FIJICLIM
Description and Users Guide

Prepared for PICCAP Fiji

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PART 1: FIJICLIM System Description

1 Introduction

The FIJICLIM prototype is based on PACCLIM which was developed by the International Global Change Institute (IGCI) as part of the Pacific Islands Climate Change Assistance Programme (PICCAP) executed by the South Pacific Regional Environment Programme (SPREP).

Both FIJICLIM and PACCLIM build directly on a comparable model development for New Zealand, known as the CLIMPACTS system (Kenny *et al.,* 1995, 1999; Warrick *et al.,* 1996, 1999). The development of CLIMPACTS has been funded by the Foundation for Research Science and Technology since 1993. Its core components, which include a graphic user interface (GUI), a customised geographic information system (GIS), and data compression routines, have provided the basis for the development of FIJICLIM. The development of FIJICLIM is complementary to similar developments that have evolved from CLIMPACTS, for Bangladesh (BDCLIM), Australia (OZCLIM), and for training in climate change V&A assessment (VANDACLIM).

There are a number of distinct advantages to country-scale IAMs:

- They integrate together relevant biophysical information, including both models and data, in a form that is readily accessible to both scientists and policy-makers alike;
- They provide the capacity for consistent application, at the country scale, of user-specified scenarios of climate and sea-level change across a range of sectors;
- By integrating relevant biophysical information and climate change scenarios, they provide the capacity for multiple simulations of climate change impacts in order to examine scientific uncertainties and alternative policy options;
- They are generally easy to use, quick running and, perhaps most importantly, can be readily updated and expanded.

2 Overview of FIJICLIM

The development of FIJICLIM has involved the linking of historical climate data and a scenario generator with sectoral impact models for four key sectors: agriculture, coastal zone, human health, water resources.

FIJICLIM comprises two main components:

- **a scenario generator** which links together historical climate data (temperature and rainfall), patterns of climate change from complex global climate models (GCMs), and output from a global temperature and sea-level change model, called MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change; Wigley, 1994);
- **sectoral models** for agriculture, coastal zone, human health and water resources.

A schematic representation of FIJICLIM is given in Figure 1, which shows the connections between these main components.

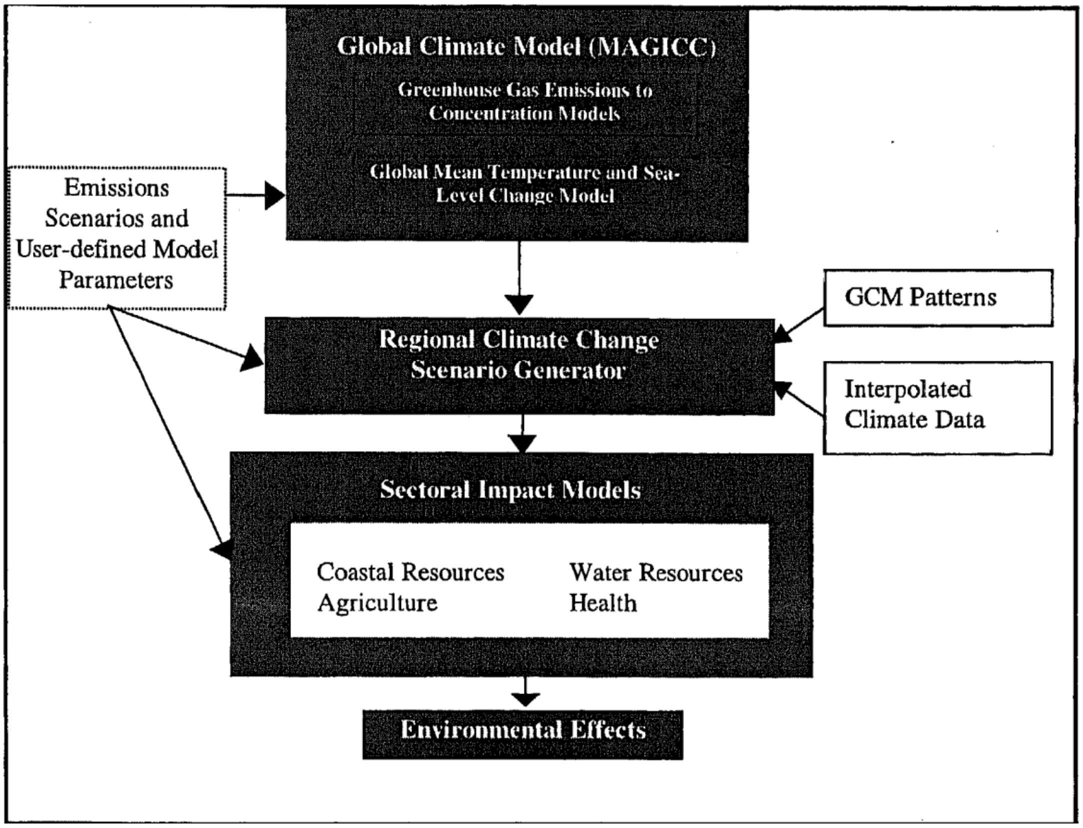

Figure 1: Schematic representation of the FIJICLIM model system

3 Overview of FIJICLIM Scenario Generator

The FIJICLIM Scenario Generator has been developed as a tool to generate scenarios of climate and sea-level change at the country scale using the best available global information.

The main components of the FIJICLIM Scenario Generator are:

1. **Library files** of output from a global temperature and sea-level change model, called MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change; Wigley, 1994);

2. **Patterns of temperature and rainfall change** for the western Pacific, derived from general circulation models (GCMs);

3. Interpolated monthly **climate data** (temperature and rainfall) for Viti Levu.

The scenario generator provides the capacity for generating two types of climate change scenario: **synthetic** and **model-based.**

- The **synthetic scenario** generator enables users to make incremental adjustments to temperature (change in °C) and rainfall (plus or minus percent change). These adjustments are applied uniformly to the baseline climate data.

- The **model-based** generator presently uses the **linked-model** approach. There are two components to this approach. At the "top end" are library files of output from a simple global climate model, called MAGICC[1] (Wigley, 1994) which provide global temperature and sea-level changes. The global temperature changes from MAGICC are used to *scale* temperature and rainfall patterns of change for the western Pacific as projected by complex global climate models (GCMs). These components, and their application, are described in detail below.

A schematic representation of the FIJICLIM Scenario Generator is given in Figure 2, and shows the connections between these three main components.

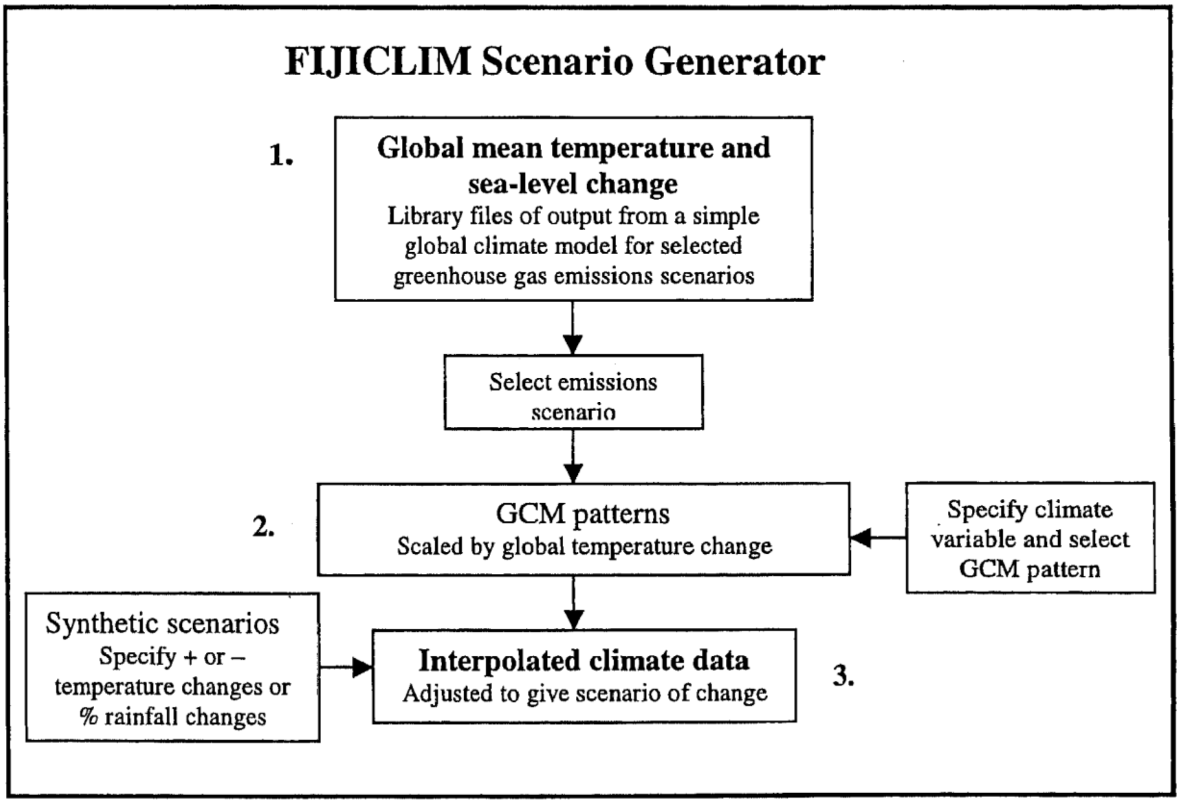

Figure 2: **Schematic representation of the FIJICLIM Scenario Generator and its main components**

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[1] Earlier versions of this model, developed at the Climatic Research Unit, University of East Anglia, UK, were used to make global temperature and sea-level projections for the Intergovernmental Panel on Climate Change (IPCC) 1990 and 1995 reports.

3.1 Library files of output from a simple global climate model

As mentioned above, a simple global climate model, MAGICC (Wigley, 1994) has been used to generate global temperature and sea-level changes. These results are incorporated into FIJICLIM.

The core of MAGICC is a one-dimensional, energy-balance, box-diffusion-upwelling climate model. The inputs to MAGICC are emissions of greenhouse gases, and the outputs are global-mean temperature (and sea-level) changes, given in 5-year increments from 1990 to 2100. It can quickly generate time-dependent global temperature changes for user-selected scenarios of greenhouse-gas (GHG) emissions. The science on which MAGICC is based is continually being advanced, and hence MAGICC is regularly updated. Additionally, scenarios of greenhouse-gas (GHG) emissions can be updated to take account of evolving international policies on emissions. MAGICC is described in more detail by Wigley (1994).

The FIJICLIM Scenario Generator contains library files of output generated from two sets of GHG emissions scenarios:

1) The Intergovernmental Panel on Climate Change (IPCC) 1995 policy scenarios (Houghton *et al.*, 1996), known *as* the IS92a,b,c,d,e scenarios;
2) The SRES marker scenarios (Al, A2, B1, B2), which are new (unapproved) scenarios developed for the IPCC, for use in the IPCC Third Assessment Report, due to be published in 2000. Details on these scenarios can be obtained from http://srec.ciesin.org/.

The example in Figure 3 shows the stored output from the IS92a. GHG emissions scenario, showing the high, medium and low estimates of global temperature change from 1990 to 2100. These estimates relate to the range of *climate sensitivity* (the average global temperature change for an equivalent doubling of atmospheric CO_2) generated from complex GCMs. Specifically, the high, medium and low estimates relate to climate sensitivities of 4.5°C, 2.5°C, and 1.5°C respectively.

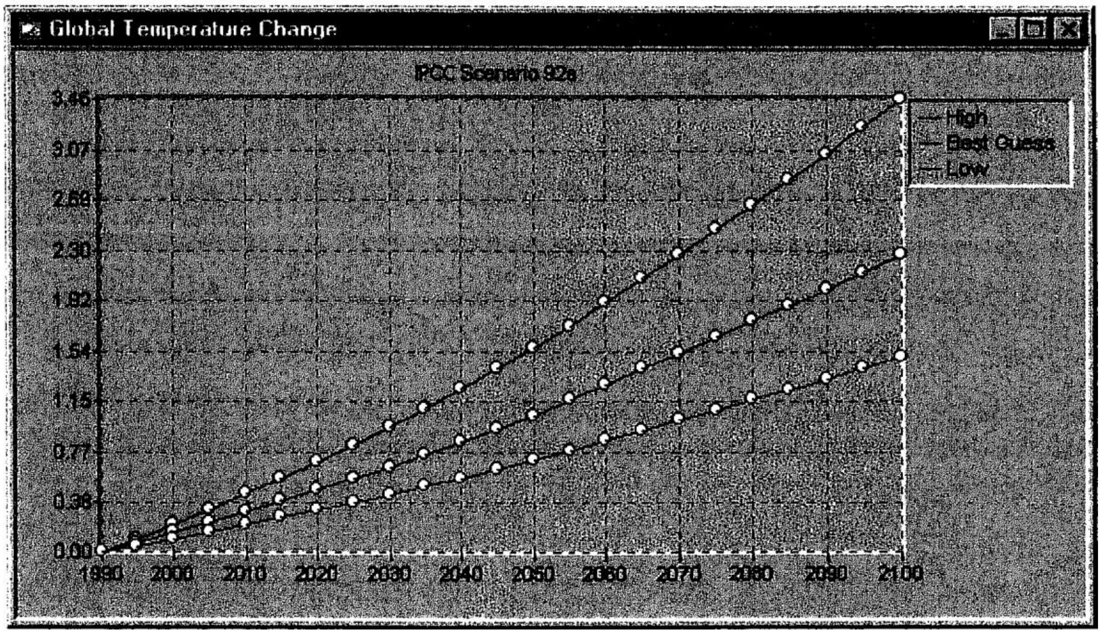

Figure 3: FIJICLIM window showing graphed output from MAGICC (Wigley, 1994) for the IS92a GHG emissions scenario.

Figure 3: FIJICLIM window showing graphed output from MAGICC (Wigley, 1994) for the IS92a GHG emissions scenario.

3.2 GCM patterns

The Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research Division was contracted by SPREP in 1998 to prepare a report on regional climate change scenarios for use by PICCAP (Jones *et al,* 1999). As part of this work the CSIRO also prepared a set of GCM patterns for the region, which have been incorporated into the FIJICLIM. The CSIRO used results from five GCM model runs for this purpose, as summarised below (Table 1).

Table 1: GCMs used in FIJICLIM

Model	**Centre**	**Author**
CSIRO-Mk2	The Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Gordon and O'Farrell (1997)
ECHAM4	The German Climate Research Centre (DKRZ)	Roekner *et al.,* 1996
GFDL-R15	The US Geophysical Fluid Dynamics Laboratory (GFDL)	Haywood *et al.,* 1997
HADCM2	The UK Hadley Centre for Climate Prediction and Research	Cullen, 1993
CGCM1	The Canadian Centre for Climate Modelling and Analysis	Flato *et al.,* 1999

A detailed description of the selection and preparation of these patterns is contained in the CSIRO report (Jones *et al.,* 1999). This report also provides a description of some of the limitations to the patterns and a summary of the regional changes in temperature and rainfall. Some key points from the report are summarised below:

- The GCM patterns provide the changes in temperature and rainfall per degree of global temperature change.

- Temperature changes per degree of global warming are mostly in the range of 0.7 to 1.0°C, for the different GCM patterns and across the region.

- Rainfall increases are greatest where surface temperature increases are highest. Most of the GCM patterns show rainfall increases across the region, with the greatest increases indicated for northern Polynesia. Slight decreases in rainfall are indicated for Melanesia and southern Polynesia by a couple of the GCM patterns.

(Note: Please refer to the Jones *et al.* report for a summary of the sub-regional changes in temperature and rainfall from each of the GCMs, which can be used to guide the selection of GCM pattern for use in developing a scenario.)

3.3 Climate Data

Historical temperature and rainfall data for Viti Levu was interpolated to a 500 metre resolution grid for Viti Levu, using the ANUSPLIN model[2] (Hutchinson, 1989).

3.4 Developing a climate change scenario

The steps for developing a climate change scenario are shown schematically in Figure 2, which shows the linkages between the different components described above. In order to develop a climate change scenario using FIJICLIM, the user must choose:

- The climate variable of interest (temperature [max, min, or mean] or rainfall);
- An emissions scenario, and associated with this:
  - the low, best guess, or high case (which encompasses the range of uncertainty in model parameter values), and
  - the year of interest (in 5-year increments from 1990-2100);
- A GCM pattern.

The selected GCM pattern, which gives the change per 1°C of global temperature change, is scaled by the selected global temperature change from the MAGICC library. This scaled pattern of change is then used to adjust the baseline climate data, as follows:

- In the case of temperature:

  Future temperature = present temperature + (MAGICC value x GCM pattern of temperature change, in °C).

- In the case of rainfall:

  Future rainfall = present rainfall x (MAGICC value x GCM pattern of rainfall change, in %).

Sectoral impact models have been incorporated for: agriculture, coastal zone, human health and water resources.

4 Coastal zone

A number of complex, dynamic models are available for examining processes related to sediment transport, wave energy effects, beach profile changes, and so on. While the rigour of such models is clearly an advantage for predicting physical changes and examining coastal processes, their application is severely limited for vulnerability and adaptation assessments in Pacific island countries, for two reasons. First, such models often demand good quality, high resolution data for a range of variables and model parameters. In Fiji, good quality data is very limited and therefore the selection of methods in evaluating the vulnerability and adaptation assessment is also restricted. Second, the more complex coastal models are not well suited to addressing the issues of sea-level rise because very different time and space scales are involved. In such circumstances, the detailed

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[2] The ANUSPLIN model is used to interpolate climate data from sites to give a spatial representation of climate. At a large island scale, the site climate data are combined with topographic data to give a spatial climate.

processes and predictive accuracy of the model may be less important than the capability to conduct *simulations* for the purpose of examining model sensitivities and uncertainties under sets of "what if' scenarios on coarse temporal and spatial scales.

Consequently, following the guidance given in the USCSP Handbook (Benioff *et al.,* 1996, Chapter 5.5), two appropriate methods that can be applied satisfactorily to Fiji coastlines are: (1) a variant of the 'Bruun Rule'. This method appears most suitable for impact assessments of beach and dune systems; (2) a simple inundation model (`drowning' concept). This method appears most suitable for low islands and for the coastal floodplains of high islands with very low gradients and low energy environments.

4.1 Bruun Rule

The concept behind the 2-dimensional "Bruun Rule" model is explained in the USCSP Handbook (Benioff *et al.,* 1996). In effect, in the Bruun Rule the equilibrium profile of a beach-and-dune system is re-adjusted for a change in sea level. A rise in sea level will cause erosion and re-establishment of the equilibrium position of the shoreline further inland, as follows:

$C_{eq} = z\,l / (h + d)$ where:

C_{eq} is the equilibrium change in shoreline position (in metres)
z is the rise in sea level (in metres)
l is the closure distance (the distance offshore to which materials are transported and "lost", in metres)
h is the height in metres of the dune at the site
d is the water depth in metres at closure distance ($1/(d+h)$ thus gives slope)

There are two important drawbacks to using this simple model to examine shoreline change under a trend of rising sea level. First, it gives only the "equilibrium" (or steady-state) change. In reality, coastal systems do not adjust instantaneously; rather, there is apt to be some time lag in the response. Second, in reality shoreline retreat, as evidenced by historical data on beach profiles, is apt to occur in "fits and starts" over time, not as a steady, year-by-year incremental change. This uneven response of the shoreline is partly a function of the chance occurrence of severe stormy seasons, which often cause erosion (in contrast, a season of very few, or mild, storms may allow the natural system to replenish the sediment supply and the shoreline to advance).

For these reasons, the Bruun Rule was modified slightly to add a response time and a stochastic "storminess" factor as follows:

$dC/dt = (C_{eq} - C)/\tau + S$ where:

t is time (years)
C is the shoreline position (metres) relative to that of $t=0$
C_{eq} is the equilibrium value of C
τ is the shoreline response time (years)
S is a stochastically-generated storm erosion factor

In other words, the yearly change in shoreline is a function of the difference between where the shoreline *should be* (according to the Bruun Rule) in that year and where it actually is (as a consequence of what has occurred in previous years), as well as the effect of storms. The greater the difference, the greater the potential for erosion in that year, subject to the rapidity at which the system can respond.

The model is forced by changes in sea level (projections selected by the user) and by the randomly selected "storms". The model runs year by year and the results are displayed graphically.

4.2 Inundation Model

One of the more pressing impacts of climate change and sea level rise on the coast will be loss of land due to permanent inundation. Relative sea level change is likely to have serious impacts on the natural and socio-economic resources of Fiji. Land loss due to inundation is a function of slope; i.e.; the lower the slope, the greater the land loss.

A simple inundation or 'drowning' concept requires that a high-water mark is vertically shifted landward by the same amount of the relative sea level rise scenario used. This means that if a relative sea level rise scenario is 1.0 m then the high-water mark would be shifted inland to a topographic contour which is 1.0 m higher. In very flat terrain, this could be rather far inland. This concept does not necessarily account for local factors (eg: tidal variations) and the natural system's capacity to adjust through changing patterns of sedimentation.

In FUICLIM, a simple inundation model is available. There are three components which determine "drowning" of land and which require the user to specify values:

- **Global sea-level rise.** This is a consequence of the emission scenarios chosen and the uncertainty attached to the model parameters. As noted above, one of the choices is the "baseline" scenario, which sets future global sea level rise to zero, thus allowing one to examine storm effects in isolation, as noted below.

- **Net vertical land movement.** Long-term vertical land movements also affect relative sea level – the level of the sea surface *relative* to the land elevation.

- **Storm flooding.** An important additional hazard is storm surges from tropical cyclones. In general, a rise in sea level will mean that flooding from an extreme storm surge of a given magnitude will extend further inland. As well, the frequency of storm surges could well change as a consequence of global warming. The FIJICLIM user can examine the storm surge element by choosing a storm surge with a particular return period. The frequency-magnitude relationship can also be adjusted by the user in order to examine possible consequences of global warming on severe storm surges.

The combined effect of all three user-defined components can be viewed on the Viti Levu topographic map.

5 Water resources

The **flow analysis/flooding model** is used to assess the climate change impact on surface water as represented by two catchment areas in Viti Levu. A stochastic approach is adopted to analyse the impact on both high and low flow events, which are related closely to the flooding and water quality problems in small island countries.

5.1 Flow analysis/flooding model

The flow analysis/flooding model is built on a stochastic approach, which uses the generalized extreme value (GEV) distribution[3] to analyse the extreme high and low flow events. The generalized extreme-value analysis (Jenkinson, 1955) is widely used for modeling extremes of natural phenomena, and it is of considerable importance in hydrology (Natural Environment Research Council, 1975). Extreme events are defined in terms of unusual values of a sequence of observations of certain meteorological elements. The term "extreme events" is used in a broad sense, encompassing both the occurrence of extraordinary values (i.e., a record-breaking maximum or minimum) and the exceedance above or below a particular threshold level. Typically, the problem is to estimate the probability that an extreme value of a sequence of observations of a meteorological variable will be higher or lower than some constant threshold level, or alternatively, to estimate that threshold value which will be exceeded with a desired fixed, small probability. These extreme values and associated probabilities are then used in the solution of related design problems or cost-risk calculations. Historical observations of the appropriate meteorological variables are used for the identification and fitting of the desired extreme probability distributions. The utility of these estimators depends to a great extent on the length and the homogeneity of the observational record, especially in cases when the record return period of the required design value is significantly longer than the observational record.

6 Agriculture

For examining the impacts on agriculture, the kinds of detailed, process-based crop-simulation models often recommended for use in climate change V&A assessments (e.g. by Benioff et al., 1996; Carter et al., 1994; UNEP, 1996) are simply not appropriate for Pacific island countries. For many plant and tree crops of the Pacific, such simulation models simply do not exist. Even where such models may be available, the detailed data needed to calibrate, validate and run the models are not available.

For this reason, FUICLIM has adapted a much simpler, indices-based model for use in conducting spatial analyses in which the effects of changes in climate are of principal concern. This model, called PLANTGRO, was developed by Clive Hackett (Hackett, 1988, 1991). PLANTGRO was designed for application in a Pacific Island context as a means of capturing and expressing local knowledge about plants and how they perform in different environments. There are three important components to PLANTGRO: climate files, soil files and plant files. The climate and soil files provide the basis for examining suitability of specified crops at either specific sites, or over areas. A total of 23 climate and soil factors are considered. There are two key elements to output from PLANTGRO: suitability, which reflects how people perceive plants are suited to their environment;

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[3] For a theoretical description of the GEV distribution see Annex A.

and limitation, which is how plants respond to their environment. The latter concept is based on Liebig's Law of the Minimum, as described in Hackett (1988).

PLANTGRO has been applied in a wide range of contexts, including GIS applications for the Cook Islands and Fiji (through joint ventures with Landcare Research) and for matching trees and sites in Asia (Booth, 1996). The FIJICLIM application is unique in that PLANTGRO is directly linked to spatial climate and soils data, and to a scenario generator for evaluating sensitivity to climate change.

In using the FIJICLIM spatial version of PLANTGRO, the user has a large range of options. There are 28 different tropical and sub-tropical plants from which to choose. Additional plant files can be developed and added, as described by Hackett (1991). The user specifies the climate data that drive the model. Typically, for V&A analyses one may wish to run the model under "present" climate (in this case, the 1961-90 reference climatology) and also under the user-defined scenario of future climate change, and compare the results. The planting date option can be used to explore the effects of management decisions for adapting to changed climate conditions for annual crops. As indicators of effects, the user can select one or more of the following model outputs:

- Suitability rating: a composite index taking into account soil and climate conditions at each grid site;
- Greatest limitation: the most critical limiting factor amongst 23 factors;
- Yield: Relative yield in relation to potential maximum yield;
- Growing season length.

The model can be used to answer a vast range of questions in relation to climate change vulnerability and adaptation; for example:

- How well suited is the crop to the present climate?
- What are the limiting factors to production and what would be the effects if they were overcome?
- Is the crop more sensitive to changes in temperature or rainfall?
- What are the threshold levels of climate change that bring about large impacts?
- What other alternative crops could be grown at present? Under future climate change?

It could be argued that the drawback of the PLANTGRO approach is its simplicity, particularly the lack of process-based modelling. However, despite its simplicity – or rather because of it – the strength of the FIJICLIM/PLANTGRO system is its versatility. This versatility is manifested in at least four ways.

First, **data:** as compared to more complex crop models, it can be developed and run with data that are available for many Pacific islands. Data availability is one of the biggest constraints to conducting climate change V&A assessment in developing countries.

Second, **speed:** the model set-up and running time is quick, thus allowing multiple simulations and facilitating sensitivity analyses.

Third, **spatial approach:** the models can be developed for spatial analyses and still run quickly (a single simulation takes about one minute). The ability to provide spatial information, on maps, makes a significant step toward decision making and implementation of adaptation strategies.

Fourth, **local knowledge base:** traditional knowledge about the array of tropical and sub-tropical plants is large, but often not formally documented. In the PLANTGRO system, the user can easily alter the data files, and develop new ones, to incorporate such knowledge — thus blending traditional knowledge with scientific tools.

7 Human health

Assessing the possible impacts of climate change on human health *is* a complex task. On a purely biophysical level it is possible to characterise relationships between climate and the incidence of various diseases. However, public health effects are considered in a much wider context as is explained in the UNEP Handbook (UNEP, 1996), Chapter 7. Within Fiji there are a wide range of public health issues that may be affected by future climate change. Many of these cannot be characterised in a simple model structure. Many of the public health effects will arise from effects on other sectors, such as agriculture, the coastal zone and water resources.

The UNEP Handbook (UNEP, 1996) describes a range of approaches to assessing impacts of climate change on human health. Two broad approaches are used here:

(1) biophysical indices which estimate risk of vector-borne disease as influenced by temperature and rainfall;

(2) an integrated approach, which requires the user to evaluate effects on the other three sectors included within FIJICLIM, in combination with relevant socio-economic information, to determine possible secondary effects on public health.

7.1 Vector-borne Diseases (Malaria and Dengue Fever)

Several models have been developed for estimating malaria and dengue fever risks, either for national or global applications. These range from empirical-statistical models (e.g. see the example in Chapter 7 of the UNEP Handbook (UNEP, 1996)) to empirical process-oriented models, such as that developed by Martens *et al.* (1995) for Malaria and Patz *et al* (1998) for dengue fever.

Output from these models has been adapted for application within FIJICLIM. Both these models relate ambient temperature to epidemic potential. Epidemic potential (which can also be understood as transmission efficiency) is an indicator of how easily an epidemic will be triggered and escalate if the disease along with the disease vector were introduced to a susceptible population. Where epidemic potential is high epidemics will occur more easily, grow faster and smaller vector numbers would be required to sustain the epidemic. Conversely, where epidemic potential is low, epidemics will be less likely to occur, increase more slowly and require a larger vector population to be sustained.

- **Malaria risk model**

Epidemic potential is calculated as a function of temperature (see Martens *et al,* 1995 for a detailed description). This relationship is described by a third-order polynomial function, with a maximum value of 1. A range of uncertainty in maximum daily survival probability is described for this model. For FIJICLIM, the central estimate has been used. While temperature is a major determinant of epidemic potential, the actual incidence of malaria may also be influenced by moisture levels. For this reason Marten's *et al* (1995) included a rainfall limitation which excludes dry areas from malaria transmission and thus more closely defining present distribution limits of endemic malaria areas. The rainfall limitation is a minimum of 1.5 mm per day, which translates (for application in FIJICLIM) to 45 mm per month on average.

- **Dengue fever risk model**

The dengue fever risk model is similar to the malaria risk model. Based on output from the complex process models CIMSIM and DENSIM, epidemic potential is described as a function of ambient temperature (see Patz *et al,* 1998). This relationship is the basis of the simple biophysical index model used in FIJICLIM which describes relative changes in dengue fever risk resulting from changes in ambient temperature. Unlike the malaria model there is no rainfall limitation. This is because the main dengue fever vector in Fiji, *Aedes Aegypti,* is adapted to the peri-urban and domestic environment where breeding sites may be created by artificial containers of water. Depending on the range of human activities, such container breeding sites may be equally available under low rainfall conditions.

7.2 Integrated approach

Many of the health effects from future climate and sea-level change are likely to be secondary effects arising from impacts in other sectors, including agriculture, coastal zone and water resources. Such effects are not easily modelled, but may require an expert judgment approach which may draw on analysis using the range of sectoral impact models within FIJICLIM.

PART 2: FIJICLIM Users Guide

8 Introduction

When you double click on the FIJICLIM icon an introductory screen will appear. Click "OK" and the main menu will appear (Figure 4).

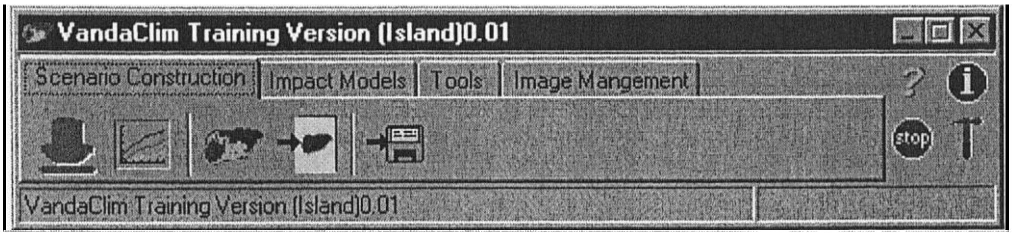


Figure 4: Main menu of FUICLIIVI

The menu options that will be used mostly are the Scenario Construction and Impact Models options. The Scenario Construction option can be used to view the baseline climate data, and to develop and view climate change scenarios. The Impact Models option gives access to the sectoral impact models, which can be applied with both baseline climate and user-specified scenarios of climate change.

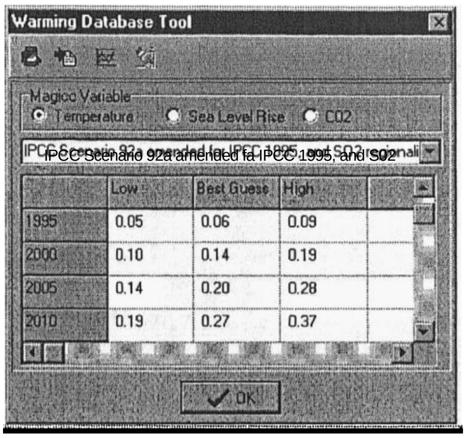
The Tools option gives access to the daily climate data for Viti Levu, and also an extreme event analysis tool. The latter can be applied to the present climate only. The Image Management option allows the user to retrieve and customise previously saved images. Customising of images can also be made as they are created.

9 Scenario Construction

There are four active icons in the Scenario Construction sub-menu which are described below:

9.1 The MAGICC database tool

The MAGICC database tool contains a library of output files produced from MAGICC. These give time series of global temperature and sea-level changes for a range of GHG emissions scenarios, as well as the time series of associated carbon dioxide changes. This tool (see Figure 5) can be used to extract values for selected scenarios (by scrolling through the time series of values), or to view a selected time series on a graph (by clicking the graph icon at the top left of the menu box).



Magicc Variable
● Temperature ○ Sea Level Rise ○ CO2

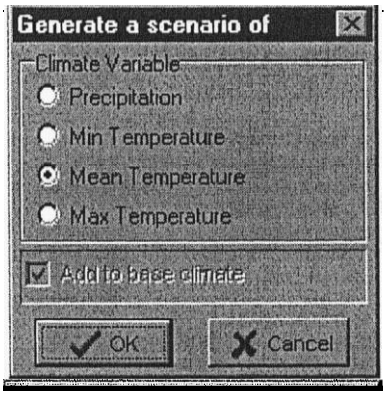
IPCC Scenario 92a amended fa IPCC 1995, and S02

	Low	Best Guess	High
1995	0.05	0.06	0.09
2000	0.10	0.14	0.19
2005	0.14	0.20	0.28
2010	0.19	0.27	0.37

Figure 5: Menu options for viewing MAGICC library file

9.2 Generate a scenario

To generate a baseline or a scenario click the 2nd (from left) active icon in the Scenario Construction sub-menu.



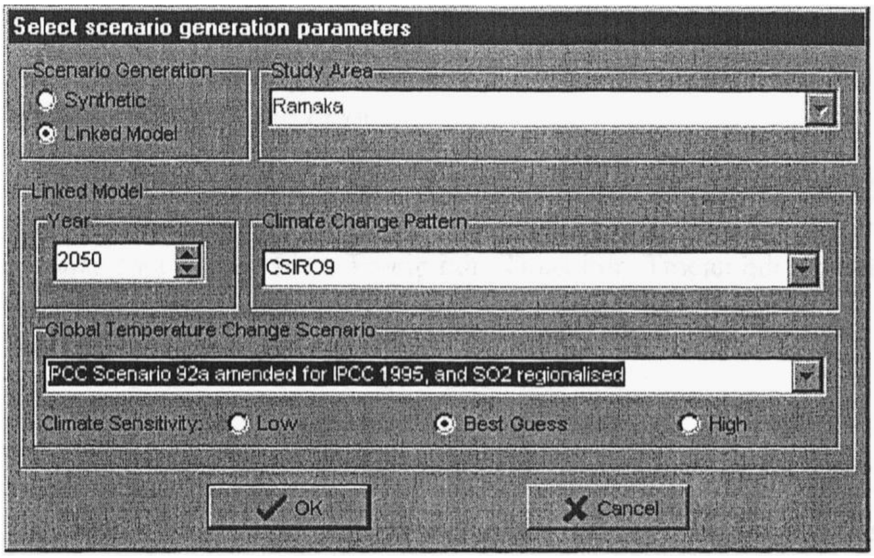
Climate Variable
○ Precipitation
○ Min Temperature
● Mean Temperature
○ Max Temperature

☑ Add to base climate

Figure 6: Menu for selecting climate variable for scenario generation

This activates the above menu of choices (Figure 6). Because of the small size of Viti Levu the changes in climate that are generated are uniform across the country. Thus, when a scenario is generated the output is an image which shows the future climate (baseline adjusted by the climate change scenario).

Select the climate variable of interest and the menu shown below (Figure 7) will appear. This is used to select the scenario generation parameters



Scenario Generation: ○ Synthetic ● Linked Model

Study Area: Ramaka

Linked Model

Year: 2050

Climate Change Pattern: CSIRO9

Global Temperature Change Scenario: PCC Scenario 92a amended for IPCC 1995, and SO2 regionalised

Climate Sensitivity: ○ Low ● Best Guess ○ High

Figure 7: Menu for selection of scenario generation parameters

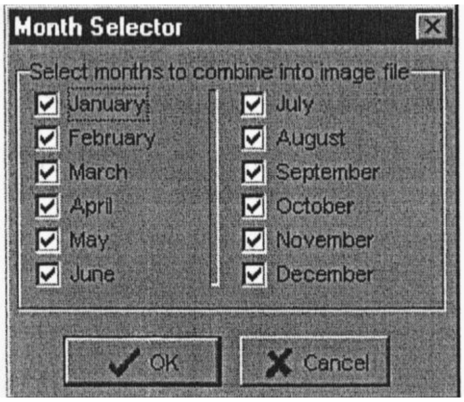
To generate a baseline, set the Year to 1990 and click OK.

Scenarios can be generated in two ways, by using the Synthetic or the Linked Model options.

- To develop a synthetic scenario, select this option and then specify plus or minus changes in temperature and plus or minus percent changes in rainfall.

- To develop a climate change scenario, the parameters to specify are: Year; Climate Change Pattern; Global Temperature Change Scenario; and Climate Sensitivity. In the above example (Figure 7) the choices are: 2050; CSIRO9 pattern; IS92a GHG emissions scenario; best guess climate sensitivity.

The baseline climate or the specified scenario can be viewed as individual, or combinations, of months simply by checking the boxes (Figure 8). Click OK and the specified image will appear on screen.



Select months to combine into image file

☑ January
☑ February
☑ March
☑ April
☑ May
☑ June
☑ July
☑ August
☑ September
☑ October
☑ November
☑ December

Figure 8: Menu for selecting months or combinations of months

9.3 Extract a raster image from a scenario

This option is presently mis-named. It's primary purpose is to access the stored image files for the baseline climate of Viti Levu.

Click the 3rd (from left) active icon to activate this option. Click Browse to find a Surface Header File. Double click the Viti Levu sub-directory, then double click the BaseClm sub-directory. This contains four header files: Precip.hdr; Tmax.hdr; Tmean.hdr; Tmin.hdr. Select from these to view the climatology of interest, and Open. Use the Month Selector to get the desired combination of months.

9.4 Export a climatology to a text file

This option is available to export surface header files for the baseline climatology to an ASCII format, which is used for images created within FIJICLIM and is also compatible with the IDRISI Geographical Information System (GIS).

10 Impact Models

There are four main options within the Impact Models sub-menu, covering the coast, health, water resources and agriculture sectors (Figure 9).

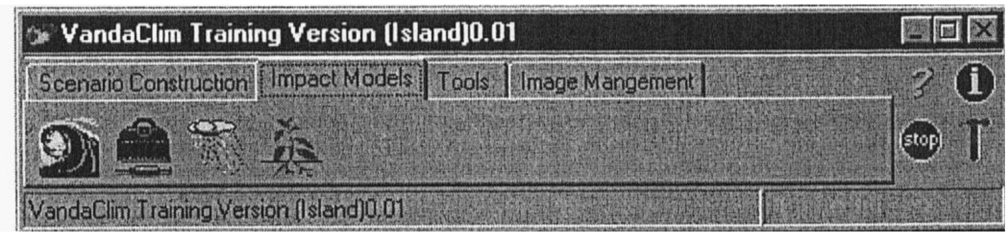


Figure 9: Menu for selecting impact model options

11 Coastal models

Clicking the coastal model icon activates a dialogue box with three model options:

a) shoreline change (sand);
b) shoreline change (coral);
c) coastal inundation.

Ignore the shoreline change (coral) option as this is still under development. The two active models for the coast are for shoreline change (sand) and coastal inundation. These models have a range of options that enable to user to conduct quite detailed *sensitivity* analyses.

11.1 Shoreline change (sand)

In order to use the modified version of the Bruun Rule, the user must then select values for each of the following: site-related model parameters; sea-level rise scenario; and storm characteristics.

Site: There are sites in the Viti Levu for which the modified version of the Bruun Rule is deemed applicable. The user should click on one of the dots provided on the map to **choose a site.**

For each site, it is necessary to select the values for the model parameters (as noted above):

- The model parameter called ***residual movement*** is the very long term change (on the order of centuries) in shoreline position. This factor largely relates to long-term trends in sediment supply and transport as they affect erosion and accretion.

- The **characteristic response time** (ti) governs the responsiveness of the system to sea-level rise in a given year. For example, if τ is set to 6, the annual change in shoreline will be one-sixth of the "potential" change indicated by the equilibrium situation (if sea level is constantly rising, the system is continually in dis-equilibrium).

- The **closure distance (1)** is the distance offshore at which sediments are effectively "lost". For Viti Levu, this is nominally taken to be the distance to the edge of the reef.

- The **depth (d)** is the water depth at closure distance at which the sediments are lost. It is assumed that the depth is greater at high wave energy sites.

- The **height (h)** is the "dune" height (or the equivalent thereof for small islands).

For the Viti Levu, as well as for most small islands in the world, there is considerable uncertainty regarding the actual values of these parameters.

SLR Scenario: The input to the model is sea level rise, selected through the user choice of sea-level scenarios. First, the user can set the value for the **residual sea-level rise** (which is the historical trend, in metres per year), assumed to be due to a combination of vertical land movement, global sea-level trends and regional trends. The value chosen will be applied up to the year 1990 and added to the scenario of future sea level rise for 1990-2100.

Second, there is a large library of **future scenarios** of greenhouse gas emissions (for 1990-2100) from which the user can choose. The choice of "baseline" scenario (the last selection in the library) sets future sea-level rise to zero and instead provides a simple extrapolation of the past rate of sea level rise into the future.

Third, there is a choice of **climate sensitivity.** The choice reflects the range of scientific uncertainty in climate and sea level modelling. Here, the user selects a low, best guess or high projection to be associated with the choice of scenario.

Storm Parameters: The model assumes that particularly stormy seasons provide the energy required to potentially erode the shoreline. The "storminess", and thus the *erosion potential,* in any given year is selected randomly from a normal distribution with a mean of one and a standard deviation of 10 metres (default values, selected on an *ad hoc* basis to give a reasonable interannual variability in shoreline change). For randomly-selected values that are zero or negative, the erosive potential is set to zero, which usually allows accretion to occur and the shoreline to advance toward its equilibrium position. Positive values are scaled according to the state of dis-equilibrium and applied to the shoreline erosion. The user is encouraged to change the mean and standard deviation in order to examine the effects on shoreline change on yearly, decadal and longer time-scales.

Each simulation of the model provides a unique sequence of past and future storm seasons. This is useful for looking at short-term variability and extremes in relation to long-term trends in average sea level change as they can potentially affect the coastline.

For more sophisticated analyses in which the user is interested in the statistical properties of the such storm effects, one can perform a **Monte Carlo Simulation** (see dialogue box). With this option, the model is run repeatedly in order to obtain a sample from which the mean and distribution for each year can be described. The user selects ***the number*** *of simulations (i.e.* the sample size) and the *confidence interval* to be displayed graphically. This analysis can provide information on the average conditions as well as an assessment of risks arising from the natural variability in the system.

Results: To run the model, click on **Run Simulation** at the bottom of the dialogue box. The model begins running in 1940 (in order to "warm up" the model) and ends in 2100. The results of the analysis immediately appear in tabular form. To view the results graphically, click on a column heading, which will give you the choice of outputs to view. Choose the outputs to view and click OK, which will bring up a graph. In most cases, the key output variable to examine is the ***current shoreline.***

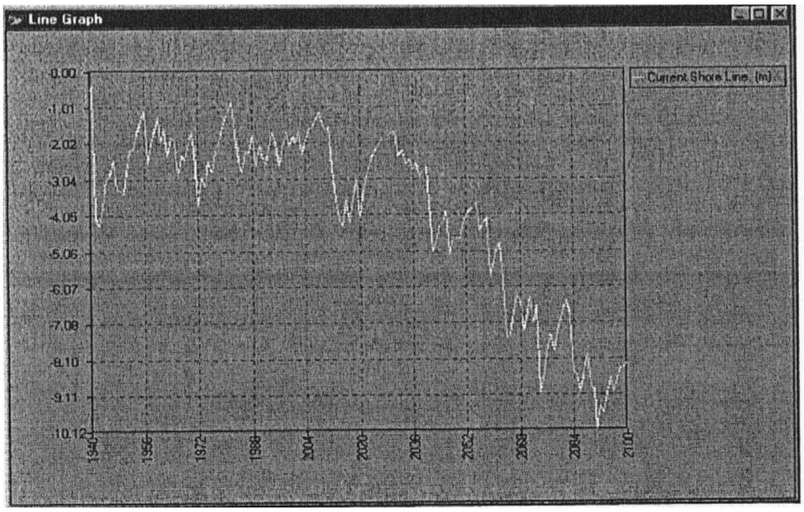


Figure 10: Example of model results showing changes in current shoreline

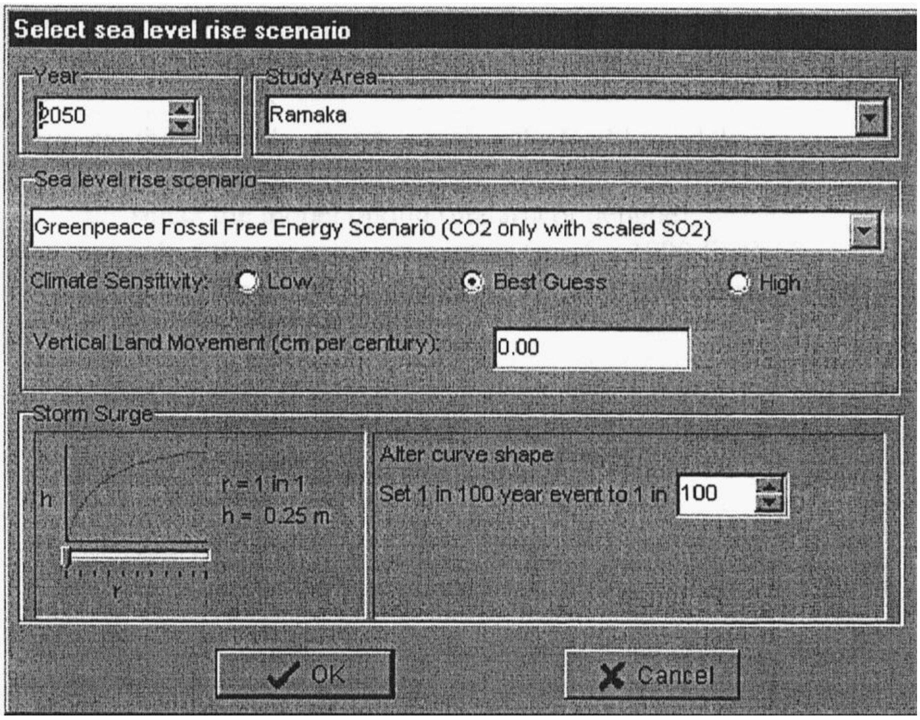
An example of the model results is shown in Figure 10. Although the model begins in 1940, at least the first decade of results should be ignored as the model is "winding up". The vertical axis shows the change in shoreline position from the "equilibrium" position in 1940 (i.e. zero). The negative values indicate shoreline retreat in metres. In order to estimate the result of the chosen scenario of sea level rise, one should take the difference between the average shoreline positions around 1990 and the future date of interest (e.g. 2050). This difference can be estimated visually. For example, in Figure 10, the retreat of the shoreline between 1990 and 2100 is about 7 metres.

11.2 Coastal inundation

As explained in the description of the coastal inundation model there are three important factors which will determine the effects of sea-level rise:

i. the sea-level rise scenario;
ii. net vertical land movement;
iii. storm surge flooding.

How these options might be varied for present and future conditions within the coastal inundation model is explained by referring to Figure 11. The box called **storm surge** shows a curve defining the relationship between storm surge ***heights (h)*** and ***their return periods*** **(r)** – that is, how long, *on average,* between the occurrence of floods of a given height or larger. This provides information about the ***risk*** of storm flooding.



Select sea level rise scenario

Year: 2050

Study Area: Ramaka

Sea level rise scenario: Greenpeace Fossil Free Energy Scenario (CO2 only with scaled SO2)

Climate Sensitivity: ○ Low ● Best Guess ○ High

Vertical Land Movement (cm per century): 0.00

Storm Surge

r = 1 in 1
h = 0.25 m

Alter curve shape

Set 1 in 100 year event to 1 in 100

Figure 11: Menu for selection of coastal inundation model options

In order to examine the ***current*** potential flooded area on Viti Levu for floods of given heights and return periods, ensure that the year is set to 1990 and then move the lever under the storm surge curve to select the storm surge height and/or return period of interest. Clicking OK will bring up the map of Viti Levu with the flooded area. The km^2 of flooded area is noted at the top of the map.

For ***future*** conditions, one can examine the change in flooded area for a rise in sea-level, for a change in storm severity, or both. To examine the effects of sea level rise, choose a year, emission scenario and climate projection, as you have done previously. Then, choose the storm surge height (or return period storm) of interest and click OK. The future rise in sea level will be added to the storm surge, giving a combined flood area (note: setting the lever all the way to the left will minimise the storm effects and isolate the sea level rise effect).

To examine the effects of a possible change in storm severity as a result of global warming, use the box labelled ***alter curve shape.*** This changes the frequency with which storm surges of a given height occur. For example, if one sets the 1-in-100 event to a 1-in-50 event, the curve will automatically be adjusted to give more frequent and severe storms. The effects of this can then be viewed graphically and risk assessments conducted.

12 Health models

Clicking the health model icon activates a dialogue box with two model options:

a) malaria epidemic risk;
b) dengue epidemic risk.

There is not the flexibility to explore sensitivities with the health models, as is available with the coastal, agriculture, and water resources models.

There are three simple steps to running the health models:

i. select the model option (malaria or dengue);
ii. select the scenario parameters (run for 1990 first);
iii. select the month or combination of months for which you want to generate results.

13 Water resources - flow analysis/flooding model

As explained in the description of the flow analysis/flooding model this model uses a stochastic approach to analysis the present and future climate change impact on surface flows in two river catchments in Viti Levu.

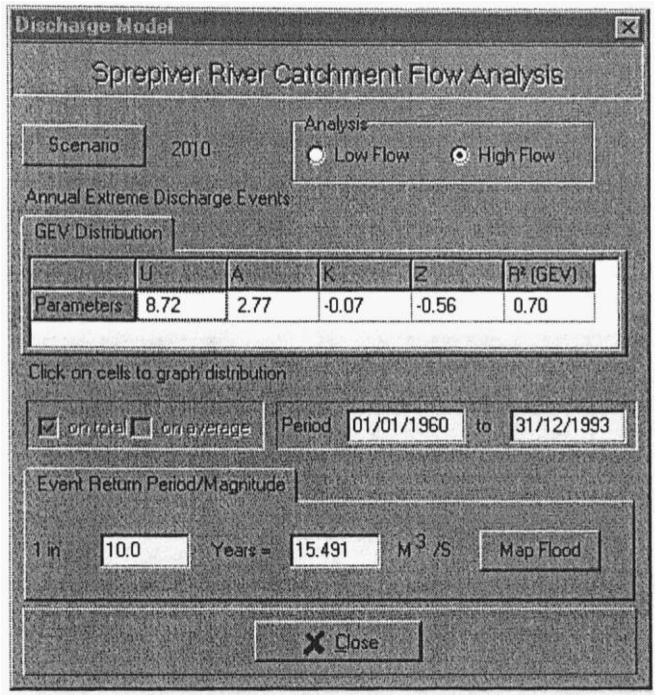
The main options that the user must specify (refer to Figure 12) are:

i. scenario;
ii. analysis for low flow or high flow events;
iii. period of analysis.

Use the **scenario option** to select the present (1990) situation or to develop a future scenario.

Select **low flow** or **high flow,** to examine the effects on river flows of either extreme dry or extreme wet conditions. **Note:** if the high flow option is selected it is also possible to produce a flood map, by selecting the Map Flood option.

The **period of analysis** can be used to specify which part of the historical record is to be used in the GEV analysis. In most cases it is advisable to leave this unchanged, i.e. to use the full period of record.



Discharge Model

Sprepiver River Catchment Flow Analysis

Scenario 2010

Analysis: ○ Low Flow ● High Flow

Annual Extreme Discharge Events

GEV Distribution

	U	A	K	Z	R² (GEV)
Parameters	8.72	2.77	-0.07	-0.56	0.70

Click on cells to graph distribution

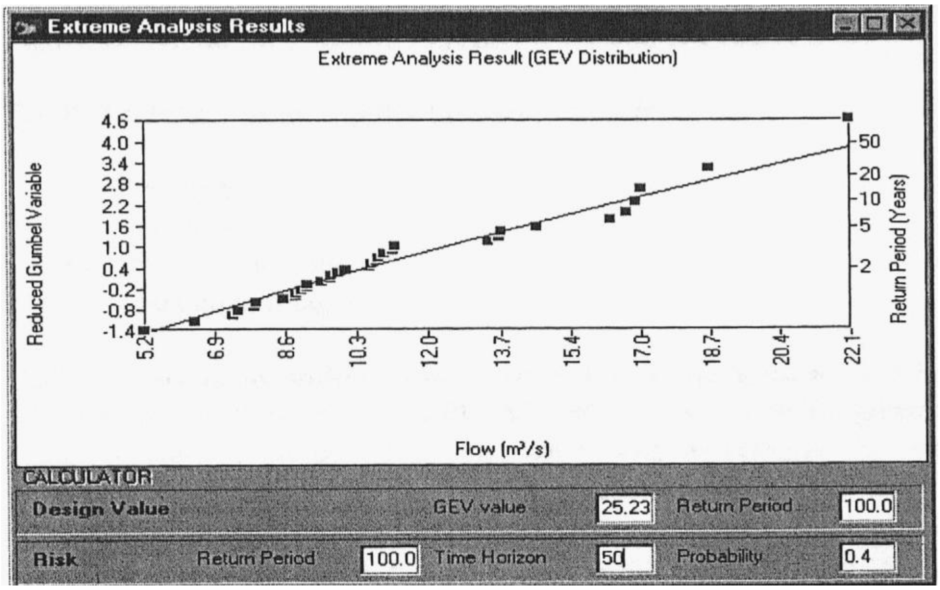
☑ on total ☐ on average

Period 01/01/1960 to 31/12/1993

Event Return Period/Magnitude

1 in 10.0 Years = 15.491 M^3/S

Figure 12: Menu options for running flow analysis/flooding model



Extreme Analysis Results

Extreme Analysis Result (GEV Distribution)

CALCULATOR

Design Value GEV value 25.23 Return Period 100.0

Risk Return Period 100.0 Time Horizon 50 Probability 0.4

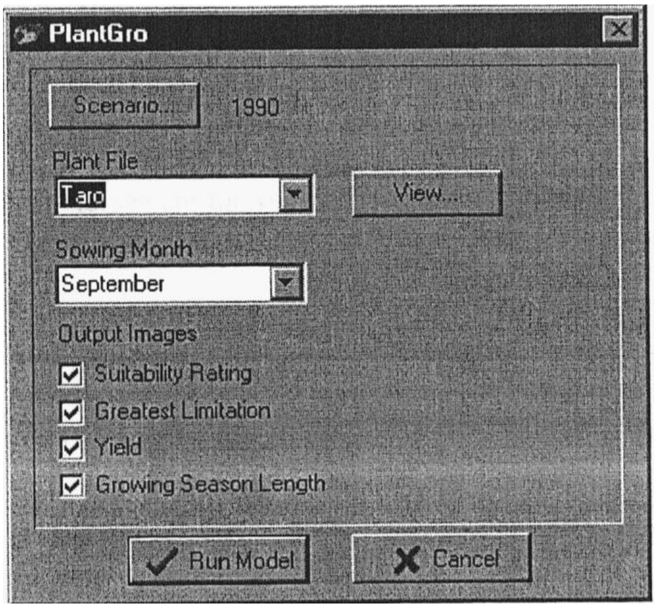
Figure 13: Extreme analysis result for *****

The GEV output values are generated very quickly and are displayed in the same box (see Figure 12). The river flow values associated with specified return periods can also be viewed, simply by editing the return period value in the Event Return Period/Magnitude box. By clicking the Parameters grid, the fitness of the model to the observed data is displayed graphically (Figure 13).

In the Extreme Analysis Results form, a design value and risk exercise can be carried out by using the Calculator at the bottom.

14 Agriculture models

Clicking the plant model icon activates a version[4] of PLANTGRO (Hackett, 1991) developed for application in Viti Levu (Figure 16). These notes do not provide a detailed user guide for PLANTGRO for which purpose it is advised that users obtain a copy of the PLANTGRO manual[5].



Scenario: 1990

Plant File: Taro

Sowing Month: September

Output Images

☑ Suitability Rating

☑ Greatest Limitation

☑ Yield

☑ Growing Season Length

Figure 16: Menu for running FIJICLIM version of PLANTGRO

The PLANTGRO menu requires the user to specify:

i. the scenario;
ii. the plant file;
iii. the sowing month;
iv. the output images.

Under the **scenario option,** either specify a synthetic scenario or a linked-model scenario. By selected the linked-model option PLANTGRO can be run for the present climate and for specified climate change scenarios. The latter are created by selecting the required scenario generation parameters.

Under the **plant file option,** select the crop of interest. The plant file associated with the selected crop can be viewed and modified. In order to modify plant files it will be necessary to spend time reading the PLANTGRO manual. A brief worked example, for taro, is given below.

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[4] This version does not contain the full capability of Plantgro, and has been customised for application in Viti Levu by special arrangement with the developer, Clive Hackett.

[5] A full version of Plantgro, and manual, can be obtained from Clive Hackett. Connect to www.ozemail.com.au/-chackett/ for ordering details. Alternatively, an on-line manual is available from wwvv.cad. gu.edu.au/ism/Plantgro/

Modifying a plant file — worked example for taro

Select taro from the plant file menu and click View. The plant file documents the response of taro to 23 soil and climate factors. Relation 17 documents the effects of Heat Damage. In the default file, the following values are given for this Relation:

```
Re1n17.   Heat damage (deg. C)
   9        0    111    111    111    111    111    111    0       0      Y(SR)
  97      100    999    999    999    999    999    999    0       0      X
   5        2      0      0      0      0      0      0    0       0      Z (misc)
```

In this example, null values are recorded beyond the first two columns

The Y values are the suitability ratings (9 = highly suitable; 0 = rapid death). Heat stress is likely to progress from an optimum tolerance range (SR=9) to rapid death (SR=0).

The X values should record, in this example, the temperature thresholds associated with the SR values. At present values of 97 and 100 are given, which are meaningless.

The Z values record, in column 1 the plant part likely to be affected by heat stress (1 = fruit; 2 = flowers; 3 = leaves; 4 = stems; 5 = underground organs), and in column 2 whether air temperature (tmax) or an estimate of soil temperature (tmean) is to be used. 1= air temperature; 2= soil temperature.

Both the X and Z values can be modified. The optimum temperature range for Taro is of the order of 24°C to 28°C, with lower and upper limits of about 20°C and 32°C. Rapid death might occur at about 40°C. These values might apply to heat damage to leaves. Thus the file might be modified as follows:

```
Reln17. Heat damage (deg. C)
   9        0    111    111    111    111    111    111    0       0      Y(SR)
  30       40    999    999    999    999    999    999    0       0      X
   3        1      0      0      0      0      0      0    0       0      Z (misc)
```

In this case the upper limit of the optimum range is given as 30°C (SR = 9) and rapid death (SR = 0) is indicated at 40°C. These values apply to taro leaves (Z_1 = 3) and air temperatures (Z_2 = 1).

Use the Save As option to save any changes, or Save if you simply wish to overwrite the existing version of the Plant file.

Changes such as these can be used to test the sensitivity of the Plantgro model to climate change.

The only other two specifications that are required are the sowing month (for annual crops) and the output images.

The **sowing month** can be varied to test climate sensitivities at different times of the year, and also to explore the effectiveness of altering sowing time as an adaptation to climate change.

The **output image** of most interest is the Greatest Limitation. This image identifies, spatially, the soil or climate factors that are most limiting to a selected crop on Viti Levu island. Some of these factors, such as soil pH, can be managed quite readily whereas others, such as heat stress require a greater degree of adjustment.

15 Tools

The tools menu provides users with a high degree of flexibility for examining the time series of observed climate data for Viti Levu.

15.1 Climate data browser

This option is used to visualise the historical climate data for Viti Levu. By clicking the site on the Viti Levu map or selecting the site in the site-list box, the user can load the defined data into a table. The time-series of data can be viewed by clicking anywhere inside the table.

Great feasibility is also given in this option for user to handling the data. For example, user can aggregate, calculate and sort the data by choosing appropriate options at the bottom of the form. The proposed data can then be saved into ASCII format by right-click the mouse and select the save option.

15.2 Generalized extreme value analyzer

This form provides the user with a great feasibility of analyzing extreme value events based on observed or user generated climate data. The analysis can be carried out for a variety of time scales. For example, it could be a user specific Julian day, or a fix period, or selected months. The analysis can be based on total amount (i.e., total rainfall of consecutive three days etc.) or based on averaged value (i.e., average maximum temperature of consecutive three days etc.), and based on entire available data (set as default) or user-specified period. Upon the availability of the data, the analysis can be carried out for a variety of climatologies. The FIJICLIM will firstly check the availability of the data. If required data does not exist, either the corresponding buttons are disabled, or an error message pups up. The final result can be visualized by clicking anywhere inside the `GEV distribution' parameter-list table.

Note: Refer to Appendix A of this report for a brief introduction of GEV distribution.

16 Customising images

Below is a result from the malaria epidemic potential model (Figure 17), which is used here to describe the menu options for customising images within FIJICLIM.

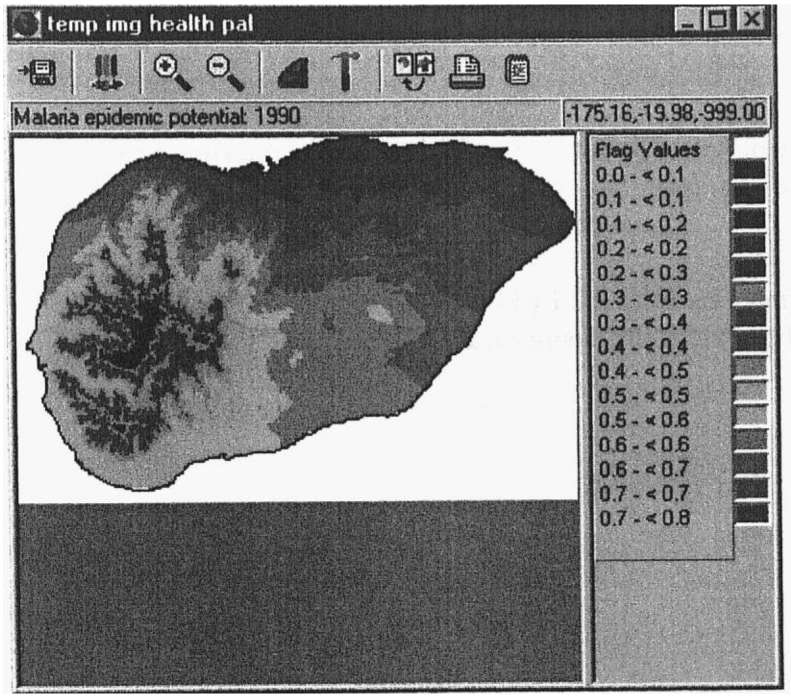

Figure 17: Result from malaria model, illustrating menu options for customising images in FIJICLIM

The options in the menu at the stop of Figure 17 are described from left to right:

1. *Save the image* – used to save images to a file for later reference and use.
2. *Edit colour palette* – used to edit the default colour palette for the image, save an edited palette, or load a different palette.
3. *Zoom in and Zoom out* – used to magnify or reduce the image on the screen.
4. *Overlay a vector file* – used to overlay a vector file. For Viti Levu Island, go to the Viti Levu folder, to locate two vector files: boundary.vec and streams.vec. The former gives the island boundary and the second gives the rivers and streams of Viti Levu.
5. *Edit display options* – used to edit the image display options. The primary application of this option is that the minimum and maximum values of the image can be edited to display a specified range. This is very useful for a couple of purposes:
    - It can be used to identify high or low risk areas resulting from a particular impact model, as in the case of malaria;
    - It can be used to identify shifts in areas of a user-specified temperature or rainfall range (which might, for example, apply to areas of suitability for an agricultural crop).
6. *Link two images* – used to link the bin ranges of two images so that they can be compared more directly. This option is activated by clicking this icon in one image and

then moving the mouse and clicking on the second image (simply click the mouse on the image).

7. *Print* — used to print the image from the screen. (Note: screen captures of images can be copied by pressing <Ctrl Prt Sc> and then pasted into Word documents or into Paintbrush or other software, for customising).

8. *Text file* — the images produced by FIJICLIM are compatible with the IDRISI GIS. This options highlights the IDRISI document file associated with the current image.

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Annex A

Theoretical description of GEV distribution

The theory of extreme values (Gumbal, 1942, 1958; Jenkinson, 1955, 1969; Galambos, 1978; Leadbetter *et al.*, 1983) has established that, for sufficiently large parent sample size *m,* the probability distribution of the standardized (or "reduced") maximum value

$$Y(m) = (X(m) - U_m)/A_m \qquad A_m > 0$$

can be approximated by one of three possible forms of generalized extreme event (GEV) distribution function:

Gumbal asymptote $G_1 = exp(-e^{-y})$

Frechet asymptote $G2 = exp(-y^{1/K})$ $\quad Y>0, K<0$

Weibull asymptote $G3 = exp[-(-y)^{1/K}]$ $\quad Y<0, K>0$

Similar formula also holds for the minimal:

Gumbal asymptote $H_1 = I - exp(-e^{-y})$

Frechet asymptote $H_2 = 1 - exp(-y^{1/K})$ $\quad Y<0, K<0$

Weibull asymptote $H_3 = 1- exp[-(-y)^{1/k}]$ $\quad Y>0, K>0$

The asymptotic extreme distributions involve three parameters;

- K- the shape parameter;
- U_m- the location parameter;
- A_m- the scale parameter.

Their determination depends upon the particular form of distribution F of the individual observations.