

LUCICAT Live

A modeling framework for predicting catchment management options

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Abstract: The LUCICAT is a distributed conceptual catchment hydrology model developed to represent the effects of land use and climate changes on streamflow and salinity generation processes. The model divides a large catchment into a number of Response Units to take into account the spatial distribution of rainfall, pan evaporation, soil salt storage and land use. Each Response Unit forms a building block in the model and represents physical processes of daily flow and salinity generation. The generated streamflow and salt load from each of the Response Units is routed using a modified Muskingum-Cunge method. The model has 7 physically meaningful parameters most of which can be estimated *a priori* and needs minimal calibration.

In this paper we present LUCICAT Live – a framework incorporating LUCICAT model, GIS interface, and data pre/post-processors. The framework runs on a .NET environment and utilizes CSIRO's TIME (The Invisible Modeling Environment) components. We present: (i) the fundamentals of LUCICAT model, (ii) design philosophy of the framework, (iii) the use of some components of TIME, and (iv) some examples how this modeling framework works. The tool has been applied to many catchments in Western Australia and can be classified into three groups: (i) land use management, (ii) yield prediction and (iii) climate change.

Keywords: LUCICAT model, TIME, Catchment modeling framework

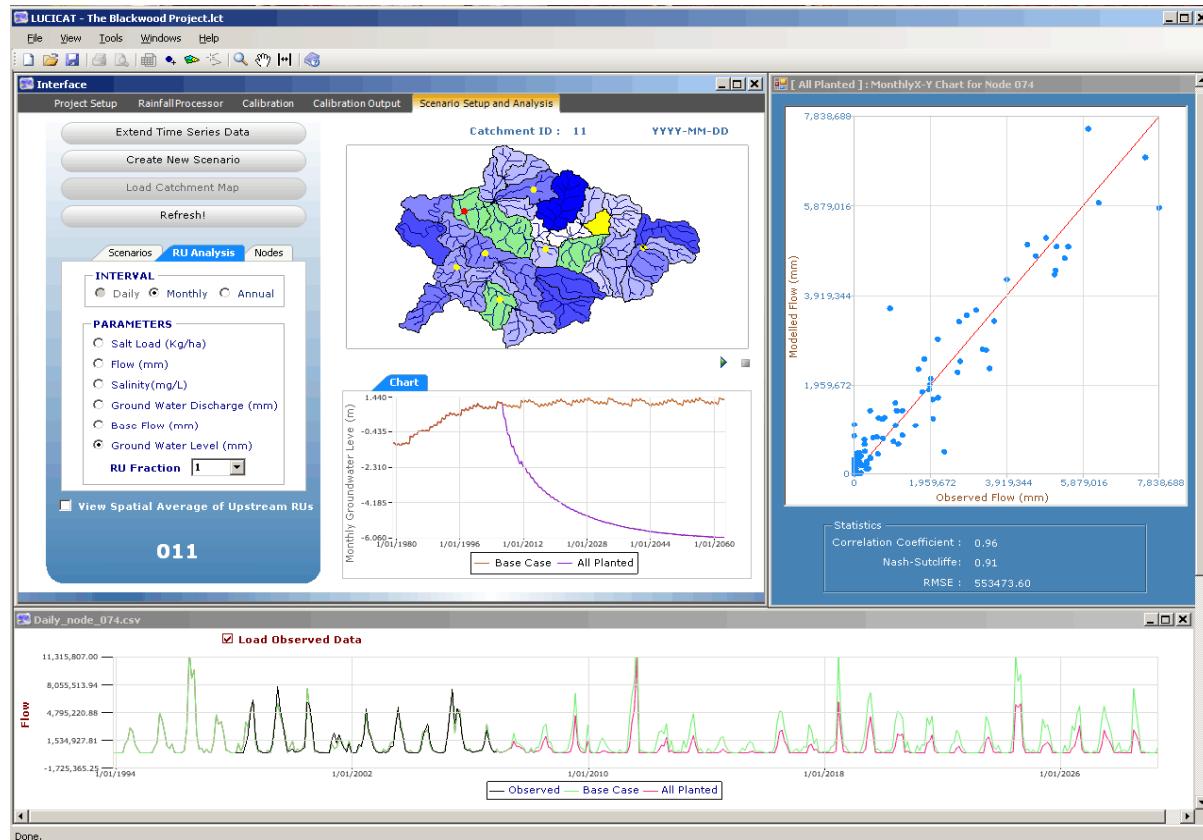


Figure 1. A screen image of LUCICAT Live modeling tool

1. INTRODUCTION

During the past four decades, a number of hydrological models have been developed and used for understanding and developing catchment management options. Most of these models are not user-friendly and processing of input and output data files are very complicated and time consuming. Recently many software packages have been developed to support one or many catchment hydrology models in an integrated way. In Australia E2, an interactive catchment modeling framework has been built upon The Invisible Modelling Environment (TIME, Rahman et al., 2005). It incorporates most of the well-known catchment hydrology models in Australia. In European Union, the Open Modelling Interface and Environment (OpenMI) provides a widely accepted unified method to link hydrology models and answers catchment management questions (Verweij, et al., 2005). The Delft Hydraulics' Flood Warning System (Delft-FEWS) incorporates a large range of data handling utilities, and provides an open interface to external forecasting models (Lahey and Robinson, 2008). All these software packages are available for free on the Internet.

We particularly investigated TIME, as it is an Australian development and many models are already incorporated and operational into it. However to incorporate the LUCICAT model, some of the features, particularly the distributed dynamic landuse history and catchment physical properties, were necessary. As TIME was not capable to provide these features, we developed LUCICAT Live framework using as many components of TIME as possible and write codes where absolutely necessary. In this paper, we present major features of LUCICAT Live framework and its potential applications.

2. THE FRAMEWORK

The LUCICAT Live consists of the following modules: (i) LUCICAT_Geopro, (ii) LUCICAT_Rain, (iii) LUCICAT_Main, (iv) Calibration, and (v) Developing management options (Figure 2). The core model is written in FORTRAN 95, but the framework for the LUCICAT model was developed in C# using Microsoft .NET environment. The development was object-orientated and utilises objects from CSIRO's TIME codes for its capability to produce maps and charts for better understanding of the data and the model. It is designed to allow FORTRAN executables to be run separately in a command shell. The minimum requirement for installation of LUCICAT Live is 2GB RAM with at least 2GHz Intel processor. It also needs Microsoft .Net environment 2.0 SP2, which is freely available through its website. The framework is under continuous development.

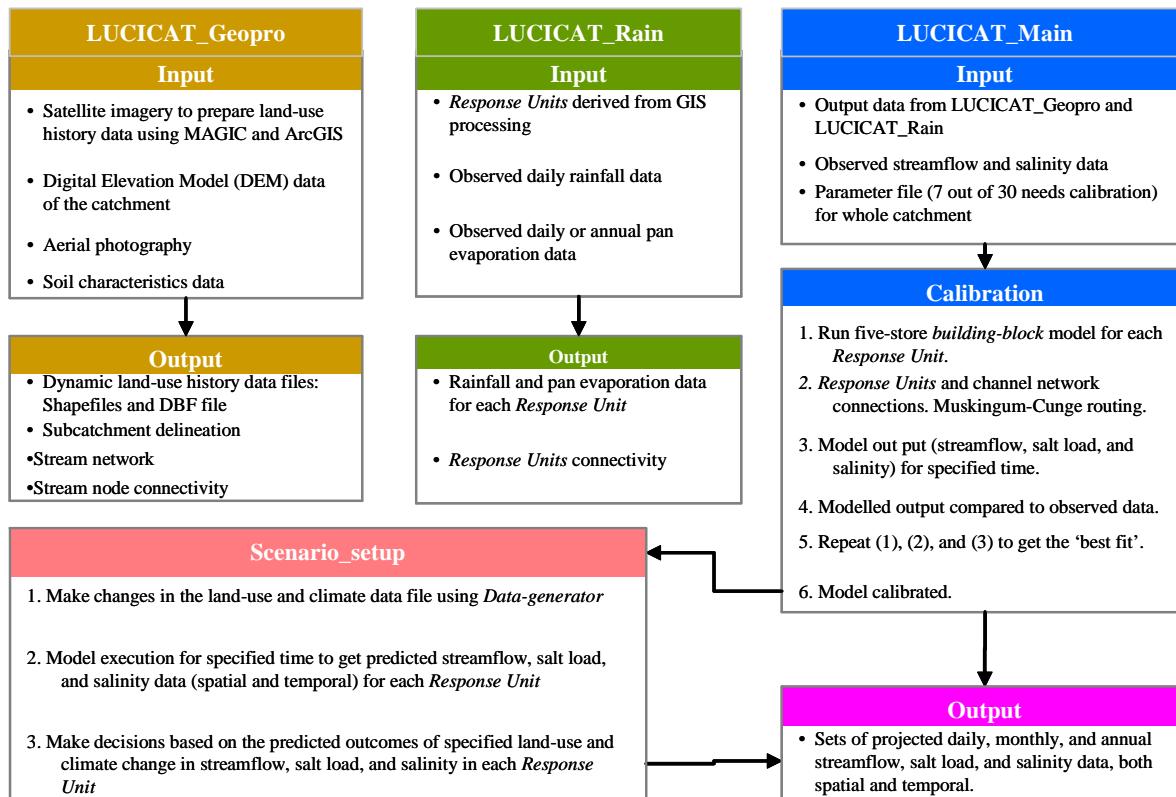


Figure 2. Flow chart of the LUCICAT system

3. THE LUCICAT MODEL

The LUCICAT_Main module contains the fundamental ‘building block’ water and salt balance model and the streamflow routing component. Response Unit attributes of soil depth, groundwater level and change in land use are also incorporated (Bari and Smettem 2003; 2004; Bari *et al.*, 2005; Bari, 2005; Bari and Smettem 2006a, b; Bari, 2007). Each Response Unit also forms a building-block in the model and consists of (i) Dry, Wet and Subsurface Stores (ii) saturated Groundwater Store and (iii) a transient Streamzone Store. The physical processes that the building-block model emulates are listed below:

Evapotranspiration comprises three components: interception, transpiration and evaporation from soil. Interception is represented by a canopy store, which is dependent on the Leaf Area Index. The rest of the rainfall reaches the soil surface and either infiltrates or creates runoff. Transpiration is modelled as a function of the Leaf Area Index, the relative root volume in all five stores, the moisture content and the potential energy (pan evaporation). Evaporation takes place from the Dry, Wet and Subsurface Stores and the Streamzone Store (if exists).

Surface runoff is generated from variably contributing dynamic saturated areas along the streamzone. Where part of the streamzone is saturated by the presence of the permanent groundwater system, additional surface runoff is generated. The near-stream dynamic saturated area is also responsible for the generation of salt flux associated with surface runoff and interflow. The contributing areas vary both spatially and temporally within a Response Unit.

Interflow is the contribution of shallow, intermittent groundwater after rainfall recharge. If the permanent groundwater system does not discharge to the stream, interflow controls the recession limb of the streamflow hydrograph. Interflow is a function of the lateral hydraulic conductivity of the topsoil and the water content of the Wet Store.

Percolation is the amount of vertical water flow between the highly conductive topsoil (Dry and Wet Stores) to the less conductive Subsurface Store. It is controlled by the vertical conductivity, the water content in the Wet Store and the soil moisture deficit in the Subsurface Store. Most of the percolated water is transpired by the deep-rooted trees and only a small amount of the water reaches the Groundwater Store. Recharge to the Groundwater Store comprises both matrix and preferential flow.

Base flow is the contribution of the (permanent, unconfined) groundwater system to streamflow. It ensues where the Groundwater Store comes into play when the conceptual groundwater level is calculated to be at or above the stream invert. It is a function of the lateral hydraulic conductivity of the aquifer, hydraulic gradient and discharge area along the stream. Salt brought about by surface runoff, interflow and groundwater flow is freely mixed in the stream zone.

Streamflow and salt load generated from each of the Response Units is routed downstream by Muskingum-Cunge routing scheme (Miller and Cunge, 1975). Before starting the daily loops, the model checks, organizes, connects and develops all the links and processing order of Response Units. Similarly the model also organizes and connects all the channel segments within both a Response Unit and the whole catchment, before streamflow routing starts. The time step for streamflow routing was reduced to hourly from daily – primarily to avoid iterations and instability within the solution scheme. The overland flow routing is not considered and the generated streamflow and salt loads are uniformly distributed along the stream channel segments within a Response Unit. Water and salt balances of lakes and reservoirs in the catchment are also computed.

4. THE GEOPROCESSING MODULE

The module is still isolated and develops Response Unit boundaries, profile thickness, salt storage, delineates stream channel networks, channel segments, nodes, topological connectivity and their attributes, stream lengths and the associated roughness parameters (Blake *et al.*, 2008). Through ArcGIS three dbf and associated shape files are developed which can be edited through the framework and the FORTRAN code would be able to read the edited files.

This module (Figure 2) also develops the dynamic land-use history of a catchment through the use of ArcGIS and MAGIC (Mauger, 1996). Seven types of vegetation are represented – ‘for’ for native forest, ‘pin’ for pine, ‘ref’ for reforestation, ‘apa’ for annual pasture, and ‘pp1’, ‘pp2’ and ‘pp3’ for different types of perennial pastures. Users can create a new entry in the history file to represent any change in land use such as Leaf Area Index, rooting depth and vegetation type/ area within the catchment. All the information is contained in a dbf and associated shape files which can be edited through the framework. The locations of the rainfall and pan evaporation stations are recorded in a dbf file.

5. SETTING UP THE FRAMEWORK AND PROJECTS

Once installed, a new project can be opened through clicking LUCICAT symbol from the desktop. The ‘Project Setup’ menu will appear and welcome the user! The user then needs to type the catchment name – a base name with which all the file name begins (e.g. Warren), and then navigate to the input directory from where the model will read all the input files. The framework creates a default ‘output’ folder but the user can define any as well.

6. THE RAINFALL PROCESSOR

The rainfall processor has the capability of processing daily rainfall from two different sources – point data and Bureau of Meteorology’s 5 km gridded data from SILO. Before processing rainfall the user must load the catchment attribute file by navigating through ‘Rainfall Processor’ and then pressing ‘Load Catchment’ button (Figure 3a). The user can process daily rainfall for all the Response Units by pressing any of these two options and specifying the start and end date of processing. The rainfall of each Response Unit can be compared with the observed data (Figure 3a) and the time trend and spatial distribution can be displayed (Figure 3b). An animation can be generated to show the spatiotemporal variation of rainfall.

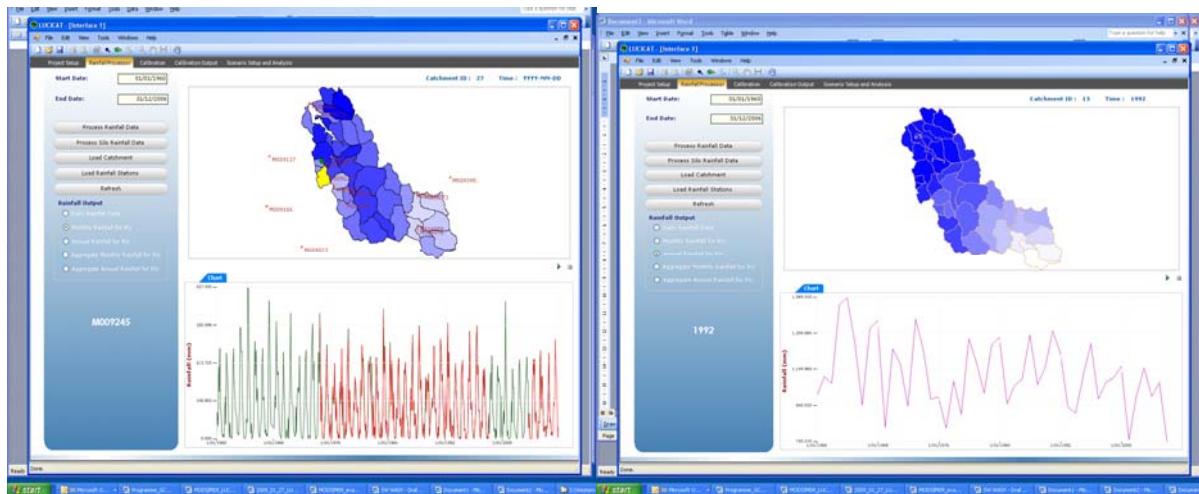


Figure 3 Screen image of the rainfall processing module

7. THE MAIN MODULE AND CALIBRATION

The main module consists of the ‘Calibration’ and ‘Calibration Output’ menus. The calibration menus is mainly for specifying the simulation period, loading and editing all the catchment attributes, channels landuse history files. The changes in landuse, area and Leaf Area Index of different types of vegetation can be seen through clicking ‘Landuse File’ button (Figure 4). The user can also specify the simulation period and output directory before running the model.

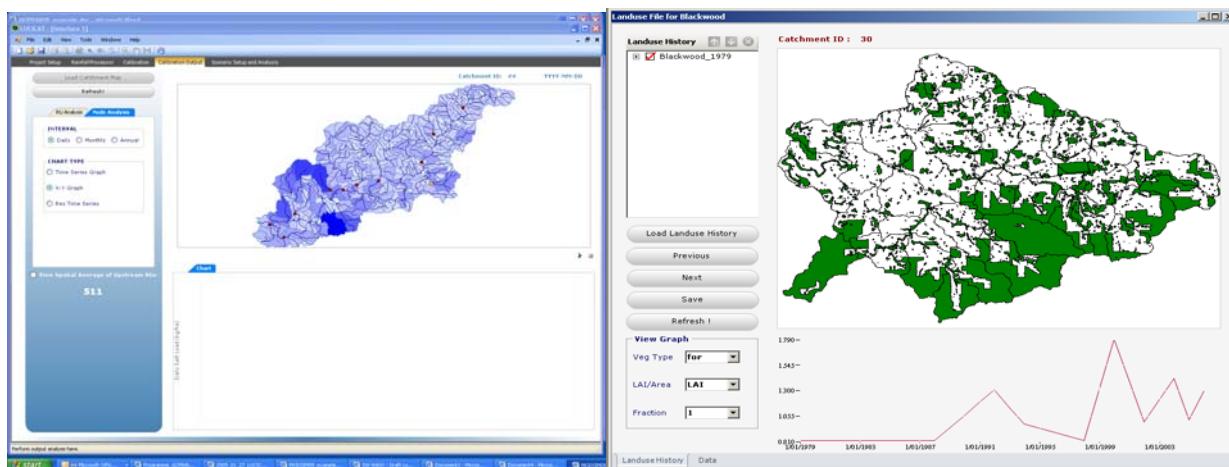


Figure 4 Landuse history and changes in Leaf Area Index (a) and calibration output (b)

7.1 Parameters and Calibration

There are 30 model parameters and are grouped into two: one that can be estimated *a priori* and do not need calibration, and the other a group of seven physically meaningful parameters, known as the ‘variable set’, that can initially be estimated from previous applications but need to be calibrated for the best model fit (Figure 5a). All Response units in a catchment share one parameter set. The values of these variable set of parameters can be changed through the ‘Calibration’ menu of the framework (Figure 5a) and saved by clicking ‘Save Changes’ button. The Response Unit attributes and channel properties can be edited through clicking ‘Attribute File’ of ‘Channel Link File’ buttons. Spatial upstream average water and salt balance components of any Response Units and node outputs anywhere in the channel network can be specified by clicking ‘Print Output?’ Button (Figure 5b). A calibration run is completed by clicking ‘Run LUCICAT’ from the ‘Calibration’ menu of the main module (Figure 5a). Once a run is complete the framework duplicates all the input files, attaches a time tag on the output folder (e.g. output~230220091201) and then loads all the output for display through ‘Calibration Output’ menu (Figure 4b). Any of the old runs can also be displayed by selecting the folder through ‘Project Setup’ menu.

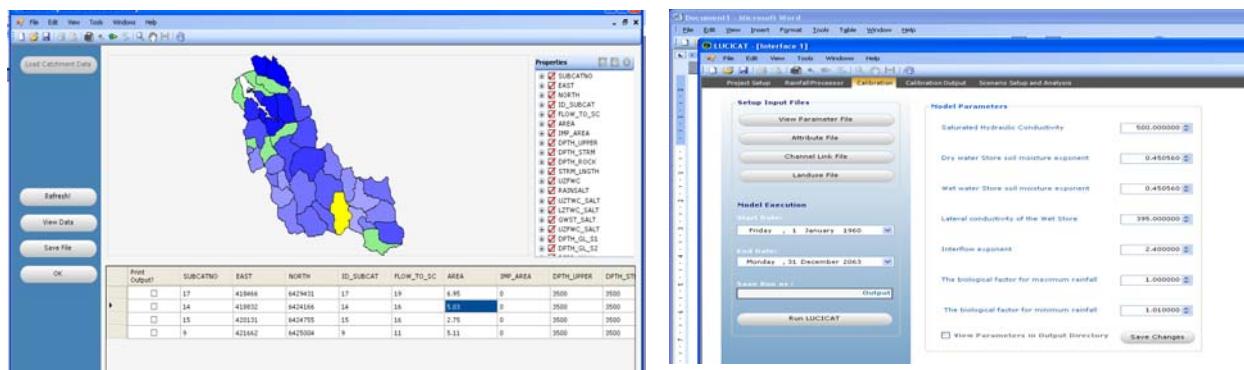


Figure 5 Display of calibration parameters (a) and editing of attributes file (b)

7.2 Model output

The model generates three types of outputs – (i) spatial, (ii) spatial average water balance components of all upstream and (iii) Nodes anywhere in the channel network. Spatial outputs are default and include daily runoff, salinity, salt load, groundwater discharge and baseflow (Figure 4b). Spatial average of water balance components and node outputs are user specified through editing of catchment attribute file. Nodes outputs are user specified and include daily streamflow, salinity and salt load. All the model outputs can be displayed through the framework. At the end of the simulation period, the LUCICAT model writes key annual water balance variables representative of the whole catchment. All the spatial maps and graphs can be copied from the ‘Calibration Output’ menu and inserted into the word processing files.

7.3 Typical calibrations

Once a calibration run is completed the model performance can be evaluated through LUCICAT Live framework by displaying graphs and comparing other statistical criteria. The performance of LUCICAT is assessed by matching observed and predicted time-series against a range of statistical criteria, such as: (1) joint plots of simulated and observed daily series, (2) scatter diagram of monthly and annual series, (3) flow-period Error Index, (4) Nash-Sutcliffe Efficiency, (5) Explained Variance, (6) Correlation Coefficient, and (7) overall water and salt balances, and (7) flow duration curves. Model calibration is achieved through trial and error method. For example, Nash-Sutcliffe Efficiency and Correlation Coefficient should be greater than 0.5 and 0.75 respectively for daily streamflow for all gauging stations within the catchment (Figure 6a). The daily flow-duration curves should also closely match (Figure 6b). For monthly and annual, those criteria should increase above 0.8, 0.85 and 0.9, 0.95 respectively. The model met all the calibration criteria for all gauging records within the catchments. Overall, the simulated mean annual streamflow and salt load for all gauging stations must be within $\pm 5\text{-}10\%$ of the observed data. The LUCICAT model has successfully applied and satisfied the required performance criteria for more than 10 large catchments in Western Australia.

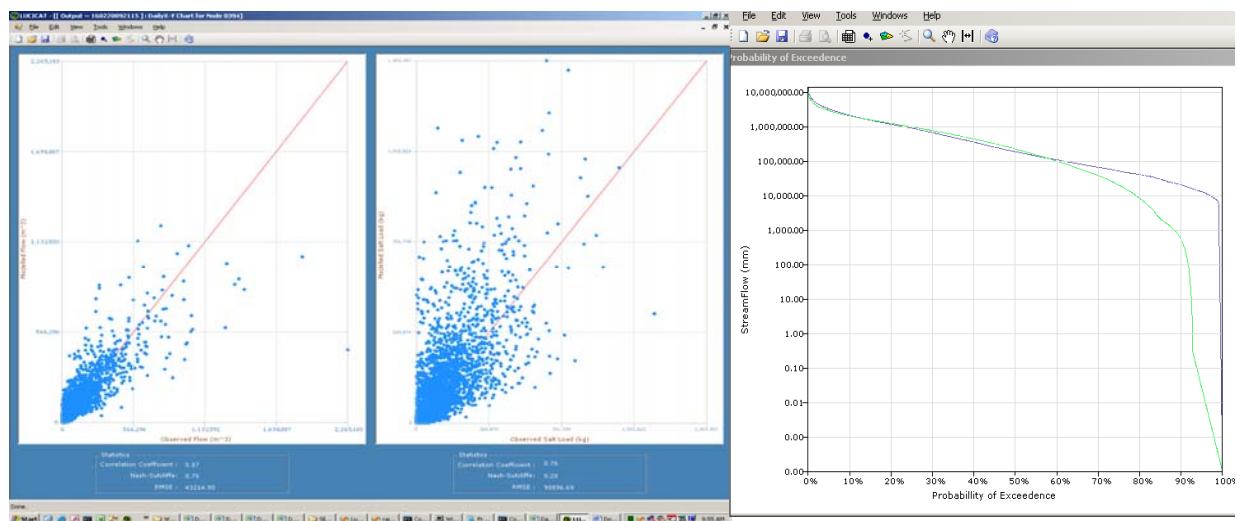


Figure 6 Display of observed and predicted annual streamflow, salt load and salinity (a) and daily flow durations

8. DEVELOPING MANAGEMENT OPTIONS

Catchment management options are developed through the LUCICAT Live framework using the ‘Scenario Setup and Analysis’ module (Figure 7). There are mainly two types of management options – landuse and climate changes. Landuse management options may include planting and harvesting trees and/or perennial or annual pastures or forest thinning or burning within the catchment.

The landuse management options are fully dynamic – for example trees can be planted and then harvested partially or totally within a Response Unit any time during the simulation period. Rainfall and pan evaporation data from the historical records are repeated for the future. The with-and-without management options are then compared to project/estimate the effects of the proposed management options (Beverly *et al* 2005; Dixon and Bari, 2008). The LUCICAT Live framework can also be used for predicting the effects of climate change on catchment water yield. Long-term streamflow records (100 years) can also be generated using the modelling system (Bari *et al*, 2005; Bari and Senathirajah, 2005; Charles *et al*, 2007).

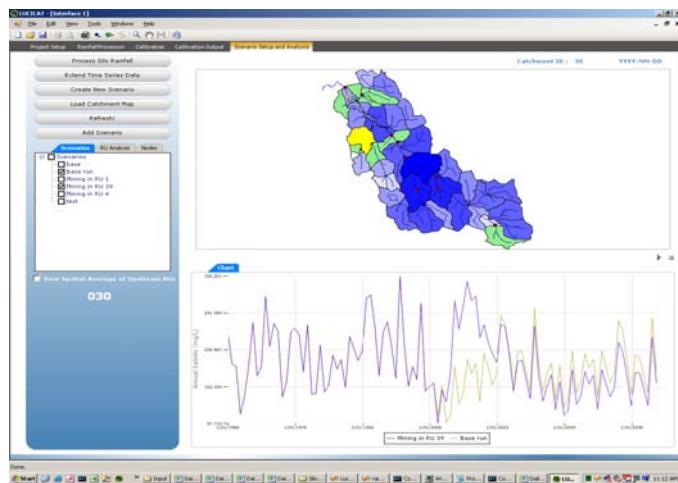


Figure 7 Development landuse management scenarios.

9. FUTURE DEVELOPMENTS

At present the Geo-processing module is completely separate from the LUCICAT Live frame work. Initiatives should be undertaken to integrate it into the framework. There are some opportunities in further development of the landuse management options – inclusion of satellite photos, selection of the area needs to be treated and when. The URBS model (Carroll, 2001) is used for flood predictions and possibility of inclusion of that model to LUCICAT Live framework should be investigated. Recent studies show that the value of ensemble flow forecasts, developed to characterise model parameter and projected weather information uncertainties, is greater than that of deterministic forecasts for catchment and reservoir management under present and potential future climate regimes (Geogakakos, et a., 2004). In future ensemble prediction options would be included into the framework. The model is calibrated through the framework on trial and error method. Initiatives could be undertaken to incorporate auto calibration modules into the framework.

10. CONCLUSIONS

- The LUCICAT Live modelling framework has been developed as an integrated modelling environment of to incorporate the LUCICAT, a distributed conceptual catchment hydrology model. It is still under continuous development and refinement.
- The framework development was object-orientated and utilises objects from CSIRO's TIME codes for its capability to produce maps and charts for better understanding of the input-output data and the model. The framework needs Microsoft .Net environment 2.0 SP2, which is freely available, while the core model is written in FORTRAN 95 and uses Intel FORTRAN Compiler 9.1. The FORTRAN executables relevant to different modules of the framework could be run separately through DOS prompt.
- The framework has the capability of display and editing of different spatial input files – such as landuse history, catchment attributes and channel networks. Different spatial outputs can be displayed through maps and animations. User-specified outputs along the channel networks can be compared with the observed data through charts, graphs and simple statistics. Model can be calibrated using the framework.
- Landuse and climate change scenarios can be developed, run, compared assessed using the LUCICAT Live framework. It is a convenient modelling environment specially designed for catchment management decisions.

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