A.1

Soasoa Integrated Watershed Management Plan

Historic Flood Report

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JBP scientists and engineers

Pacific Community
Communauté du Pacifique

Contract

This report describes work commissioned by Patrick Fong of EcoPacifika Consulting, on behalf of SPC. Ellie Vahidi, William Prentice and Daniel Rodger of JBP, together with Patrick Fong of Eco-Pasifika Consulting carried out this work.

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Purpose

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The methodology adopted and the sources of information used by JBP in providing its services are outlined in this report. The work described in this report was undertaken between October 2020 to December 2021 and is based on the conditions encountered and the information available during this period of time. The scope of this report and the services are accordingly factually limited by these circumstances.

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Executive Summary

This historic mapping report for the Soasoa catchment, Fiji, has been undertaken by JBPacific, in conjunction with Eco Pasifika, on behalf of the Pacific Community (SPC).

SPC and the Ministry of Waterways and Environment (MoWE) is planning to enhance the resilience of vulnerable coastal communities in Fiji to climate change and natural hazards. This will be achieved by scaling up of drainage and coastal protection infrastructure with integration of community and ecosystem-based adaptation. This project will prepare an Integrated Catchment management Plan for the Soasoa catchment, located within the Macuata Province, on the northern coastline of Vanua Levu. Historic flood mapping will help support these goals, which can be used to plan new drainage improvements and catchment management actions

Historic flood mapping has been undertaken for the historical TC Victor (2016) and TC Keni (2018) events. The mapping shows that the lower reaches of the catchment are more vulnerable to flooding, which can inundate transport links, government assets and private properties. The upper reaches of the catchment are less prone to flooding, however given the high velocities may be prone to scour and erosion.

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Abbreviations

AWS .... Automatic Weather Station
BoM .... Bureau of Meteorology
JBP .... Jeremy Benn Pacific or JBPacific
MoWE .... Ministry of Waterways and Environment
PCRAFI .... Pacific Catastrophe Risk Assessment and Financing Initiative
SPC .... The Pacific Community

1 Introduction

1.1 General

This historic mapping report for the Soasoa catchment, Fiji, has been undertaken by JBPacific, in conjunction with Eco Pasifika Consulting, on behalf of The Pacific Community (SPC).

The Republic of Fiji includes over 320 Islands. Fiji is second only to Papua New Guinea as the Pacific island country having been most affected by natural disasters since 1990[1]. It experiences experience a range of extreme weather, from cyclones, monsoons, rainfall, flooding and coastal surges. Integrated infrastructure upgrades, disaster management and catchment management is seen as an increasingly important step to support local economic activity, to promote and enhance biodiversity, and increase resilience to extreme weather.

The key natural hazards effecting Fiji are due to tropical cyclones and extreme weather. These events lead to extreme rainfall, riverine flooding, storm surges and coastal flooding. These effect a range of economic sectors, public infrastructure, coastal settlements, and tourist facilities, which can be located in flood-prone catchments of in low-lying coastal areas.

SPC and the Ministry of Waterways and Environment (MoWE) is planning to enhance the resilience of vulnerable coastal communities in Fiji to climate change and natural hazards. This will be achieved by scaling up of drainage and coastal protection infrastructure with integration of community and ecosystem-based adaptation. This project will prepare an Integrated Catchment management Plan for the Soasoa catchment, located within the Macuata Province, on the northern coastline of Vanua Levu. Historic flood mapping will help support these goals, which can be used to plan new drainage improvements and catchment management actions.

1.2 Objectives

Key objectives of this report are:

- Present a desktop review of technical reports, published articles, and policies
- Present the information gained from rapid site inspections
- Undertake hydrologic analysis of catchment to define the river inflow characteristics for historic flood events
- Establish a hydraulic flood model for the study area to determine flood hydraulic behaviour.
- Prepare flood mapping for historic flood events.

1.3 Structure of the report

In addition to this introductory chapter, this report contains the following:

- **Section 2:** Background information on the study area and site inspections
- **Section 3:** Available data
- **Section 4:** Flood modelling
- **Appendix A:** Flood maps

1 ADB (2005) “Fiji Islands: Country Environmental Analysis”, Asian Development Bank.

2 Background on the study area and site inspections

The Soasoa catchment is located within the Macuata Province, on the northern coastline of Vanua Levu. The catchment forms part of a major three-river estuary system, which includes the Labasa, Qawa and Wailevu rivers, which converge and discharge into the ocean. It has a relatively small catchment area, around $20km^2$, with steep upper regions (see Figure 2-1). The steep upper catchments include some of the highest mountains on the island, and face into the common north-westerly cyclone direction. This topography creates exceptional orographic rainfalls, which are rapidly converted into runoff (Terry & Raj 1999)[2]. During flood conditions extreme runoff can merge within the lower catchment, which has flat alluvial terraces and wider floodplains.

Figure 2-1: Study area

2.1 Climatology and hydrology

Fiji is second only to Papua New Guinea as the Pacific island country most affected by natural disasters since 1990 (ADB 2005). This is due to the range of extreme weather phenomenon that occur throughout the islands, which includes tropical cyclones, monsoons, extreme rainfall, flooding and coastal surges.

2.1.1 Cyclones

Analysis of the historic cyclone tracks show 40 tropical cyclones have passed through Fiji waters between 1969 to 2018, each with the potential to make landfall (See Figure 2-2, based on BoM 2020)[3]. Coinciding with the threat of tropical cyclones during the Fiji wet season, which falls between November to April. Flooding due to heavy rain typically occurs between January to March and can be exacerbated by tropical cyclone precipitation. Significant floods occurred in Labasa district in 1929, 1938, 1950, 1986, 1988, 1997, 1998, 2000, 2003, 2007, 2009, 2016, 2018 and 2020.

2 Terry, J., and Raj, R. (1999) Island Environment and Landscape Responses to 1997 Tropical Cyclones in Fiji. Pacific Science 53, 257–272.

3 BoM (2020) "Southern Hemisphere Tropical Cyclone Data Portal". Accessed on 20 Oct 2020 from: http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/history/tracks/.

2.1.2 Precipitation and flooding

A range of historic and recent flood events are described in Table 2-1, with several images shown in Figure 2-2. These include investigations undertaken by McGee (2010) [4], which has been supplemented by recent data.

Prior to Tc Yasa, which occurred during development of this study, the most extreme flooding within the region is believed to be during TC Ami, which made landfall in January 2003. During this event, the three rivers surrounding the Soasoa catchment produced record-breaking flows, which coincided with a cyclone-generated storm surge, and caused widespread inundation. The peak discharge for the Labasa River was estimated by the Hydrology Division of the Fiji Public Works Department soon after flood waters receded.

Table 2-1: Flood events in Labasa district (adopted from McGree et al 2010)

Date of Peak	Reason for High Rainfall	Flood Description and Areas Affected
1929 Dec 11-12	Hurricane	Qawa River flood peak 3 ft (0.9m) above 1912 peak at Labasa Mill
1938 Dec 22	Cyclone	Qawa River rose 4.5 ft (1.4m) above high tide level
1950 Mar 30	Moderate storm	Significant flood damage in Wainikoro and Bucaisau districts; flood 2 ft (0.6m) over Wainikoro office floor.
1986 Dec 28-30	Hurricane	Labasa River experienced worst flood since 1929, Labasa town's main street under 1m of water for the first time since 1929
1988 Feb 25	Hurricane	Flooding in the area
1997	TC Gavin	Extensive flooding of Labasa town (McInnes et al. 2014).
1998 Dec 24-25	Hurricane	Flooding in Labasa and Northwestern Viti Levu
2000 Apr 14-15	TC Neil	Flood peak in Qawa River estimated 'major' since Labasa Mill flooded, possibly highest event there in 50 years
2003 Jan 14	TC Ami	Strong storm surge along northern coast of Vanua Levu, combined with severe river floods, led to record flooding at Labasa
2007 Mar 9-14	Low pressure trough, leading to heavy rainfall received in the northern and western parts of Fiji.	The Qawa River burst its banks at about 5pm on 10th.
2009 Feb 20	Trough moved eastward than retrogressed across the country between 18th and 24th.	Flash flooding due to heavy local rain and blocked drains.
2018	TC Keni	Roads closed due to flooding in Macuata (see Figure 2-2)
April 2020	TC Harold	Roads closed due to flooding in Macuata. Wider impacts included F$100 million of damage across Fiji (FBC 2020)

4 McGree, S., Yeo, S. W., & Devi, S. (2010). Flooding in the Fiji Islands between 1840 and 2009. Risk Frontiers.

Flooding in Labasa during TC Ami (2003)

Flooding in Labasa during TC Ami (2003)

BoM Tropical Cyclone Portal showing historic tracks

Soasoa flats flooding during Cyclone Keni 2018

Figure 2-2: Flood images for various TC and rainfall events

2.1.3 Site inspection

Rapid site inspections were undertaken in October 2020 to review catchment conditions. Site images are shown in Figure 2-3 to Figure 2-5. These inspections identified the flood levee and gate structures in the lower catchment to be important for flood mapping. Detailed structure information has been requested for use in this project, however, this information is not available at the time of this report. Should this information be made available it is recommended to be incorporated into the flood model.

Figure 2-3: Upper Soasoa catchment (Source: Patrick Fong 2020)

Figure 2-4: Lower Soasoa catchment (Source: Patrick Fong 2020)

Figure 2-5: Levee and flood infrastructure at lower catchment (Source: Patrick Fong 2020)

2.2 Flood infrastructure

Number of drainage and flood management actions have been undertaken within the catchment. In the late of 1970s a series of levees and floodgates constructed to protect reclaimed areas in the lower catchment. These operated relatively well until the last decade, when a reduction in performance was observed, considered due to an increased frequency of short-lived extreme rainfall events and the effect of sea level rise (GCCAPlus, 2020)[5]. Structural measures introduced in 1980's include dredging rivers and constructing seawalls.

5 GCCAPlus. (2020). The Global Climate Change Alliance Plus – Scaling up Pacific Adaptation (GCCA+ SUPA) Project. Access date: 18/06/2020, from http://ccprojects.gsd.spc.int/gccasupa/.

3 Available data

3.1.1 Rainfall data

Rainfall data was provided by the Hydrology Unit of the Fiji Department of Meteorology (Fiji Met). There is no gauging station in the proximity of Soasoa drainage area, therefore the gauging records of Labasa Automatic Weather Station (AWS) was used (see Figure 3-1). AWS data provided by Fiji Met was limited to two data series.

- Daily rainfall data from 1959 to 2003 year at Labasa DE, Vatunibale
- Hourly rainfall data from 2016 to 2020 year at Labasa AWS.

Figure 3-1: Closest Automatic Weather Station to the Soasoa catchment

3.2 Topographic data

Topographic data for the catchment is variable, with only the Shuttle Radar Topography Mission (SRTM) 1 second (~30m grid resolution) topographic data available consistently across the catchment. The data is limited to integer values (1m, 2m, 3m etc), which limits its performance near coastline, where small variations in elevation may change flood results. However, in the absence of more detailed elevation data, the SRTM 1 second data was used as the basis in this study.

The elevation datum has been assumed as Above Sea Level (ASL). A degree of uncertainty exists within the SRTM datum. Digital Elevation Models are often referenced to a global model of the geoid – a model of global mean sea level. Analysis of the observed height difference between the geoid and local definitions of mean sea level varies in the order of ±1.0m across the globe. Typically, coastal or flood inundation studies neglect to correct for this misalignment, and as such may significantly under or overestimate the magnitude (depth and extent) of inundation when calculated by numerical modelling. This is especially important for low lying islands such as the Soasoa catchment, where an error in the absolute vertical reference between sea levels and terrain will significantly affect the validity of the calculated hazard. This error, when propagated to the risk and economic calculations can cause significantly misleading outputs. This may be corrected through analysis of local survey information, or engaging new topographic survey within the catchment, both of which is not within the current scope of this project.

3.3 Tide information

The main river in Soasoa drainage catchment is Nababuabua Creek, which discharges into the intertidal mangrove area. Due to lack of data and measurements in this area, the tidal range was estimated based on studies undertaken for the Labasa River for the Labasa Bypass Project (3SProspect, 2020[6]). This study referenced the maximum tidal range for the Labasa River, which based on the reading from the Labasa Civic Centre Gauge. The maximum tidal range was found to be up to 1.8 m above sea level (ASL).

3.4 Storm surges

Extreme sea levels were estimated for Fiji by McInnes et al (2000)[7], which included statistical analysis and modelling to estimate cyclone-induced storm surges for a range of return periods without wave effects. Table 3-1 shows the estimated extreme sea levels. Whilst not specifically stated, this is assumed to be reported to a mean sea level datum (ASL).

Table 3-1: Extreme sea levels at Labasa (McInnes et al 2014)

Return period	Level
20-year	0.91
50-year	1.16
100-year	1.32
200-year	1.46
500-year	1.60
1000-year	1.68

6 3SProspect (2020) 1D-2D Flood modelling for the Labasa By Pass Project. Prepared for Fiji Roads Authority, Revision 1 – Date-27/07/2020 by K. Wyborn.

7 McInnes K., Walsh K., Hoeke R., O'Grady J., Colberg F., Hubbert G. (2000) Quantifying storm tide risk in Fiji due to climate variability and change. CAWCR Centre for Australian Weather and Climate Research, CSIRO Marine and Atmospheric Research, Aspendale 3195, Australia

4 Flood modelling

Watershed mapping, rainfall analysis and flood modelling was undertaken to produce historic flood maps.

4.1 Watershed mapping

Catchment analysis and hydrological modelling was undertaken to understand how runoff flows through the catchment. Catchment delineation has been undertaken using the SRTM 1 second (~30m grid resolution). It was used to determine the Soasoa catchment, which was split into 18 discrete watersheds. All subcatchments were analysed to identify key statistics, including hill slope, catchment slope, flow route, stream network, gradient and catchment area. The drainage basin area was found to be 17.5 km^2, with steep upper regions with a hill slope gradient of 0.24, and a flat lower channel with a 0.12 gradient.

Table 4-1: Sub-catchment parameters

Number of sub-catchments	Maximum sub-catchment area (ha)	Minimum sub-catchment area (ha)	Average sub-catchment area (ha)
18	212	48	102

Figure 4-1: Soasoa subcatchment delineation

4.2 Design rainfall estimation

A frequency analysis was applied to the 50 years of annual maximum daily rainfall provided by Fiji Met, which was used to estimate design rainfall for the standard return periods. The design rainfall was obtained based on the Annual Maxima Series, using the Generalised Extreme Value (GEV) fitted by probability weighted moments (see Figure 4-2). A summary of the design maximum daily rainfall for a range of return periods are provided in Table 4-2. For design flood modelling, temporal patterns have been based on TC Keni, which produced a worst flooding in the catchment.

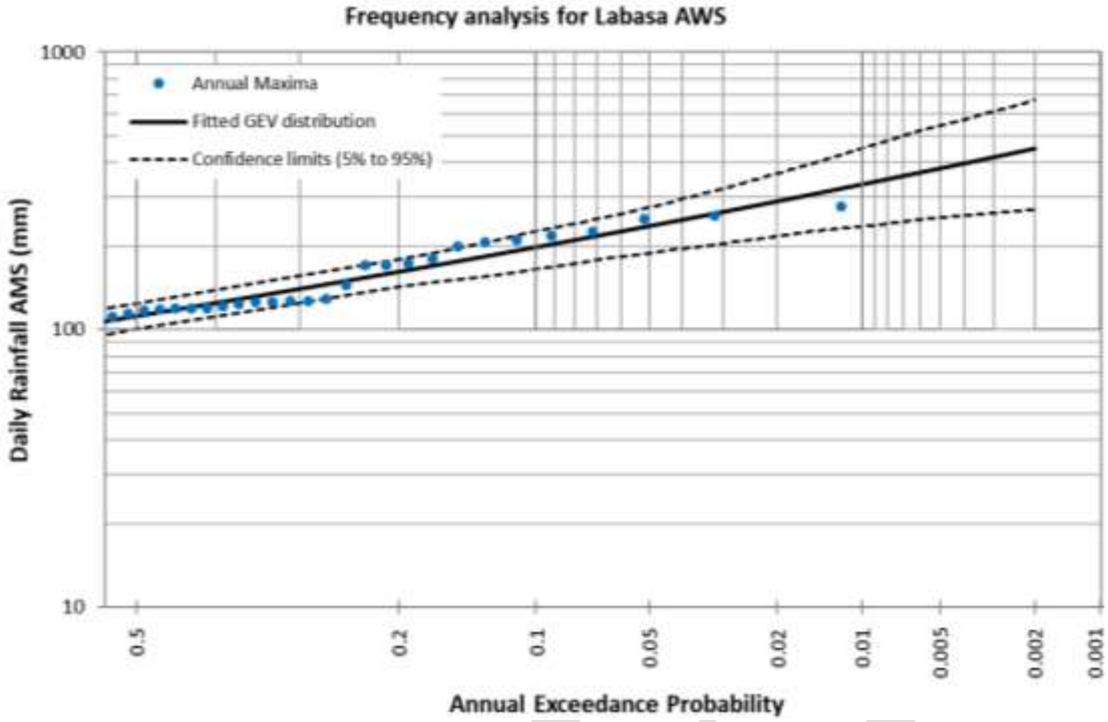

Figure 4-2: GEV L-Moments analysis of historical annual maxima series at Labasa AWS

Table 4-2: Extreme daily rainfall estimates at Labasa AWS

Design event (year ARI)	Design daily rainfall (mm)
1	63.9
5	162.2
10	198.9
50	290.8
100	321.4
200	382.1
500	450.2

4.3 Historic rainfall analysis

Historical flood mapping was undertaken for events where hourly rainfall records were provided by Fiji Met (which spanned 2016 to 2020). The two most significant events selected within this data set were TC Victor (2016) and TC Keni (2018). Their daily rainfall totals were compared against the design return periods shown in Table 4-2 to estimate their magnitude in terms of Average Return Interval (ARI):

- 2016 (TC Victor) - 170 mm maximum daily rainfall: ~5 year ARI
- 2018 (TC Keni) - 226 mm maximum daily rainfall: ~20 year ARI

Rainfall hyetographs for these events are shown in Figure 4-3.

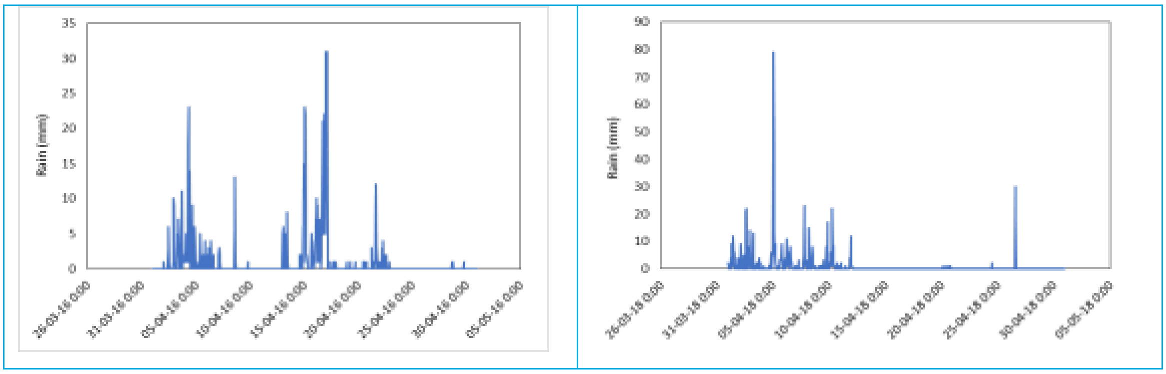

Figure 4-3: Rainfall hyetographs for TC Victor (left) and TC Keni (right)

4.4 Flood modelling

The TUFLOW hydrodynamic software was used to develop a two-dimensional (2D) hydraulic model over the full study area. This was as an appropriate approach due to the absence of detail topographic data to model 1D channels. TUFLOW is an industry-standard flood modelling platform, which was selected for this assessment. The model was developed and ran using TUFLOW 2018-03-AE-iDP-w64 version and TUFLOW "Classic" computation scheme were selected for the study.

4.4.1 Configuration of Hydraulic Model

4.4.1.1 Spatial configuration and grid cell size

The model covers an area of 18.8 km^2 of the catchment. The downstream boundary has been established at the outlet of Qawa River, where flood infrastructure has been observed (See Figure 2-5). The 2D modelling domain has a 10m grid resolution (i.e. it uses 10m x 10m cells), which reflects the catchment topography, with overland flow roughness based on land use. Watercourses were represented in model domain using lowered grid cells connecting lowest ground elevations along the watercourse. The model domain is shown in Figure 4-4.

Figure 4-4: TUFLOW model configuration

4.4.1.2 Model Topography

The digital terrain model is based on the global SRTM data (see Section 3.2). The topography ranges from 540m in the north of the model domain, to approximately 1m to the south west of the site near the downstream boundary. The town levee was defined using breaklines, which was cut from the SRTM as a raised levee.

4.4.1.3 Surface Hydraulic Roughness

All parts of the study area within the TUFLOW model were assigned hydraulic roughness (Manning's n) values in the TUFLOW material file according to the river form, floodplain land use and ground cover. Model roughness was defined using the Fiji spatial dataset obtained from PCRAFI. The adopted Manning's n values are based on widely-used parameters from literature (Chow, 1959),which are shown in Figure 4-5 and summarised in Table 4-3.

Table 4-3. TUFLOW model hydraulic roughness values

Material	Manning n value
River channel, watercourse, ocean bed	0.025-0.035
Floodplain	0.035
Light vegetation	0.06
Medium density vegetation	0.08
Heavy vegetation and mangroves	0.12
Grass areas	0.03
Buildings	1

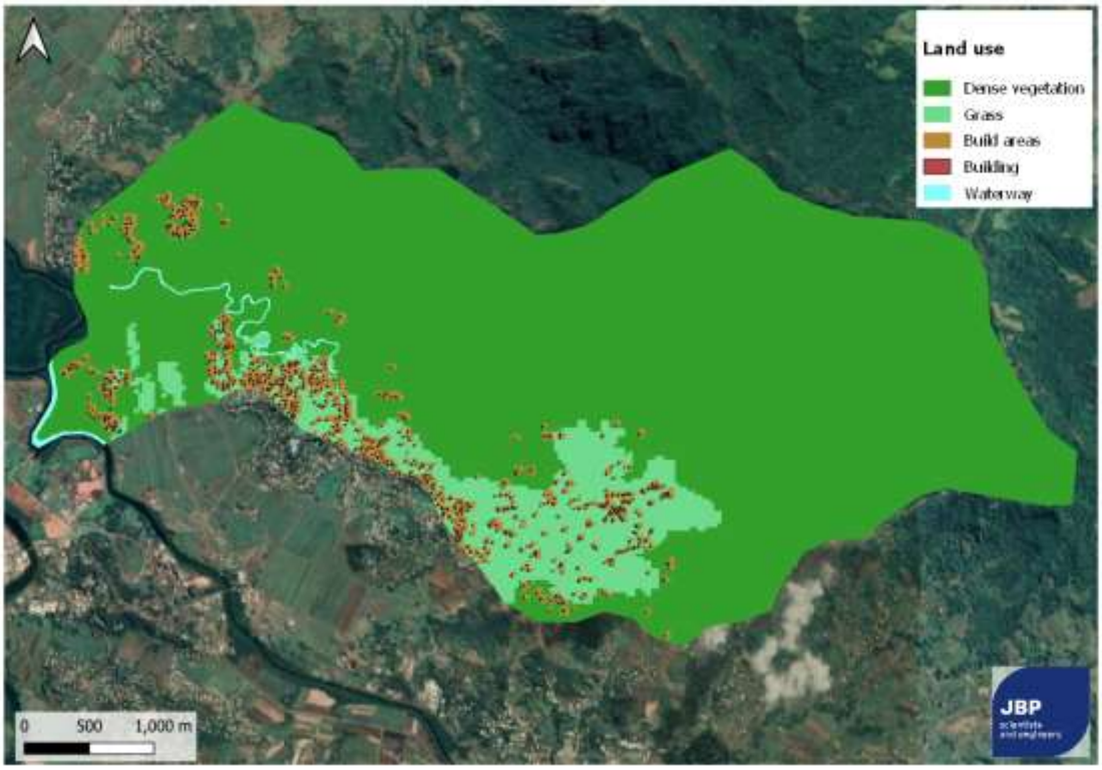

Figure 4-5: TUFLOW land use

4.4.2 Model Boundaries

4.4.2.1 Inflow Hydrographs

A rainfall hyetograph was applied for each sub-catchment area for historical (2016 and 2018) and design (100-year ARI) rainfall events. Knowing the sub-catchment area, initial and continuous losses values, the inflow hydrograph was estimated for each river branches in the Soasoa catchment area using TUFLOW model. The initial loss (IL) was estimated based on the empirical relationship between the initial loss and potential maximum retention (S) developed by Soil Conservation Service (SCS). The maximum retention is related to the curve number, CN. The CN for a watershed can be estimated as a function of land use, soil type, and antecedent watershed moisture, using tables published by the SCS. The CN value in this study was defined based on the recent flood modelling study for Labasa (3SProspect, 2020) as 81.5. The zero continuing loss was considered as a most conservative scenario.

4.4.2.2 Outflow Boundaries

The Labasa River is tidal up to 3 km inland (3SProspect, 2020). The Nababuabua Creek outlet is located in 1.4 km distance from the Labasa River, therefore, it is a logical to state similar to Labasa River. The downstream boundary of Nababuabua Creek is believed to be controlled by the flood infrastructure observed in Figure 2-5. This will influence the downstream flood levels, and is important for flood mapping. Detailed structure information has been requested for use in this project, however was not provided. Should this information be made available it is recommended to be incorporated into the flood model.

Given the conflicting information on tidal range (up to 1.8m ASL - see Section 3.3), extreme sea levels (up to 1.68m ASL for a 1000-year event - see Section 3.4) and the unknown influence of this flood infrastructure, a constant downstream sea level of 2m has been applied as a conservative estimate.

4.5 Historical flood results and mapping

Figure 4-6 and Figure 4-7 show flood mapping for the historical TC Victor (2016) and TC Keni (2018) events. Full details are shown in Appendix A, which includes information on depth, water level and velocity.

Due to limited historical data and images of flood extent, the model calibration for the two historical events was not possible. As discussed throughout this report, flood levels will be influenced by the flood infrastructure observed within the bottom of the catchment, which could not be incorporated within the model due to a lack of data. Should this information be made available it is recommended to be added into the flood model.

The flood extent for the two historical events shows that the lower reaches of the Nababuabua Creek are more vulnerable to flooding. Flooding in this area can inundate transport links, government assets and private properties. The upper reaches of the catchment are less prone to flooding, however given the high velocities may be prone to scour and erosion (see Appendix A).

Figure 4-6: Flood depth in 2016 event (TC Victor)

Figure 4-7: Flood depth in 2018 event (TC Keni)

5 Discussion

This historic mapping report for the Soasoa catchment, Fiji, has been undertaken by JBPacific, in conjunction with Eco Pasifika Consulting, on behalf of The Pacific Community (SPC).

In order to enhance the resilience of vulnerable coastal communities in Fiji to climate change and natural hazards, a new flood study was carried out in Soasoa catchment, Macuata Province. The historic flood mapping can be used to plan new drainage improvements and catchment management actions.

Historic flood mapping has been undertaken for the historical TC Victor (2016) and TC Keni (2018) events. The mapping shows that the lower reaches of the catchment are more vulnerable to flooding than the upper reaches, which can inundate transport links, government assets and private properties. The upper reaches of the catchment are more prone to scour and erosion due to high velocities areas.

5.1 Limitations

Due to limited historical data and images of flood extent, model calibration was not possible. Flood mapping has been based on 30m SRTM elevation data only. No detailed survey was provided for the catchment. During site inspections flood infrastructure was identified in the lower catchment which is believed to influence tides, coastal surges, and flood levels. However, no information could be provided for the structures, and they could not be incorporated into the model. Uncertainty exists within the downstream tide and storm surge levels, with different sources quoting a range of levels. Uncertainty within the Local Vertical Elevation Datum, which will influence sea level estimates and coastal flood extents.

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