substantial rainfall was measured during Gavin (Fiji Meteorological Service 1997d), only a single new 1-day extreme value for the month of March was established in the highlands of Viti Levu (see below), although this can be attributed in part to the fact that March is usually wet and has experienced cyclones in the past (e.g., Tia in 1980, Oscar in 1983, Sarah in 1983, Gavin in 1985, Bola in 1988, Rae in 1990).

The distribution of maximum 1-day rainfall for both cyclones (Figures 2 and 3) reveals that the interior highlands of Viti Levu experienced the greatest deluge twice, owing to orographic lifting effects of the storms' peripheral rain bands. At an elevation of over 760 m, Monasavu weather station in the center of Viti Levu received a torrential 610 mm of rainfall on 7 March during Cyclone Gavin and 341 mm on 4 May during Cyclone June. Associated maximum rainfall intensities, calculated over 10 min from rain gauge chart traces, reached a drenching 152 mm/hr for Gavin and 40 mm/hr for June. Apart from this location, however, the two storms show contrasting patterns in maximum daily rainfall. For Cyclone Gavin it was the northwest coast of Viti Levu that experienced more intense precipitation, whereas for Cyclone June it was Vanua Levu and Taveuni. Because May is usually the beginning of Fiji's dry season, several new extreme rainfall records were established for this month with Cyclone June coming at this time (Table 3). New 1-day extreme rainfall values were set at Rakiraki in north Viti Levu, Matei airport on Taveuni, Monasavu in the highland interior of Viti Levu, and Labasa on the north coast of Vanua Levu (Fiji Meteorological Service 1997e).

An interesting question is why the largest rainfalls associated with Cyclone June were in the more easterly parts of Fiji compared with Gavin, considering that June's track was farther west and that June was less intense than Gavin. An explanation can best be found by examining the visible satellite images of both systems (Figures 4 and 5). For Cyclone Gavin, the structure of the storm was preserved throughout its traversal of Fiji waters. In contrast, Cyclone June experienced strong vertical shear on 4 and 5 May at the onset of its decay. This meant that upper levels of the storm, and associated cloud-bearing rain, shifted to the east although the cyclone eye remained to the northwest of Viti Levu. Studying the location of the cyclone track alone therefore gives a misleading impression of Cyclone June, because the mass of June's rain-bearing clouds was to the east of the track, giving a more easterly distribution of high-intensity rainfalls.

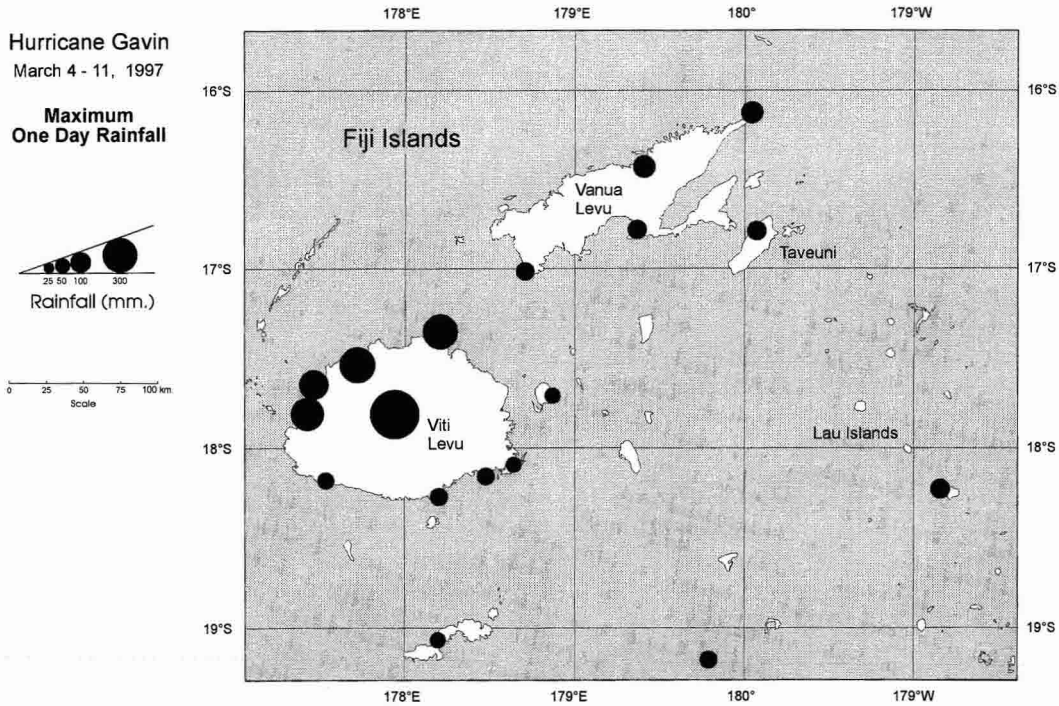

FIGURE 2. Maximum 1-day rainfall produced by Cyclone Gavin across the Fiji Islands.

River Flooding

VITI LEVU. The contrasting rainfall patterns over Fiji's main islands during Gavin and June led to different responses in river rises and consequent flooding. Overall, Cyclone Gavin caused more serious flooding. This was mainly because of the more prolonged duration of this storm compared with June, bringing higher precipitation totals, although the much stronger hurricane force winds must also be considered because strong winds against the shore can effectively retard the discharge of flood waters out of river estuaries.

Fiji's larger islands, Viti Levu and Vanua Levu, are steepland volcanic islands with mountainous interiors. Consequently, rivers on these islands with drainage basins extending inland to the windward side of the tropical storms had the most substantial flood peaks. The remaining small islands experienced less flooding because of the shorter lengths and limited catchment areas of their streams. An exception is the island of Taveuni, which had serious floods due to the record rainfalls received (discussed later).

For Cyclone Gavin, all the major rivers on Viti Levu (Figure 6) responded with notable discharge peaks, although not all flooded their banks (Table 4). The Nadi River in the west has a catchment area of 490 km^2 and the steepest long profile for all rivers in Viti Levu with a bed gradient of 1 : 70. In Nadi Town near the estuary, the flood peak rose to 6.5 m above sea level, which was sufficient to overtop the banks. As a result some parts of the town, particularly the market and main street, were extensively flooded to depths between 1 and 2 m. The Ba River in the north also has a steep catchment, covering 930 km^2. The peak flood level surveyed at the old bridge site of Ba Town was 6.53 m above mean sea level, which is only 0.25 m and 2.27 m below 1993 (Cyclone Kina) and 1931 record flood levels, respectively. Maximum

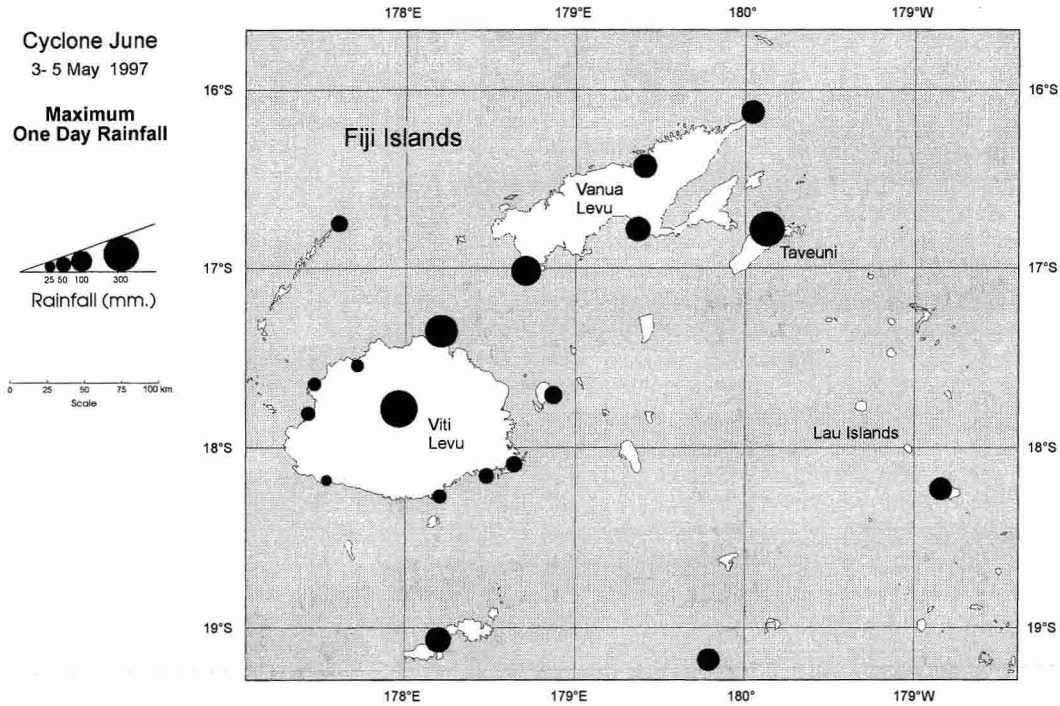

FIGURE 3. Maximum 1-day rainfall produced by Cyclone June across the Fiji Islands.

TABLE 3

NEW EXTREME RAINFALL RECORDS SET BY CYCLONE JUNE

CLIMATE STATION	NEW 1-DAY RECORD (mm)	NEW MONTHLY RECORD (mm)
Labasa, Vanua Levu	139 on 4 May	—
Matei, Taveuni	294 on 4 May	728
Rakiraki, north coast Viti Levu	261 on 5 May	682
Monasavu, interior highland Viti Levu	341 on 4 May	995

Data source: Fiji Meteorological Service.

over-bank flood waters reached depths of 1.6 to 1.7 m in the Ba industrial and town areas (Figure 7), causing substantial damage.

The Sigatoka River draining southwestern Viti Levu has the second largest catchment area of Fiji's rivers (1450 km^2) and drains from Tomaniivi (Mount Victoria) with an elevation of 1320 m (Fiji's highest mountain). The upper third of the catchment is mountainous and the remainder is hilly. The average slope of the river bed is 1 : 134. Rainfall records for this part of the island indicate relatively low rainfall near the coast, with much more substantial rainfall at higher elevations (e.g., 610 mm at Monasavu in 24 hr). For this river, flooding therefore caused more damage in the middle reaches of the valley, whereas lower flood heights in the lower reaches caused less extensive inundation.

The drainage basin of the Rewa River is the largest in Fiji, spanning 2900 km^2 or almost a third of the land area of Viti Levu.

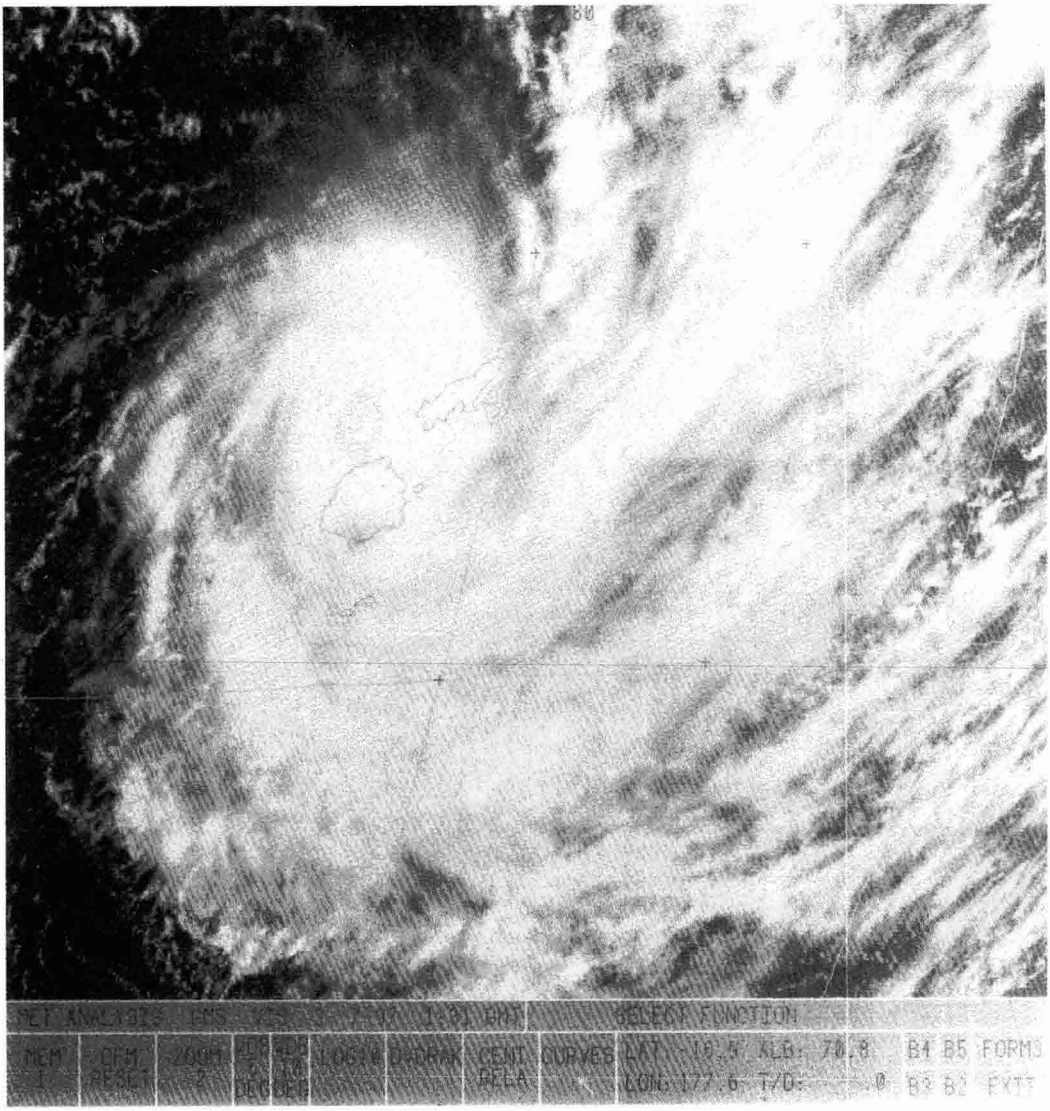

FIGURE 4. Satellite image of Cyclone Gavin, 1400 hours local time, 7 March 1997. Note the well-developed structure and the large cyclone eye, approximately 80 km in diameter, being distorted by land influences of north Viti Levu. Photo courtesy of the Fiji Meteorological Service.

The Rewa has four major tributaries: the Waimanu, Waidina, Wainimala, and Wainibuka Rivers. These drain southern coastal, southern interior, interior highland, and northeastern Viti Levu, respectively. During Cyclone Gavin, the Wainimala and the Wainibuka tributaries produced most runoff because of the high rainfalls in the highlands and on the northern coast, but the other tributaries had lower peak flows because their catchments were more sheltered on the leeward side of the island. Consequently, below the confluence of its tributaries, the main Rewa River was able to contain the maximum 4.52 m rise in water level.

For Cyclone June, there was less impact of

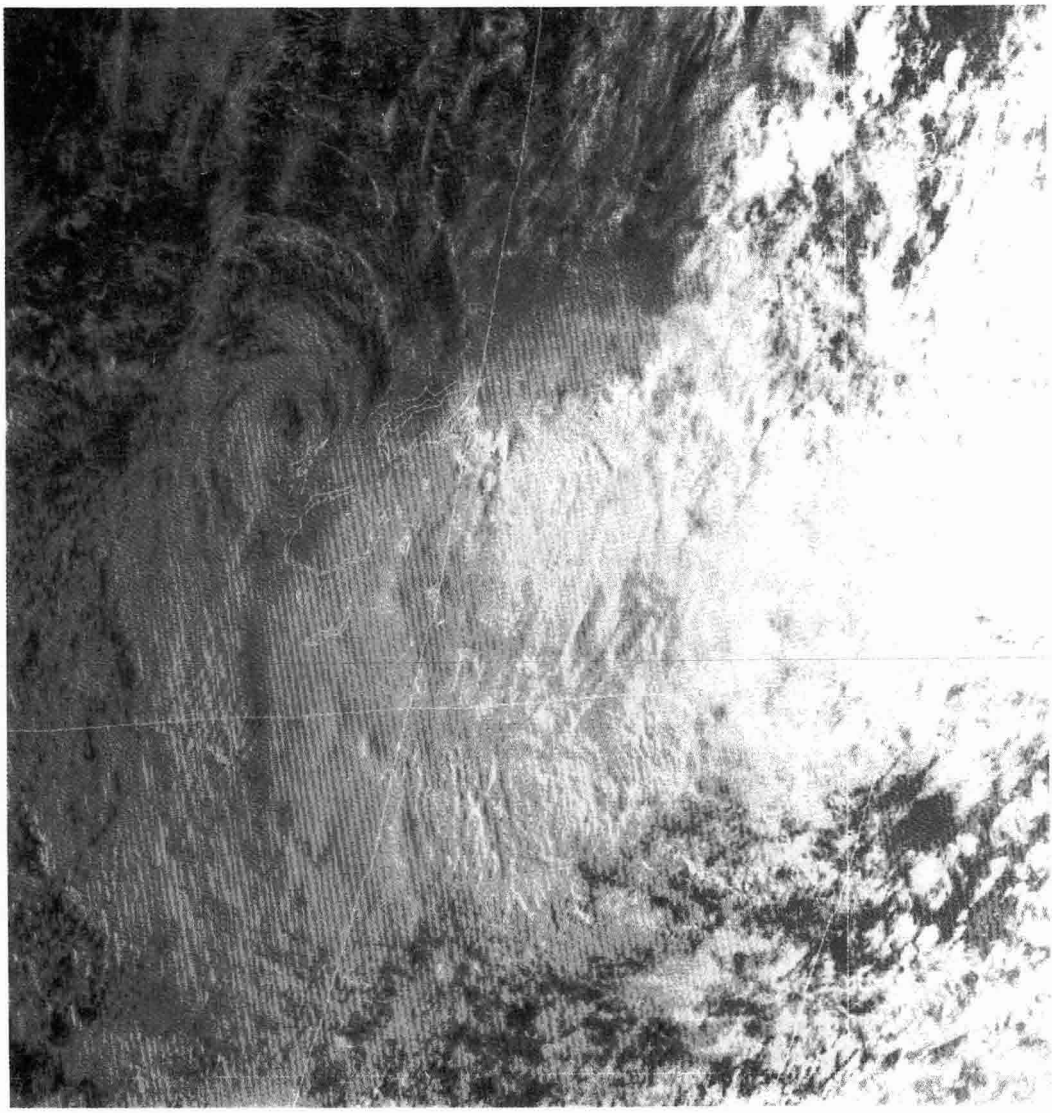

FIGURE 5. Satellite image of Cyclone June, 0800 hours local time, 5 May 1997, showing clearly the exposed low-level circulation, with the upper-level canopy shearing off rapidly to the east. Photo courtesy of the Fiji Meteorological Service.

river flooding on Viti Levu because of the lower rainfall totals.

VANUA LEVU. River floods generated by Cyclone Gavin in Vanua Levu were lower than previous records because of the relatively low rainfall on this island; Tropical Cyclone Raja in 1987, for example, had much higher rainfall, causing far larger floods (Table 4). However, the Labasa River flooded at Labasa Town from the combined effects of rainfall in the catchment and storm surge. Rainfall on Vanua Levu during Cyclone June was higher than for Gavin, but no reports of any major flooding were made.

The island of Taveuni (430 km^2) off the

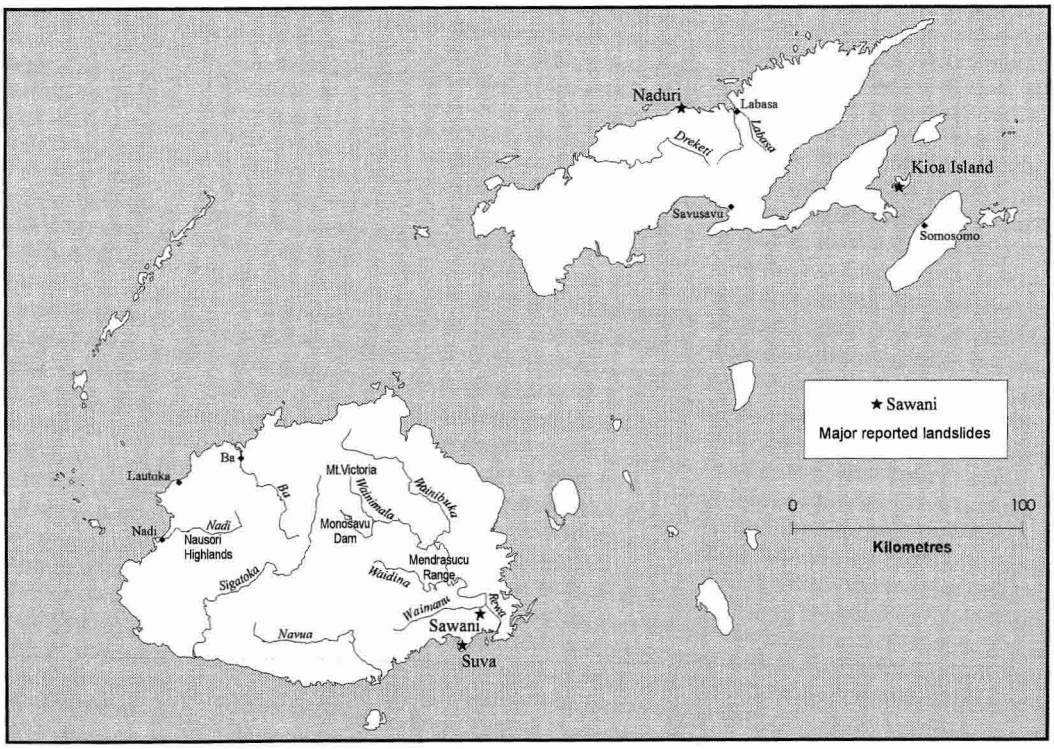

FIGURE 6. The principal rivers in Fiji, most of which flooded their lowland reaches (see text), and the locations of major reported landslides resulting from heavy cyclone rainfalls.

TABLE 4

PEAK FLOOD LEVELS FOR FIJI'S MAIN RIVERS DURING SOME RECENT CYCLONES

		PEAK RIVER HEIGHT (m)[a]						
RIVER	CATCHMENT AREA (km^2)	OSCAR 2 March 1983	RAE 29 March 1990	RAJA 30 December 1986	KINA 3 January 1993	POLLY 27 February 1993	GAVIN 8 March 1997	JUNE 4 May 1997
Viti Levu								
Ba	930	5.46	5.49	8.80	6.51	6.00	6.30	ns
Nadi	490	6.61	5.93	3.70	ns	7.06	6.66	ns
Sigatoka	1,450	3.90	3.03	nd	4.81	ns	3.44	ns
Rewa	2,900	4.54	4.99	2.82	6.66	nd	4.52	4.46
Vanua Levu								
Labasa	93	ns	5.61	6.64	1.52	ns	ns	ns
Dreketi	317	ns	6.78	11.00	1.77	ns	ns	ns

[a] All river levels are heights above fixed benchmarks; comparison should be made along the rows to examine the impact of different tropical cyclones on individual rivers. nd, no data; ns, no significant flood peak.

FIGURE 7. Flooding in Ba Town after Cyclone Gavin, resulting from over-bank flow of the Ba River and storm surge inundation. Photo courtesy of the *Fiji Times*.

southeast coast of Vanua Levu has small rivers. The largest stream is the Somosomo Creek draining the northern slopes of the island. However, because it is a mountainous island with a high central volcano (Mt. Koroturaga, rising to 865 m), stream catchments are steep. Streams therefore show a flashy response to heavy rainfall. During Cyclone Gavin, Taveuni received modest rainfall compared with other areas in Fiji. During Cyclone June, however, rainfalls were record breaking (e.g., 294 mm on 4 May at Matei airport, causing localized flooding on the northern coast and consequent damage to infrastructure and property [Figure 8]). Local hydrologists reported that stream flood levels for the island were some of the highest in living memory (Duilomaloma, pers. comm.).

Soil Erosion and River Channel Change

The lower catchments of the Nadi, Ba, Sigatoka, and Labasa Rivers, which are the principal sugarcane-growing areas of Fiji, are more prone to accelerated soil erosion than most other rural land-use types, with the possible exception of village gardens or areas of forestry clearance on the steeplands of the Rewa River basin. The heavy rainfall associated with cyclones Gavin and June no doubt caused sheetwash erosion on areas of bare soil or where high winds caused vegetation defoliation and crop damage. No figures are available, but evidence lies in the high turbidity in Fiji's rivers caused by increased loads of suspended sediments, even several days after the heavy rainfall had abated.

Besides hillslope soil loss, in-stream sources also provide an input of sediments during cyclones. In-stream sources include river bed and bank erosion and the resuspension of fine material held in temporary storage in deep pools. Cyclone-induced flows are usually the highest river discharges experienced on islands in regions vulnerable to tropical storms and are important in the development

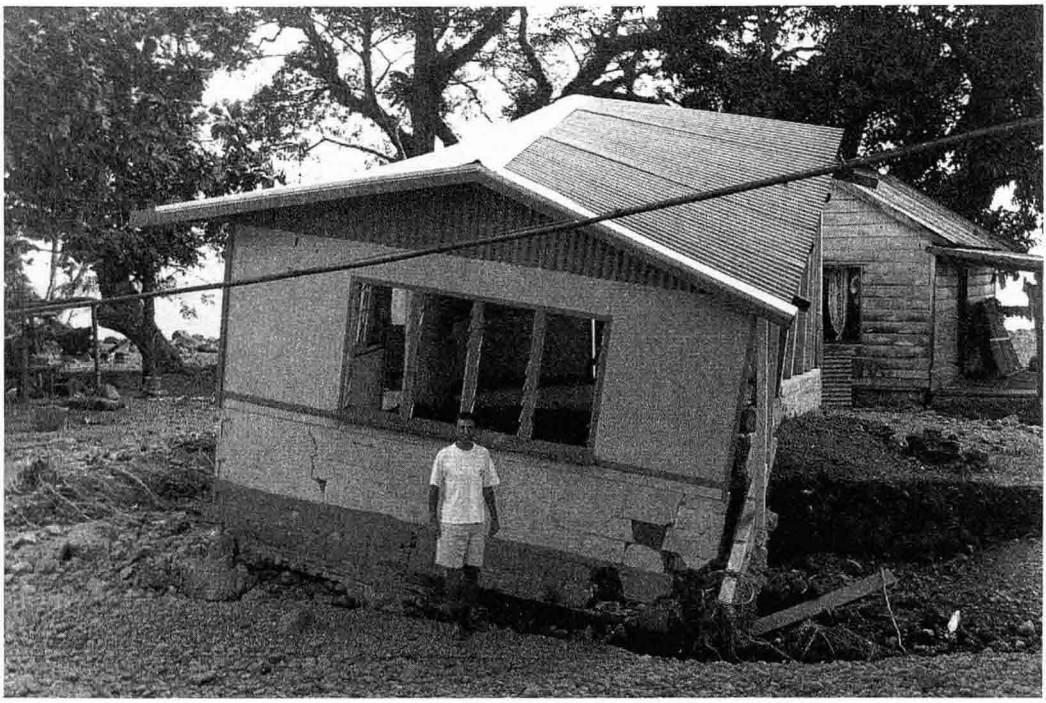

FIGURE 8. Property damage caused by stream floodwaters and erosion by coarse sediments on the island of Taveuni after Cyclone June.

of river channel morphology. Historical maps and air photographs show that meanders on the floodplain of the Wainimala River, the tributary of the Rewa draining the interior highlands, have migrated downstream in the past (Rodda 1990). On a visit to villages in this region 1 month after Cyclone Gavin, local people indicated sites where several meters of bank collapse had taken place on the outside bends of meanders because of high flows during that storm. In spite of the lack of postcyclone river studies, it is probable that similar evidence of changes in fluvial geomorphology could be found in most other alluvial river systems throughout Fiji.

For streams with bouldery channels, cyclone peak flows are a time when the coarsest of bedload sediments undergo downstream transport. Figure 9 shows, for instance, some of the large rocks that were carried down the Somosomo Creek on Taveuni during Cyclone June.

Landslides

Past studies have shown that Fiji's highland terrain is susceptible to the occurrence of landslides and other types of mass movement (e.g., Crozier et al. 1981, Howorth et al. 1981). This susceptibility is related to the predominance of clay soils, mainly humic latosols overlying red/orange clay regolith, formed on Fiji's volcanic bedrocks by deep weathering. Such tropical clays can usually support high-angled slopes without failure, but landslides may be triggered by cyclones, when heavy and sustained rainfall causes soil to become saturated, with a resulting loss of soil shear strength.

For this study, the geographic distribution of landslides triggered by cyclones Gavin and June could not be mapped because of a lack of high-resolution satellite images or air photographs taken soon after these events. A low-level traverse of Viti Levu on a commercial flight in August 1997 (5 and 3 months

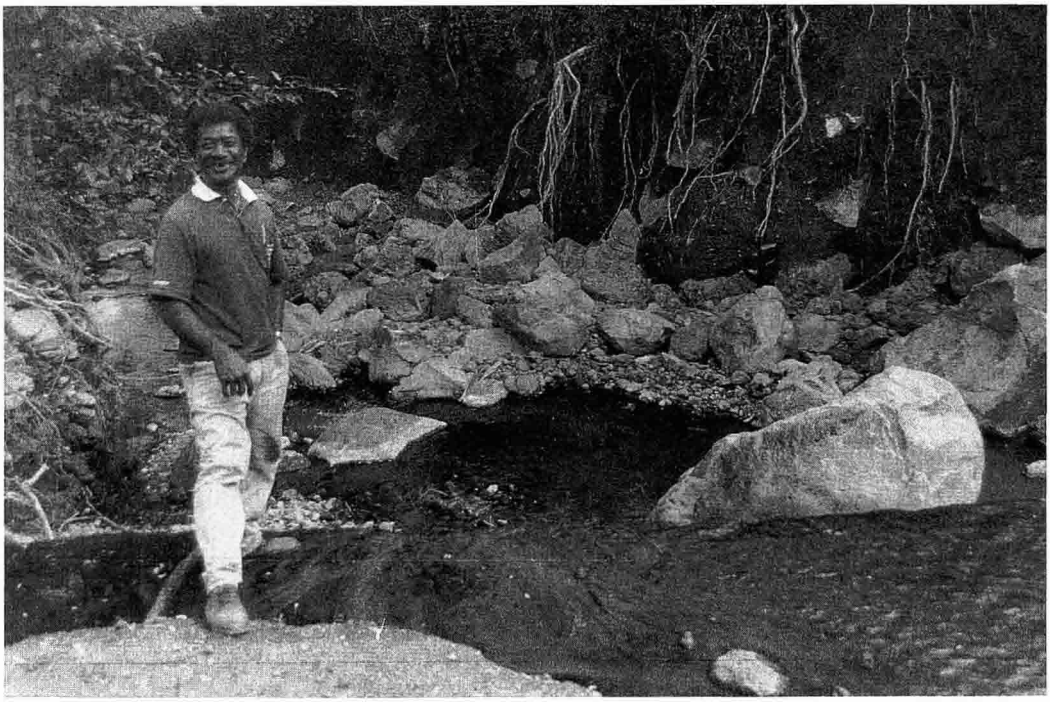

FIGURE 9. Channel erosion and some of the coarse bedload material moved during the flood peak produced by Cyclone June in Somosomo Creek, Taveuni Island.

after Gavin and June, respectively) revealed some fresh mass movements in the remote interior of the island, thought to have been caused by these cyclones.

In the Nausori Highlands (Figure 6) a rockfall from an escarpment face had become a debris slide measuring approximately 70 m in length, and in the Medrausucu Range farther east, a large section of cliff face (> 100 m) appeared very fresh, indicating the possibility of another rockfall. Elsewhere, several shallow translational landslides (with near-surface rather than deep-seated shear planes) had driven paths through the rain forest vegetation. Unfortunately, the slope failures observed were not sufficient to define a link between rainfall receipt and vegetation or land-use type. Overall, however, overflight viewing of interior Viti Levu left the impression that fewer slope failures had occurred than might have been expected if a cyclone were to pass directly over the island (e.g., see Howorth and Prasad 1981).

Some further evidence of landslide activity was available from media reports where large failures caused loss of life, damaged infrastructure, or destroyed human habitations. Potentially the most catastrophic landslide triggered by Cyclone Gavin was that at Nabala Secondary School, Naduri, on Vanua Levu on 7 March. Here a slope failure destroyed a residential dormitory for 65 boys, who were fortunately absent because that day was a public holiday. One elderly woman and a cow were engulfed by the debris. According to observations by personnel of the Fiji Mineral Resources Department, poor drainage on the upper slope led to ponding of water during the heavy rainfall. This initiated a series of rotational slips in deep soil layers in a fault or shear zone of structural weakness. The central rotational slip underwent liquefaction, producing a mudslide that traveled over 50 m downslope and destroyed several school buildings including the boys' dormitory.

Tropical Cyclone June triggered a "massive landslide" (sic) that buried two homes without casualties on the night of 4 May on Kioa Island off the south coast of Vanua Levu (*Fiji Times*, 6 May 1997), but two people were killed by a landslide in the settlement of Sawani, Viti Levu. Outside Suva City, a shallow translational slide 40 m wide in 1.5 to 2 m of highly weathered "soapstone" (Suva Marl) caused part of a main road to collapse (Figure 10) after several days of heavy rainfall in advance of the main cyclone.

Storm Surge and Coastal Inundation

A storm surge may be defined as a "temporary rise in sea level, other than that caused by tides, sometimes resulting in flooding of coastal areas" (Krishna 1984 : 6). Cyclone-induced storm surge is influenced by the very low atmospheric pressure near the center of the storm, which makes the water level rise, and the violent circulating winds that can pile water up against an island coastline. At any given location, the level and duration of storm surge depends on the depth of the horizontal atmospheric pressure gradient across the cyclone eye, the speed and radius of maximum winds, the direction and speed of cyclone movement, the time of landfall of the cyclone in relation to local tides, the shape of the coastline near the point of landfall, and the bathymetry of the nearshore zone.

Long island coastlines with many bays and inlets and a gradually sloping seabed are more vulnerable to surge conditions because there is less opportunity for the surge waters to evacuate around the sides of the island (Krishna 1984). In the Southern Hemisphere the full impact of a surge is experienced to the left of the cyclone track in the direction of approach to an island as a result of the violent onshore winds (Figure 11).

Tropical Cyclone June produced an insignificant storm surge because of its relatively weak intensity and track location in relation to Fiji's main islands. However, Cyclone Gavin had a large storm surge impact, inundating many northern coastal areas. Almost the total length of the north coast of Vanua Levu was affected, with sea walls breached in 10 places (see Figure 12). Water levels are available for the Labasa River near its estuary in Labasa Town (Figure 13) and are compared with barometric pressure measured at Udu Point, 75 km distant on the northeastern peninsula, and Nabouwalu, lying 90 km away on the southwest end of the island.

While Cyclone Gavin was approaching Labasa from the north, offshore winds drove water out of the estuary, giving an exceptionally low tide 2 hr before midnight on 6 March. After the eye of the cyclone had passed the river mouth, however, the cyclone winds were directed onshore and hence retarded outflow during low tide the next day at 1400 hours and gave a surge along the river at high tide at 1900 hours, flooding Labasa Town.

On Viti Levu, storm surge effects were evident along the north coast, causing sea flooding near Rakiraki. At Ba Town, the Ba River first flooded its banks as a result of storm surge around 1530 hours on 7 March (Figure 7), when the eye of the cyclone was in the vicinity of Nadi. It is assumed that the surge traveled upstream, but no records are available to establish the effects and surge levels. A sea level monitoring station at Lautoka wharf, operated by the National Tidal Facility of Flinders University South Australia, recorded a maximum sea level of 2.78 m at 0548 hours on 7 March. This surge is confirmed by a sharp drop in atmospheric pressure at nearby Nadi at the same time.

Because of the extra rise in sea level caused by storm surges, coral reefs that usually afford protection around island coastlines become well submerged at high tide. This can allow the large waves driven by high winds to attack exposed locations, leading to the removal or redistribution of sandy, low reef islands such as cays and motu (Nunn 1994) and the erosion of beach materials. The Yasawa and Mamanuca Islands experienced the full brunt of storm waves and many beaches suffered degradation as a result, although no systematic survey of the damage was conducted.

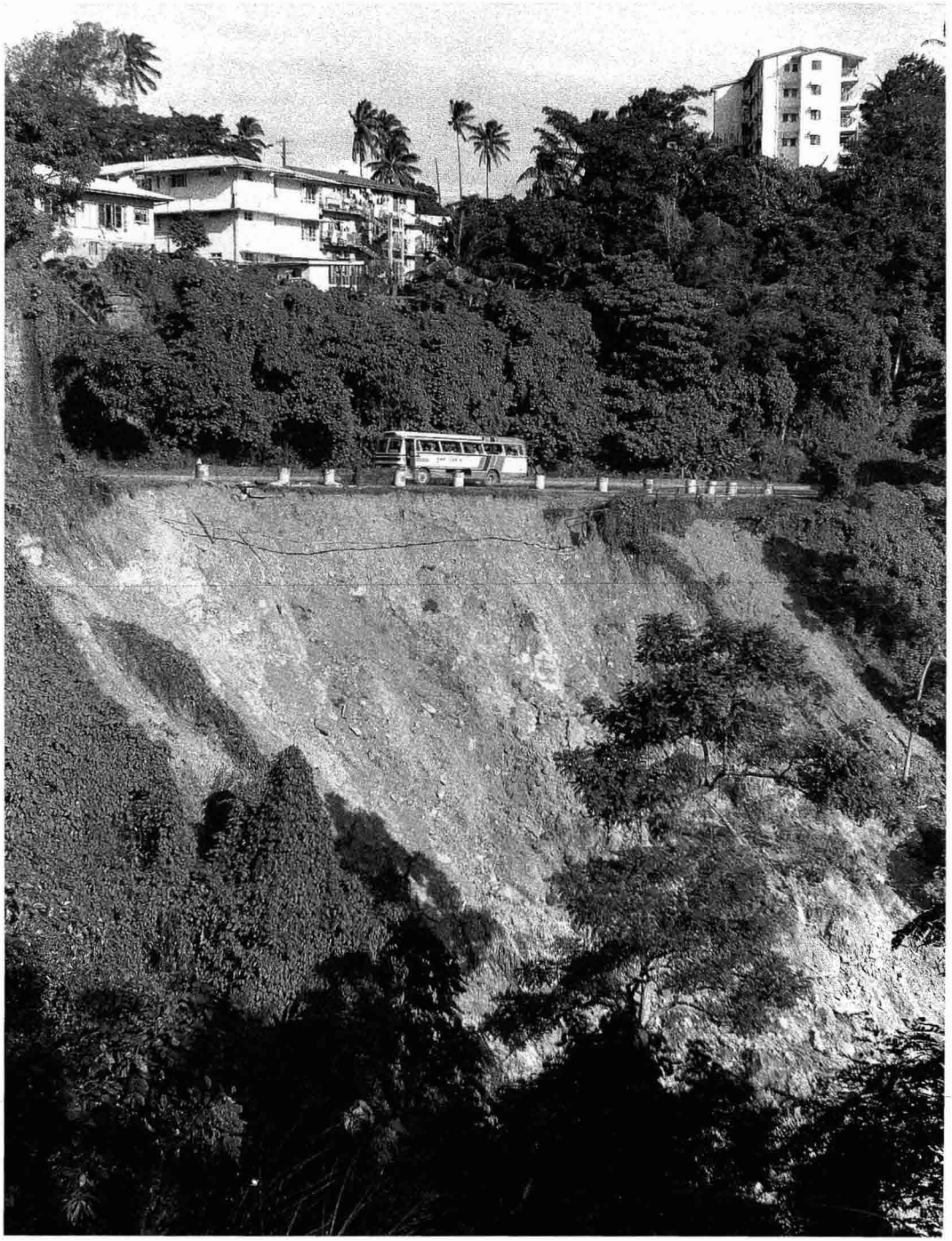

FIGURE 10. A wide, shallow landslide in highly weathered marl along Edinburgh Drive, Suva, triggered by heavy rainfall before Cyclone June. Photo courtesy of the Ministry of Information.

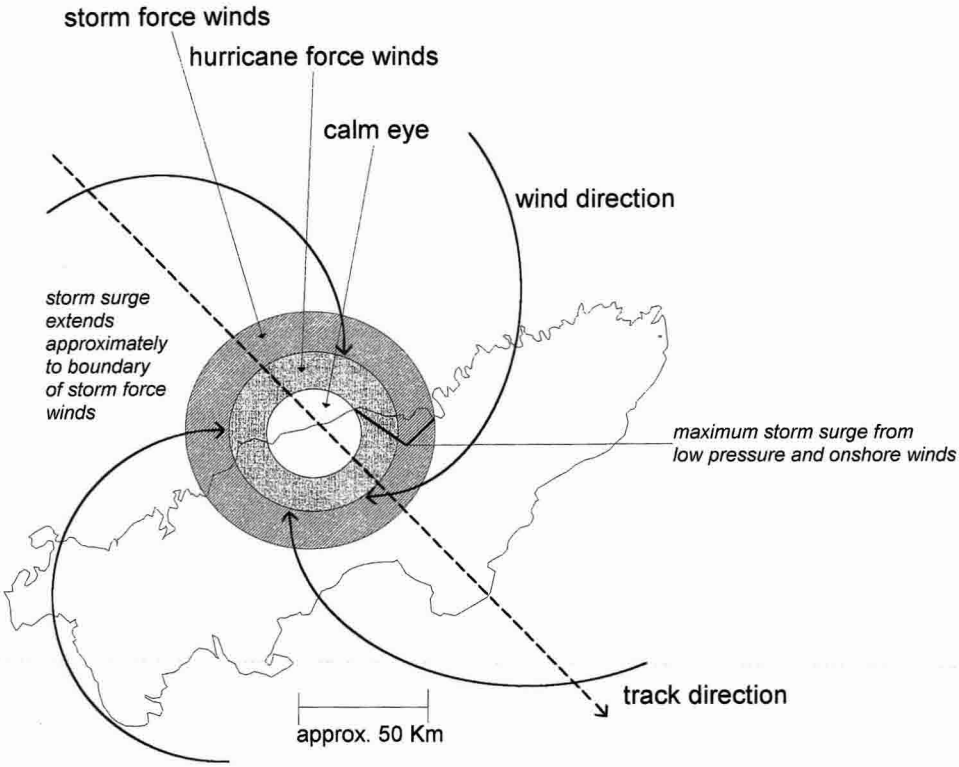

FIGURE 11. Island landfall of an idealized tropical cyclone, indicating the section of coastline that suffers maximum storm surge from the combination of low pressure and violent onshore winds (modified from Krishna 1984).

CONCLUSIONS

By virtue of their location in the southwest Pacific, lying in the belt of warm ocean currents 17° south of the equator, the Fiji Islands are susceptible to the occurrence of tropical cyclones, and by virtue of their physiographic characteristics they are susceptible to attendant environmental changes that cyclones can cause. The high volcanic island interiors cause orographic uplift of cyclonic rain bands, producing intense rainfalls; the deeply weathered clay soils are subject to mass movement on steep slopes; and the major rivers draining the highlands rise rapidly to flood the coastal lowlands. Coastal areas are vulnerable to inundation by storm surge and denudation by wind-driven waves, especially where mangrove vegetation has been cleared.

Of Cyclones Gavin and June in 1997, Gavin was the more intense storm and had a greater effect on the Fiji Islands, but the impacts of June were in places quite severe, especially considering that this cyclone occurred outside the usual wet season. There were contrasting spatial patterns in hillslope failure, river flooding, and coastal inundation by high seas across Fiji's main islands, because of differences in rainfall distribution, wind strength, and storm surge conditions between Gavin and June. This can be attributed to contrasts in cyclone characteristics, especially in terms of longevity, track location, speed and movement behavior, and size and depth of the low pressure eye at the center of the storms.

Despite Fiji's inherent vulnerability to tropical cyclone effects, cyclones should not be considered as catastrophic events in terms of landscape change in the same way as they

FIGURE 12. High seas caused by storm surge associated with Cyclone Gavin spilling over the sea wall at Tabucola on the northern coast of Vanua Levu near Labasa, 1400 hours on 7 March. Photo courtesy of Drainage and Irrigation, Public Works Department.

are regarded as natural disasters for agriculture, infrastructure, and island economies in general. Between 1970 and 1997, 37 tropical cyclones traversed Fiji waters, an average of 13.7 cyclones per decade. On a geomorphological timescale this is a frequent occurrence. Island geomorphology should therefore be thought of as developing in accordance with the regular impact of cyclones such as Gavin and June, which are an integral climatic mechanism for triggering slope failure, drainage network development, river channel modification, cycles of coastal zone erosion and sedimentation, and overall landscape evolution through time.

ACKNOWLEDGMENTS

We extend our appreciation to all those individuals who helped during fieldwork or took the time to send data and information. Special thanks go to the Principal of Nabala Secondary School; Mark Kersemakers and Kafoa Mani at the Fiji Meteorological Service; Rafiq Rahiman, Mr. Singh, and Ioane Duilomaloma of the Hydrology Division of the Public Works Department; Peter Toga and Arieta of the Ministry of Information; Poasa Ravea of the Regional Planning Department; the Flinders National Tidal Facility in Adelaide; and librarians at the *Fiji Times*. Photographs were produced by Willie Chung and Stella of the USP Media Unit unless otherwise stated. Illustrations were drawn by Savitri Karunairetnam under the direction of James Britton and George Saemane of the USP GIS Unit. Professor Paddy Nunn is thanked for his useful comments on the draft manuscript. The University of the South Pacific is gratefully acknowledged for providing financial support.

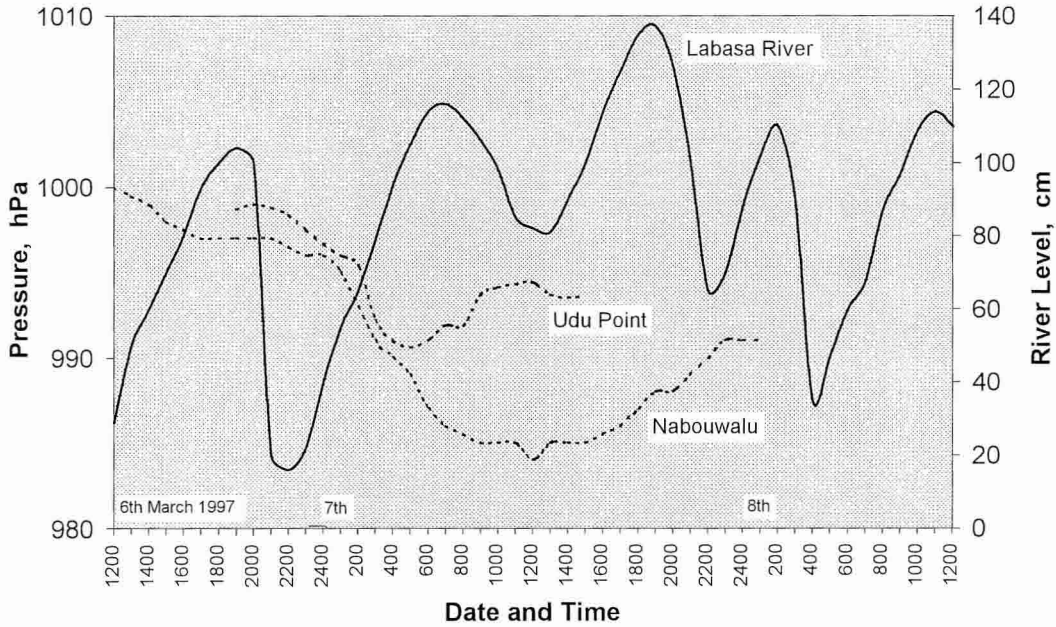

FIGURE 13. Water level in the estuary of the Labasa River at Labasa Town and corresponding barometric pressure at Udu Point and Nabouwalu on the northeast and southwestern ends of Vanua Levu (75 km and 90 km distant, respectively) during Cyclone Gavin; maximum storm surge occurred around 1900 hours on 7 March.

LITERATURE CITED

CROZIER, M. J., R. HOWORTH, and I. J. GRANT. 1981. Landslide activity during Cyclone Wally, Fiji: A case study of Wainitubatolu catchment. Pac. Viewpoint, 22 (1): 69–88.

FIJI METEOROLOGICAL SERVICE. 1997a. Preliminary report on Tropical Cyclone Gavin, 4–11 March 1997. 4 pp.

———. 1997b. Preliminary report on Tropical Cyclone June, 3–5 May 1997. 5 pp.

———. 1997c. Tropical Cyclone June. Tropical Cyclone Report 97/2.

———. 1997d. Monthly weather summary for Fiji—March 1997. No. 55/2. 4 pp.

———. 1997e. Monthly weather summary for Fiji—May 1997. No. 55/2. 4 pp.

HOWORTH, R., and S. PRASAD. 1981. Morphology of typical landslides which occurred Good Friday 1980 in the Serua Hills, Viti Levu, Fiji. Mineral Resources Department, Report No. 28. 29 pp.

HOWORTH, R., M. J. CROZIER, and I. J. GRANT. 1981. Effects of Tropical Cyclone Wally in southeast Viti Levu, Fiji, Easter 1980. Search (Syd.) 12:41–43.

KRISHNA, R. 1984. Tropical cyclones. Fiji Meteorological Service, Publication No. 4.

NUNN, P. D. 1994. Oceanic islands. Blackwell, Oxford, U.K. 413 pp.

RODDA, P. 1990. Rate of movement of meanders along the lower Wainimala, and heights of alluvial terraces. Mineral Resources Department, Note BP1/85. 15 pp.