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1 Executive summary

This project aimed to develop, customise and promote seasonal climate forecast (SCF) technologies to improve the management of irrigated agricultural production systems in Lombok, Indonesia. The climate of Lombok is highly variable being significantly influenced by the El Niño Southern Oscillation (ENSO) phenomenon, which greatly affects the productivity of the predominantly rice-based local agriculture. By customising ENSO-based SCF technologies for use in regional agricultural management and planning, there is significant potential to increase Lombok's agricultural productivity and revenue in favourable seasons and reduce the risk of crop losses in dry years and prolonged droughts. To achieve this, the objectives of the project embodied a range of decision support and “systems-modelling” development, capacity-building and information dissemination components including:

- Collecting, synthesising, modelling and collating hydrologic and climatic data for integration into a climate-based decision support system.
- Developing decision support tools for optimising choice of crop, crop area and irrigation water allocation based on seasonal climate information.
- Promoting SCF-based planning amongst irrigators, government officials and community leaders.
- Building local capacity in the development and operational use of decision support systems.

Commencing in mid 2004, this project continued on from an earlier ACIAR project LWR2/1996/215 “Capturing the benefits of seasonal climate forecasts in agricultural management” (1999–2001) which demonstrated the benefits of SCF-based decision making across four countries (India, Zimbabwe, Australia and Indonesia) including the Lombok region. For the next five years, the objectives of this project have been addressed by the Australian and Indonesian teams in the presence of a range of technological, institutional, educational, and political barriers. At project-end, not all objectives have been met and recommendations will be made to conduct follow-up projects using remaining funds to address the unmet objectives. While most of the scientific components of the project have been successfully completed, capacity building, implementation of the technology and information dissemination components have only been implemented at a basic level. The finalisation of the main scientific components occurred towards the end of the project. This did not allow time for the Australian and Indonesian teams to successfully implement the developed technologies in the field, and therefore minimal benefits have been experienced by the local communities.

The most important accomplishments of the project have been the development of a range of powerful decision support tools and methodologies that have application both within and outside of the project boundaries. These include:

- a comprehensive meteorological and hydrological database for southern Lombok
- hydrological models for simulating streamflow and irrigation water use in southern Lombok
- the CropOptimiser software for optimising cropping patterns for different seasonal, climatic, physical and social constraints
- the FlowCast software for seasonal climate forecast generation and analysis
- a land-use model (HowLeaky) for assessing cropping practices and investigating supplementary water supplies.

Regional climatology and groundwater studies were also undertaken.

A prerequisite for undertaking this project was the hypothesis that ENSO is the main driver of seasonal climate variability across Lombok and can therefore be used for seasonal prediction. A literature review of Indonesia's climate and an in-depth assessment of seasonal climate forecasting skill in the Lombok region verified this hypothesis. The literature review indicated that ENSO can be linked to about two-thirds of Indonesia's climate variability while the skill analysis indicated that a number of ENSO-related predictors could be used as part of an operational forecast system throughout Indonesia. The analyses showed that Lombok rainfall is often highly predictable outside of the January to April wet season, using ENSO-based predictors. Streamflow and irrigation water availability were also predictable outside of the wet season, especially in the south-east of the island. However, during many periods, our ability to predict these variables was less than that of rainfall due to the anthropogenic influences of streamflow extraction and diversion. The onset of the monsoon was found to be highly predictable as it occurs when ENSO's influence on Lombok's rainfall is strongest.

The effectiveness of the key climate-based decision support software developed in this project (FlowCast and CropOptimiser) depends upon the presence of these 'climate signals'. Then, given adequate long-term (>50 years) monthly rainfall, streamflow and irrigation diversion data, the software can capture the regional climate variability to provide useful predictions for agricultural management under various climate scenarios. However, obtaining this long-term data was the most difficult aspect of the entire project, involving extensive data collection, patching, synthesis and hydrological modelling. The methodologies developed in this process were often original and will be of much interest to the wider scientific and engineering community. The process took over two years to complete (not including delays) and was undertaken in parallel to the development of the FlowCast and CropOptimiser software.

Collection of measured meteorological and hydrological data was undertaken by the Indonesian team and much of it had to be digitised from handwritten materials. The data were sourced with much effort from the meteorology office, agricultural agencies, public works offices and from individual field officers, and unfortunately were generally of limited quality and quantity. Collected data included short-term daily and long-term monthly rainfall and maximum and minimum temperature data; and short-term daily catchment river inflows and observed irrigation data. These data are now archived online in their original digital form and managed by the Research Centre for Water Resources and Agroclimate (RCWRA) of the University of Mataram, which was initiated by members of this project in 2006.

Due to the unavailability, poor quality and/or short lengths of the sourced data, extensive patching, synthesis and hydrological modelling was required to prepare the datasets for input into FlowCast and CropOptimiser. This process was undertaken by the Australian project team and involved gap-filling the long-term observed monthly and short-term observed daily rainfall and maximum and minimum temperature time series using 'nearest neighbour' techniques. A stochastic weather data generation package (Weatherman, Pickering et al. 1994) was then used to extend the daily data time series through a process of historical monthly weather pattern matching. Three 'disaggregations' of daily meteorological time series data were generated for input into the IHACRES (Identification of unit Hydrograph And Component flows from Rainfall, Evaporation and Streamflow data) rainfall-runoff model to extend the short-term observed daily catchment river inflows. Each set of simulated long-term monthly streamflow data was then input into the IQQM (Integrated Quantity and Quality Model) water allocation model to simulate long-term irrigation diversion data. IQQM was set up to schematically represent all of the physical features and management rules of the Lombok irrigation system comprising over 64,000 ha of irrigated lowlands, from Jangkok system in the north-west to Jerowaru in the south-east. The IQQM model was calibrated using limited observed daily irrigation diversion data to simulate up to 51 years of daily streamflow and irrigation diversion data.

These data are now available for direct input into the FlowCast and CropOptimiser decision support software. Development of these software has been completed having met (and exceeded) all original design criteria. Given the power and flexibility of both software packages, they have great potential for use in other projects and in other locations around the world, and can be easily extended to accommodate future needs and requirements. It is expected that they will both be used to negotiate future funding and project development from a range of organisations including ACIAR.

FlowCast has been developed to generate and evaluate empirically-based probabilistic seasonal climate outlooks for any type of meteorological, hydrological and agronomic variables, at local and regional scales. It has been designed for scientists, water managers, and agricultural decision makers who have sufficient background knowledge in climate and its drivers. FlowCast, which was originally developed in 1999 with limited functionality, was completely redeveloped during this project to simplify its usage and provide spatial analysis capabilities enabling BMG (Badan Meteorologi dan Geofisika) to implement seasonal climate forecasts at local and national (spatial) scales. FlowCast employs two different forecasting methodologies, as well as a range of numerical skill assessment algorithms. Typical time series inputs include ‘predictors’ such as sea surface temperature anomalies or Southern Oscillation Index data, and ‘predictands’ such as rainfall, temperature or streamflow data. The user interface is highly graphical and interactive with both temporal and spatial analyses and a range of custom designed user-input tools. Detailed point-based outputs can also be overlaid on to spatial outputs, which include dynamic filtering of results and contour generation. Forecasts can be generated in the local Bahasa language. Advanced training was provided in March 2009 funded by ATSE Crawford foundation scholarship.

CropOptimiser has been developed to optimize regional cropping choice and patterns for different seasonal, climatic, agronomic and social conditions. It facilitates regional-level agricultural planning, providing advice that can be disseminated back through government officials and community leaders to the farm level. At this regional level, strategists can geographically optimize cropping choice and area based on the likelihood of available water determined from climate forecasts to maximize yield and protect market value. In doing so, this ensures food security and avoids overproduction of particular crops, which could affect the market price and demand, while adhering to social conventions for staple food supplies. Originally prototyped by the Indonesian team in Microsoft Excel, CropOptimiser is now stand-alone software that replicates this functionality within a simplified graphical user interface. CropOptimiser employs an optimizing algorithm to maximize fiscal profit, subject to physical and social constraints for defined cropping seasons, and climate characteristics based upon the ENSO phenomenon. Regional inputs include available land area, soil types, rainfall, and irrigation system diversion time series data. Crop characteristics are defined by potential yield, water demand, soil productivity index, growing costs and yield prices. Social constraints are easily defined through the user interface using commonly used terminology. The user interface is highly graphical and interactive, with both dynamic textural reporting and GIS-based mapping of results, including recommended cropping distributions, water-use and fiscal outputs.

Additional objectives were commissioned during the project to address outcomes from another ACIAR project SMCN/1999/005 “Improved soil management of rainfed Vertisols in southern Lombok” led by Dr Judy Tisdall (La Trobe University). These objectives were to assess alternative and supplementary agricultural water supplies. This work involved reviewing past studies and conducting new groundwater studies to obtain additional information, and undertaking water balance modelling to determine the potential and economic benefit of capturing run-off water in on-farm storages (embongs).

Investigation of Lombok’s groundwater found that it is contained in shallow aquifers with poor transmissivity. The yield of dug wells will vary depending on recharge quantity in different seasons, well dimensions, aquifer properties and individual well management. Average sustainable extraction from dug well records suggests they are only likely to provide supplementary irrigation requirements of high value crops grown in the dry season. However, the safe yield of individual dug wells could be increased quite significantly depending on the available drawdown, well dimensions and lining conditions, provided that the yield does not exceed the percolation rate. Dug wells which are appropriately and sustainably managed and used in conjunction with highly efficient local hand watering represent a valuable supplementary source of irrigation which must be preserved. Maintenance of sustainable small-scale groundwater irrigation systems requires general well management guidelines to be abided by.

Water-balance studies using the HowLeaky (McClymont et al. 2009) software demonstrated that significant in-crop runoff may occur during the first cropping season (wet season) and represents a valuable supplementary water resource, as previously found by ACIAR project SMCN/1999/005. However, significant emphasis and consideration must be given to the inter-annual variability of runoff volumes. This poses an important consideration for scheme-water irrigation allocations and water harvesting planning. In addition to this, under land-limited situations, there is a trade-off between increased dry season yields (from the use of stored irrigation water), and the reduction in cropping area from land-used to host the water storage (embong). Determining a suitable storage size and management strategy is complicated by the impacts that variations in soil parameters, cropping types and management practices can have on annual runoff volumes, farmers' differences in adversity to risk and individual economic circumstances. These complexities, combined with the previously mentioned delays, resulted in the proposed economic impact study of water harvesting and inclusion of harvested water in CropOptimiser to be undelivered.

Success for a project such as this requires building local capacity to understand and use the developed technologies. Therefore education and training has been a key objective targeting key scientific individuals, government officials, extension officers and rural community leaders and farmers. This was undertaken on two levels including training key local scientists and engineers in developing and applying specific components of the decision support technologies, and promoting climate-based agricultural management at the government, rural and field levels.

During the project, local scientific capacity was developed to have a limited but useful understanding of the hydrological modelling, seasonal climate forecasting and decision support component. The lack of experience with the application and use of these new technologies means that a level of guidance will be required for a number of years. A number of individuals associated with the project now possess a high level of proficiency in key project areas such as agricultural management, linear programming, and climate applications, with some having undertaken higher education as a part of this project. While the project has not developed enough scientific capacity to internally replicate the scientific development, there is sufficient knowledge and skills to manipulate and apply outputs into the local community.

At this stage, it is unlikely that there is sufficient field-level capacity to collectively and effectively implement the outputs from the decision support tools to improve irrigated agricultural management. This is despite efforts to promote the importance and background theory of climate and risk management in agriculture. Evidence also suggests that there is still a reluctance to change practices. In August 2007, this was addressed at a workshop in Toowoomba facilitating the development of revised communication and capacity-building plans. It was recognised that the low level of schooling of farmers (<25% have ever attended school) poses special difficulties when implementing new practices, although this is compensated by the strong role of government agencies in agricultural decision-making. Therefore agencies such as BPTP NTB (Balai Pengkajian Technology Pertanian), WOC (Water Operation Centre), Dinas Pertanian, BMG and the University of Mataram have been specifically targeted in training workshops in both Indonesia and Australia. Computer packages such as FlowCast and CropOptimiser have since been demonstrated as tools for policy makers during such events. Informal meetings with policy makers, farmers' group leaders and water user association leaders are also seen as an important mechanism in promoting an understanding of these technologies.

Despite these attempts at capacity building and dissemination, local communities have yet to receive any tangible benefit from the project outputs. While the theoretical benefits of the project have been extensively documented, significant real impacts are yet to be seen and a general reluctance to change practices at the field level. Indirectly, the communities have received some benefits from the increased exposure to trained officers at experimental sites, facilitated focus group discussions and village level workshops with local farmers, village leaders and traditional elites. Stakeholders should now have greater climate awareness, and an increased agricultural support network.

This research has provided a clear framework for conducting further studies on the impacts of climate change and climate variability in the region. We recommend that ACIAR consider the following options to further build on the achievements of this project using remaining funds:

- Objectives which were not met during this study should be followed up in subsequent projects to ensure the benefits of this research are maximized.
- A study should be conducted to implement operationally the cropping strategies provided by the CropOptimiser software for at least three cropping seasons to assess the validity of the outputs and how they relate to real-world performance.
- A range of workshops on climate awareness, seasonal climate forecasting, and climate risk management should be undertaken across Indonesia using the FlowCast software.
- Promote the use of the HowLeaky water-balance model to agricultural researchers in the region to evaluate and compare different land-uses and cropping systems.
- Consideration should be given to applying the technologies developed in this project to other regions of south-east Asia.

2 Background

Approximately 25% of Indonesia's croplands are irrigated, with the majority used for paddy rice production. Historically, drought has had a devastating effect on rice production, rural livelihoods and the general economy in the region. Droughts, and consequently low rice production years, tend to be linked to El Niño events associated with El Niño Southern Oscillation (ENSO). These events can be forecast with some accuracy using seasonal climate forecasts (SCF).

The ACIAR project LWR2/1996/215 "Capturing the benefits of seasonal climate forecasts in agricultural management" (1999–2001) conducted in the eastern Indonesian island of Lombok, showed that while rainfall in this region during the main wet season (Jan–Apr) is not predictable, rainfall in the transition months (Oct–Dec, May–Jul, Aug–Sep) can be predicted with significant forecast skill. On this island, much of the cropping (about 60,000 ha) is irrigated by stream diversion. Preliminary project modelling of streamflow and irrigated cropping in this system suggested that using SCF to plan cropping ahead of the wet season offered the prospect of significantly increasing productivity of the irrigation system and reducing the risk of crop loss. This parallels the results of using SCF throughout southern Queensland as an input to management decisions such as deciding on the area of irrigated cotton to be planted.

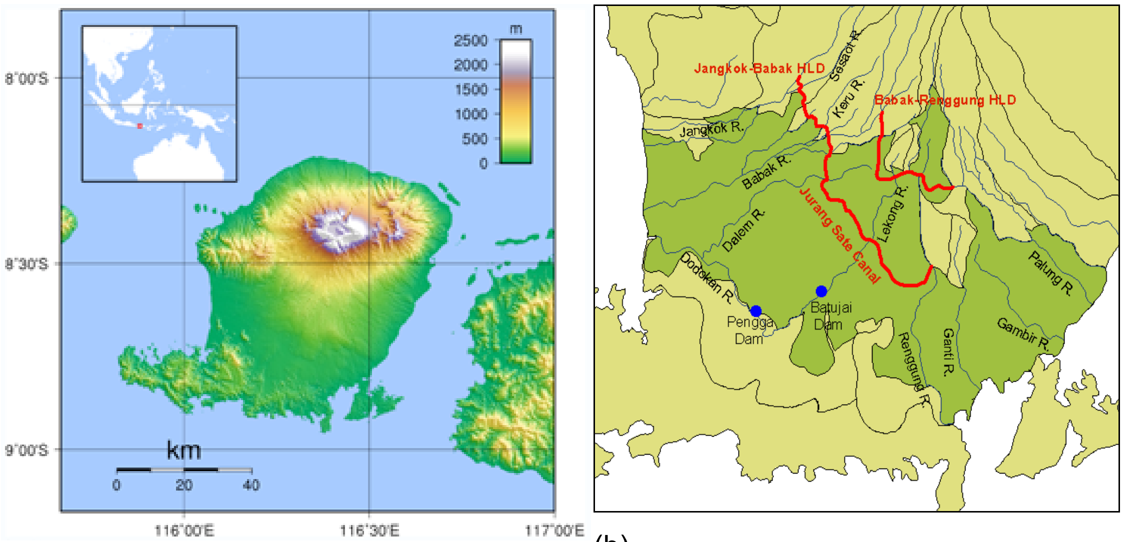
The review of LWR2/1996/215 recommended consideration of a new project in Lombok to apply the potential of SCF to manage the irrigation system. This was supported by Indonesia-ACIAR country consultation in August 2002. Subsequently, with ACIAR's encouragement, discussions between the project leader and organisations in Lombok, led by the University of Mataram, resulted in the development of this project SMCN/2002/033 "Seasonal climate forecasting for better irrigation system management in Lombok", which commenced on 01 July 2004. The overall aim of this project is to use SCF to better optimise Lombok's irrigation agricultural and water resources to achieve greater and more secure crop production.

A meeting held in March 2005 with Dr Yahya Abawi (QCCCE), Dr Christian Roth (ACIAR) and Dr Judy Tisdall (La Trobe University), resulted in an expansion of project objectives to include water management at the farm level. This was designed to address recommendations made by an external review of another ACIAR project SMCN/1999/005 "Improved soil management of rainfed Vertisols in Southern Lombok" in December 2004. This project stated measured benefits from permanent raised bed (PRB) farming of a 50% improvement in water harvesting and over 100% increase in rice yield compared to traditional paddy-grown rice (gogorancah).

2.1 Study area

The study area for this project is located in the agricultural catchment area of southern Lombok, West Nusa Tenggara province, Indonesia. Lombok is part of the Lesser Sunda Islands in the eastern part of the Indonesian Archipelago located between latitudes 8° 12′ and 9° 01′ South and longitudes 115° 46′ and 116° 43′ East. It is roughly circular in shape, being about 70 km across, and covering a land area of approximately 4,800 km^2 (www.wikipedia.org/wiki/Lombok; CIDA and Crippen, 1975). It is one of more than 17,000 islands located within Indonesia in Southeast Asia. The Indonesian Archipelago is located between 15° S and 8° N and 90° to 140° E, and shares boarders with Papua New Guinea, East Timor, Malaysia, Brunei, Singapore, the Philippines and Australia.

Lombok Island (Figure 2.1a) is dominated by a ridge of volcanic cones including Mt. Rinjani (3726 m)1 that run across the island from east to west dividing the island into unequal parts. The larger part that is about two-thirds of the island lies to the south of the ridge; the rest lies to the north (Le Group AFH, 1993). Typically, the land slopes very steeply from the ridge crest to the bases of volcanic cones. From the base, the land slope gradually reduces until it reaches the sea in the southeast and the southwest. A band of low hills runs from the southwest coast to the south central part of the island. Gently sloping land, which forms the majority of the cultivated area lies between the mountain range and southern hills (CIDA and Crippen, 1975).



(b)

(a)

Figure 2.1 (a) Topography of Lombok showing centrally-located volcano Mount Rinjani (3,726 m) that last erupted in June-July 1994. (http://upload.wikimedia.org/wikipedia/commons/b/bb/Lombok_Topography.png). (b) Map of Lombok Island showing the catchment study areas (dark green), rivers, storages (blue dots) and high level diversion canals (red).

The climate of Lombok is tropical, having distinct dry and wet monsoonal periods. The dry season lasts from May to October and the wet season runs from November to April. Rainfall can vary significantly between seasons and regions. Parts of the island are quite wet, while other areas are dry and can have long periods of drought and famine.

Rivers are the main source of water supply for irrigation in the study catchment. The major rivers in Lombok are Jangkok and Babak flowing to the west, Renggung to the south and Palung to the southeast. In the middle are Lekong River and Delem River. The upper catchments of the western flowing rivers lie within the highest rainfall zone on the island, and all these rivers are characterised by high flows.

The western part of the island is generally wet and has less agricultural land due to the steep topography of the land. In contrast, most of the productive agricultural land is in the central and southern part of the island which is in a drier zone. Two diversion schemes (High Level Diversions - HLD) have been built to divert water from the western part of the island to the central and southern region, where there are recurring water shortages. The Jangkok-Babak HLD canal transfers water from the Jangkok/Sesaot/Keru Rivers to the Jurang Sate canal. The second HLD transfers water from the upper reaches of the Babak River to the Renggung River, with an extension to the Palung River. The river systems in Lombok are

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1 Other peaks include Mt. Condo (2947 m), Mt. Sangkareang (2588 m), Mt. Buanmangge (2895 m), Mt. Pusuk (2330 m), Mt. Daya (1914 m) and Mt. Punikan (1400 m).

regulated through a series of weirs and two main storages, Batujai Dam with a capacity of 27 GL and Penga Dam with a capacity of 25 GL (Figure 2.1b). In excess of 65,000 ha of land is currently under irrigation (mainly for rice) and has available an annual irrigation water diversion of about 850 GL (Table 2.1).

Table 2.1 Annual diversion and irrigation area in Lombok catchment.

Region	Annual Diversion (GL)	Irrigated Area (ha)	Water (ML/ha)
North	407.5	29,927	13.6
Middle	259.5	17,274	15
South	183.6	17,841	10.0
All Regions	**850.6**	**65,042**	**13.0 (avg)**

Rice is the primary crop grown in the study area (and throughout Indonesia). Rice provides food security for farmers and their families, while the government recommends the crop for national and regional food security. Generally where water is accessible, farmers will try to grow two crops of rice a year followed by alternate secondary crops. However, with a three to four month wet monsoon season, rice can only be grown once without irrigation. The average cropping intensity each year ranges from 1.75 to 2.25 crops. Total rice production is estimated at 800,000 tonnes of unhusked rice grain per annum, which equates to about 150% of the annual demand for the three million inhabitants of Lombok.

Secondary crops such as chillies, corn, soybeans, mungbeans and cowpeas are grown in the second growing season. While legumes are very simple to grow, requiring little maintenance during the growing season, they contribute lower income than chillies or vegetables. Tobacco is a cash crop grown which is usually planted in the lowland areas during the second growing season around May to August and is rarely planted at other times.

High climate variability coupled with inadequate water distribution systems in this region makes water security for cropping uncertain, which leads to frequent crop failures. In El Niño years, the onset of the monsoon season is later than normal, causing delayed planting and reduced yields. La Niña years offer the possibility of advancing the planting season, leading to increased harvest yields as well as the possibility of planting an addition crop. Knowledge of the type of wet season to be expected would therefore permit better planning of water allocation and cropping and this observation forms part of the basis of this project.

2.2 Project context (relationship to previous ACIAR research and other research)

The ACIAR project LWR2/1996/215 “Capturing the benefits of seasonal climate forecasts in agricultural management” (1999–2001) was a pilot project for this research, focusing on water and crop management in Lombok. It developed an integrated systems approach linking climatic, hydrologic, agronomic and economic components for identifying the potential of climate forecasts in managing the local agriculture (Abawi et al. 2002; McBride et al. 2001). The climate of eastern Indonesia was found to be strongly influenced by the El Niño Southern Oscillation (ENSO) phenomenon: in particular rainfall in the transition months (Sep–Dec) is strongly related to the Southern Oscillation Index (SOI), as are the first rice crop yields.

Progress was made in developing a generic river basin simulation model that can be applied to quantify stream flow and water diversion in response to rainfall in Lombok and to assess possible impacts of climate variability. However, the calibration of the model was not completed.

A prototype linear programming (LP) model, comprising the irrigation system structure and regional crop and soil information was developed for the optimization of cropping strategies that best suited current climate, water, land and market requirements. Initial runs with the preliminary Lombok model, in which cropping patterns were adjusted according to the SCF, showed significant economic benefits. Taking full advantage of favourable climatic conditions and maximising returns through timely tactical adjustment (e.g. choice of crop and area to plant) is extremely important since there are few other opportunities to improve returns in unfavourable years. In the preliminary analysis, the greatest benefits were achieved by increasing land utilisation through selecting crops that best suited expected climatic conditions. These recommendations could be enforced through the local authorities with a survey of Lombok farmers revealing a tendency to accept recommendations of the authorities when it came to water availability and which crops to plant.

The results of the cropping study (Table 2.2) showed that rice planted in the first two cropping seasons of an El Niño year represents 64% and 31% of the total irrigation area (65,000 ha). This is increased to 88% (first season) and 36% (second season) during a La Niña year. The decrease in planted rice area in El Niño years is compensated by an increase in cropping area of legumes which require less water. In the optimisation of cropping systems in the region, rice is given preference (subject to government limitation) if water is not a limiting factor. In a water-limited situation this constraint is relaxed to allow for planting of non-rice crops, which are less demanding on water. Table 2.2 highlights that in a La Niña year the percentage of total cropping area in each season is 100%, 90% and 80% respectively. By comparison these percentages are 97%, 77% and 50% in an El Niño year. Given that rainfall and streamflow are predictable, this increase of 13% (second season) and 30% (third season) in area cropped (total area 65,000 ha) represents a significant economic boost to the region. Preliminary analysis based on the data in Table 2.2 shows that additional net benefits ranging from US$42 to US$133 per hectare per season could be derived from forecasting favourable years (assuming 70% forecast accuracy). The main increases in profits are in season 2 and season 3. These figures are based on the assumption that the opportunity for increased profits mostly occurs during La Niña years and the normal cropping pattern is that of a non-ENSO year.

Table 2.2: Preliminary findings from LWR2/96/215.

Crop Type	El Niño			Neutral			La Niña		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Rice	64%	31%	0	68%	27%	0	88%	46%	0
Maize	3%	0.1%	1%	1%	2%	1%	0.3%	0.5%	2%
Legumes	18%	13%	36%	24%	5%	44%	4.5%	5%	24%
Chillies	1%	6%	8%	3%	5%	9%	1.4%	4.4%	7.4%
Vegetables	11%	11%	5%	6%	19%	10%	5.6%	26.5%	47%
Tobacco	0	15%	0	0	8%	0	0	8.3%	0
Total	**97**	**77**	**50**	**100**	**66**	**62**	**100**	**90.4**	**80**

Less than half of the necessary and readily available detail for the complete decision support model was developed in the project. The pilot project made little attempt to gain acceptance of the model as a tool by the irrigation managers and farmers. Following the review of the project in September 2001 and subsequent discussions with ACIAR Program Manager and the Indonesian BAPPEDA (Department of Regional Planning and Development), university staff, Water Resources and BMG, there was a strong support for continuation of the above research so that the full potential of the initial project results could be realised. At the country consultations meeting held in Jakarta in mid 2002, the Indonesian Government representatives and ACIAR gave their support for further research.

In March 2005 a meeting was held in Brisbane to discuss further project tasks and objectives as an outcome to another ACIAR project SMCN/1999/005 “Improved soil management of rainfed Vertisols in southern Lombok” which was led by Judy Tisdall (La Trobe University). This project was involved in the development of the ACIAR Cropping Model (ACM) where a third of the land is sown to vegetable crops grown on permanent raised beds (PRB) and the remaining two-thirds to rice and soybeans on conventional furrows during season 1 (wet season). This allows additional irrigation water and runoff water available for irrigating vegetables for one or two sequential vegetable crops during the dry season if adequate storage is available. This previous project raised questions requiring further investigation, namely:

- What is the average runoff volume during the first cropping season?
- How variable is the runoff volume from year to year?
- How sensitive is modelled runoff volume to changes in soil types, crop selection and land management? and,
- What are the implications of storage design on irrigation water availability?

Given the significant synergies between the two projects, this project was consequently commissioned with the additional objectives of addressing these questions and investigating if SCF skill exists for predicting in-crop runoff volumes prior to the first cropping season to aid in the decision to trade cropping land to water storage and vice versa.

3 Objectives

This project aims to develop the methodologies, tools and local capacity to use seasonal climate forecasting to predict seasonal water availability and achieve greater and more secure crop production, through the tactical adjustment of cropping.

Key objectives of the project are to:

- Obj. 1 Collect, synthesise, model and collate hydrologic and climatic data for integration into the decision support tools
- Obj. 2 Develop decision support tools for optimising choice of crop, crop area and irrigation water allocation based on seasonal climate information
- Obj. 3 Promote SCF-based planning amongst irrigators, government officials and community leaders
- Obj. 4 Build local capacity in the development and operational use of decision support systems.

An additional objective as a result of the project expansion was to:

- Obj. 5 Address the external review recommendations of SMCN/1999/005 through a study of farm level water resource management.

These objectives will now be defined in more detail with listed outputs and assumptions.

Objective 1: Simulation analysis to assist in the use of SCF as an operational tool in water and crop management

Outputs

1.1 An analysis of how ENSO affects the agricultural production at a regional level.

1.2 An information base of climate, hydrological, economic and agronomic data leading to improved risk management.

1.3 A database containing simulation results covering a range of climate scenarios, allocation decisions and planting options.

Assumptions:

Some validation is necessary.

The analysis may be limited to selected climate scenarios where forecasting skill is found to be high.

Objective 2: Development of decision support tools.

Outputs:

2.1 Calibration of the IQQM model to be used in water allocation studies.

2.2 Refinement of the LP model developed from previous ACIAR project.

2.3 Development of the CropOptimiser interface.

2.4 Development of FlowCast Software.

Assumptions:

Streamflow and irrigation diversion data can readily be obtained from Indonesian sources.

Calibration of the IQQM model is a major task and requires long historical data. Simple algorithms and rules-of-thumb will be developed to expedite the calibration process with no significant loss in accuracy.

Data synthesis may be necessary.

Objective 3: Consultation and information dissemination.

Outputs:

3.1 Conduct five workshops explaining the use of climate forecasts in agricultural production and natural resource management. The workshops are to coincide with key decision points in the production cycle.

3.2 An additional ten to twenty workshops are planned using local funding.

Assumptions:

Government extension officers are the primary target audience.

Dissemination of information to farms will be primarily via government advisers.

Objective 4: Capacity building.

Outputs:

4.1 Training of two Indonesian staff in the calibration and application of the IQQM model.

4.2 Training of up to twenty staff in the use of FlowCast and CropOptimiser decision support tools.

Assumptions:

Training requires staff to have sound understanding of climate processes.

Background training in climate required by some staff.

Advanced climate training will be provided to key personal.

Objective 5: Farm-level water resource management

Outputs:

5.1 Conduct a review of the current and potential extent and usage of groundwater for irrigation in southern Lombok.

5.2 Conduct a water balance study and crop modelling to independently validate or test the plausibility of the water balance determined in SMCN/1999/005.

5.3 Evaluate the potential impact of additional water from the water balance study and assess the impact of water harvesting on the scheme irrigation and water allocation decisions.

5.4 Apply these results in CropOptimiser to determine the best cropping system in different regions and seasons where water harvesting and storage is feasible.

5.5 Conduct an economic impact study of water harvesting and re-use at the farm and irrigation command level (sub-districts).

4 Methodology

The research undertaken in this project represents a series of interconnected sub-projects (often undertaken in parallel) coordinated using a "systems" approach (Figure 4.1). That is, the outputs of each sub-project provide the inputs to one or more other sub-projects. These sub-projects can be broadly categorized into:

- "Systems-modelling" (science) components (e.g. Figure 4.1 blue elements); and
- Capacity-building and information dissemination components (e.g. Figure 4.1 green elements).

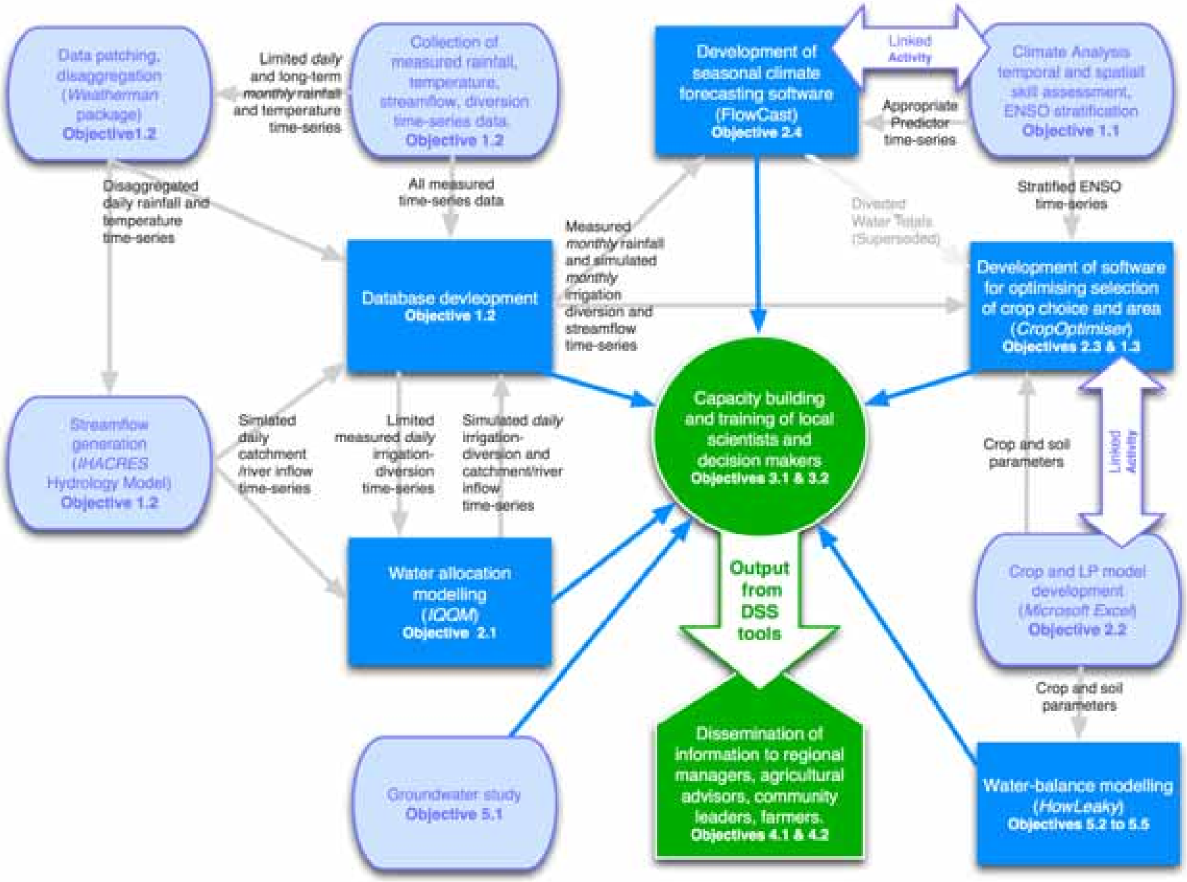

Figure 4.1 Overview of systems-approach of project methodology, showing key decision support tools (blue rectangles) and the relationships between processes.

The science components aim to collect, patch and synthesise meteorological and hydrological data, and to develop the water allocation model IQQM (Integrated Quality Quantity Model, NSW Department of Land and Water Conservation, 1998a,b,c,d,e) to simulate monthly irrigation water availability throughout southern Lombok. These outputs can then be used in the FlowCast and CropOptimiser decision support software (both of which are developed in this project) to incorporate seasonal climate signals into cropping and water decision making. Outputs from these tools (as well as the tools themselves) are then made available to key Indonesian personnel for capacity building and dissemination of findings.

The key sub-projects that were undertaken include:

1. Climate analysis (Objective 1.1)

- to understand the climate of Lombok and Indonesia
- to determine how global climate affects the study area to determine how best to derive seasonal climate forecasts
- to examine the spatial and temporal predictability of local meteorological, hydrological and agronomic time series data.

2. Hydrological modelling (Objectives 1.2, 1.3 and 2.1)
   - schematically representing the river system
   - collecting data for model input
   - pre-processing, patching, and synthesis of input data (using Microsoft Excel, Weatherman)
   - modelling/extending catchment river inflows (using IHACRES)
   - modelling diverted water for irrigation (using IQQM).
3. Development of crop optimisation (linear programming) model (Objective 2.2)
   - identifying crop, soil, and water parameters
   - identifying physical and social/political constraints
   - developing the mathematical linear programming model
   - validating the results.
4. Development of decision support software (Objectives 2.3 and 2.4)
   - developing the FlowCast software to accommodate the Indonesian and Lombok forecasting requirements
   - developing the CropOptimiser software through incorporating LP model, IQQM and climate outputs.
5. Assessing supplementary irrigation resources (Objective 5)
   - studying Lombok's groundwater potential
   - performing a water-balance study of harvesting runoff water using HowLeaky simulation software.
6. Capacity building (Objective 3)
7. Information dissemination (Objective 4)

4.1 Methodology for climate analysis

Seasonal climate forecasting (SCF) is used throughout the world to provide medium-term and seasonal predictions of rainfall, temperature and streamflow for use in natural resource and agricultural decision-making. These 'outlooks' are typically generated through a historical comparison of the predictands[2] of interest and predictor data to relate the current conditions to historical trends. Predictor data commonly used include ENSO indices such as sea-surface temperatures (SST) and the Southern Oscillation Index (SOI). The resulting forecasts are probabilistic in nature, and can be associated with a measure of skill, to relate how well that particular forecasting strategy has performed in the past. The magnitude of the skill will typically vary from location to location, and for different periods of the year, lead

[2] *Predictands refer to the type of data that we wish to forecast such as rainfall, temperature or streamflow.*

times, and season lengths. Therefore, an understanding of the nature of the skill is necessary to maximize the effectiveness of the forecasts for use in decision-making. (A background to seasonal climate forecasting and skill assessment is provided in Appendix 2)

In Australia SCF has a proven potential to increase the economic viability of cropping systems by increasing the probability that crop management decisions are attuned to expected seasonal conditions. Much of this research has been carried out in the cropping systems of north-east Australia and has been implemented using simulation models such as the APSIM cropping systems model (McCown et al. 1996). Meinke and Stone (1992), Hammer et al. (1996) and Abawi et al. (1995) reported simulated benefits from using SCF in the management of rainfed crops in South East Queensland. Abawi et al. (2001), in a study on the impact of seasonal climate forecasts on irrigated cotton in the northern Murray Darling Basin, found that the use of tactical strategies (changing planting area according to SOI forecasts) resulted in significant increases in gross margin and reduced risk (variance in gross margin).

A prerequisite for using SCF for tactically adjusting cropping in Lombok is that rainfall in the study area is predictable using ENSO-based predictors. This was demonstrated through the ACIAR project (LWR2/1996/215, “Capturing the benefits of seasonal climate forecasts in agricultural management”, 1999-2001) which showed that Lombok rainfall is predictable outside of the January to April wet season using ENSO-based predictors. However, to utilise this information in a practical role, many further questions need to be answered including:

1. Which are the best predictors of Lombok rainfall, and what is the temporal and spatial nature of forecast-skill?
2. Which are the best predictors of Lombok catchment/river inflows and diverted water volumes, and what is the temporal and spatial nature of forecast-skill?
3. How is rice production affected by ENSO?
4. Can the onset of the monsoon be predicted?

The study requires a thorough understanding of the drivers of climate in Lombok and Indonesia, to ensure that the analysis is undertaken using appropriate methodology (including choice of predictors) and is free from artificial skill. This includes reviewing existing literature on the climate of the region and the influences of global climate phenomena.

To undertake the numerical assessment of forecast skill, FlowCast version 4 (developed as part of Objective 2.4) was used with both discriminant analysis and stratification based predictive systems. Hindcast-based LEPS (Linear Error in Probability Space) skill scoring system was used to quantify and evaluate the predictability of the local climate variables. An overview of each methodology is presented in Appendix 2.

FlowCast requires three different data inputs: (1) predictand data (the variables we wish to forecast); (2) predictor data (climate indices such as SOI and SST); and (3) an ArcView 'shape-file' map of the catchment study area. Appendix 1 presents a list of rainfall predictand data used in this study sourced as part of the data-gathering phase of the project. These stations were chosen because they had the longest datasets available for the study. However, all of the evaluated data still contained some degree of missing data, while there were some discrepancies between data from the different sources for some stations. Twelve different ENSO-based predictor combinations (forecast systems) were evaluated in this study including monthly SOI values and variations of sea surface temperature anomalies in the Indian and Pacific Oceans (Table 4.1). A range of SSTaEOF data[3] (Jones, 1998) were chosen based upon the closeness of the geographical location of their representative signals (see Appendix 2.1.3) to Indonesia.

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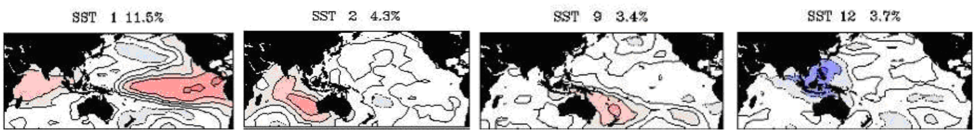
[3] *Sea Surface Temperature anomaly, Empirical Orthogonal Function.*

Four studies were conducted to assess the skill of forecasts of seasonal rainfall in Indonesia, and seasonal rainfall, streamflow and the onset of the monsoon in Lombok. The relationship between rice yield and ENSO is also investigated using a simple historical analysis. Rainfall and streamflow forecasts were investigated for three, six and nine month durations. Forecasts for the onset of the monsoon were generated by transforming Lombok daily rainfall time series into “dry-days” since 01 October where a “dry-day” is defined as being the accumulation of less than 50 mm of rainfall in the previous 10 days. A small software application was developed for this purpose, which has now been incorporated into FlowCast.

The study is undertaken by comparing LEPS skill score outputs both spatially (Indonesian and Lombok scales) and temporally (time of year, outlook duration, lead time) for each predictive system and predictand type. Results are presented through a range of graphical outputs with numerical summarisation. The results were regenerated several times during the project with the availability of new and improved predictand data, and with updates of the FlowCast software.

Table 4.1 Predictive systems used in FlowCast for skill analysis. Note: “Strat.” refers to stratified climatological forecast, and “DA” refers to discriminant analysis.

	Predictor Name	Description	Start Date	Method
1	SOI Phases	5 phases of monthly SOI: Consistently Negative; Consistently Positive; Rapidly Falling; Rapidly Rising; and, Near Zero (Stone and Auliciems, 1992)	Jan 1899	Strat.
2	3 category SOI Values	3 mth avg. SOI based on: low SOI (SOI<-5); medium SOI (-5<=SOI<=5); and, high SOI (SOI>5)	Jan 1889	Strat.
3	SOI Values(DA)	3mth avg.	Jan 1889	DA
4	ENSO Phases	Rob Allan’s ENSO phase defn (Allan et al. 1996)		Strat.
5	SSTaEOF1	2mth avg. SST (Central Eastern Pacific Signal)	Jan 1949	DA
6	SSTaEOF2	2mth avg. SST (Western Indian Ocean Signal)	Jan 1949	DA
7	SSTaEOF9	2mth avg. SST (South Western Pacific Signal)	Jan 1949	DA
8	SSTaEOF12	2mth avg. SST (Indonesian Region Signal)	Jan 1949	DA
9	SSTaEOF1&2	2mth avg. SST	Jan 1949	DA
10	SSTaEOF1&9	2mth avg. SST	Jan 1949	DA
11	SSTaEOF1&12	2mth avg. SST	Jan 1949	DA
12	Nino3.4 SSTa	1mth avg. SST	Jan 1950	DA



4.2 Hydrological modelling

The purpose of the hydrological modelling in this project is to use the IQQM water allocation model to simulate monthly irrigation water availability throughout the Lombok irrigation scheme for use in the FlowCast and CropOptimiser decision support software. At least fifty years of IQQM output data is required by FlowCast and CropOptimiser to provide adequate training lengths for forecast generation. Therefore, at least fifty years of daily streamflow is required for input into IQQM to generate these outputs. However, in this study, only around six years of measured daily streamflow data were available in most areas, and daily weather data was of limited and poor quality. Therefore, a rainfall-runoff model (IHACRES) was required to extend the daily streamflow data for the fifty-year duration, coupled with extensive stochastic weather data generation (Weatherman) for input into the model.

A summary of the hydrological modelling process is represented in Figure 4.2, showing the key software packages used (Weatherman, IHACRES and IQQM), input and output hydro-meteorological data (types and lengths), and the sequence of modelling events. During this process, long-term observed monthly and limited observed daily rainfall and maximum and minimum temperature time series are gap-filled before inputting into the Weatherman package to stochastically extend the daily data time series by matching the monthly patterns. Three disaggregations of daily meteorological time series are generated for input into the IHACRES model, along with limited catchment river inflows to calibrate the model. IHACRES is run for each set of disaggregated data to extend the limited observed daily catchment river inflow data for use in the IQQM model. Calibrated using limited observed daily irrigation diversion data, IQQM can then simulate 51 years of daily streamflow and irrigation diversion data. This procedure, along with the setup and data collection processes, will now be discussed in more detail in the following sections.

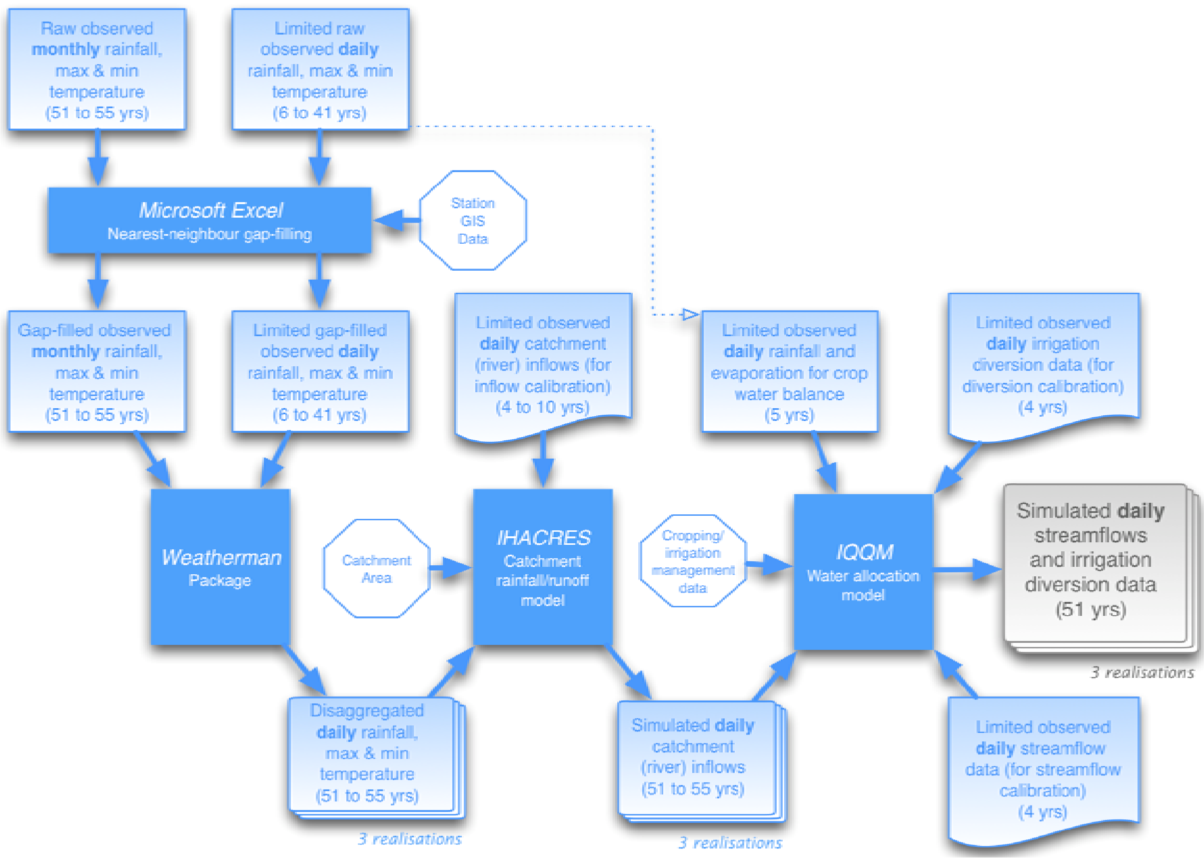


Figure 4.2: Hydrological modelling process for determining historical water use (diversion) in the Lombok agricultural catchments.

4.2.1 River system configuration

The first step in modelling a river-irrigation system using IQQM is to schematically define all of the physical features and management rules of the system. In IQQM, the systems to be analysed are represented by a series of 'nodes' interconnected by 'links'. Inflows, storage, irrigation, outflows and other point processes are associated with 'nodes', while flow routing processes are associated with 'links'. For Lombok, this involves developing nodes and links for about 64,000 ha of irrigated lowlands, from Jangkok system in the northwest to Jerowaru in the southeast. The nodes defined in this network will be later mapped onto predefined irrigation sub-areas for use in CropOptimiser, based on both practical and computational considerations.

4.2.2 Hydro-meteorological data collection

The collection of the data required to support the modelling and decision support roles of the project was a major task. The data were not readily or easily available and had to be obtained from a range of sources including the meteorology office, agricultural agencies, public works office and even from the individual field officers collecting and archiving the data. Most of the data were handwritten hardcopies and had to be painstakingly digitised by hand into computer form (Figure 4.3).

Figure 4.3 Examples of data storage and digitisation of Lombok meteorological data.

The hydrological models rely on daily weather data such as rainfall, temperature, solar radiation and humidity to simulate daily streamflow located in or around the catchment study area. For the Lombok situation (which didn't require the modelling of storages) the prominent data that was required included:

- limited daily and long-term monthly rainfall data
- limited daily and long-term monthly maximum and minimum temperature
- limited daily catchment river inflows
- limited daily observed irrigation data.

The data were collected from six main sources including: BMG (Badan Meteorologi dan Geofisika); HU (Hydrology Unit); BPTPH (Balai Proteksi Tanaman Pangan dan Hortikultura); CIDA and Crippen (Research Report, 1975); WOC (Water Operation Centre); and IWO (Irrigation Watcher Office). Information on catchment areas was available in published records and research reports (CIDA and Crippen, 1975; McDonald and partners Asia, 1986; Le Group AFH, 1993).

It is intended that the collected (and modelled) data will be archived under an internet-based database system. It will also be made available on CD to facilitate future research and analysis, particularly dealing with water resource management in Lombok. The data will be stored in its original digital form, as obtained from the sources. In the future, the hydrological database will be managed by the Research Centre for Water Resources and Agroclimate (RCWRA) of the University of Mataram. This research centre was initiated by members of this project and has been operational since 2006. Therefore, this important database can be continuously maintained and updated.

4.2.3 Hydro-meteorological data pre-processing, patching and synthesis

In order to obtain long-term daily streamflow data (river/catchment inflows) from the IHACRES model, long-term daily meteorological data (rainfall, temperature) is required as an input. While long-term monthly meteorological data were available, only short-term (6 to

41 years) daily meteorological data could be sourced, requiring the use of weather generating software to synthesise or 'disaggregate' the monthly data to its daily equivalent. This type of software uses stochastic algorithms to "part-randomly" generate daily data matching the monthly meteorological distributions, requiring several disaggregations of the data to account for the uncertainty in the process.

Several weather generating software packages were investigated for use in this project including WGEN (Richardson and Wright 1984), CLIGEN (Nicks and Gander 1994), ClimGen (Stöckle et al. 1999) and WeatherMan (Pickering et al. 1994)[4]. Considering the data formatting, data requirements, inter-annual variability of climate data and suitability to Lombok data situation (with the availability of long-term monthly rainfall), the WeatherMan program was adopted in this study. Weatherman generates daily meteorological data through estimating daily parameter values using a mean-preserving, segmented linear interpolation technique (Mavromatis and Hansen 2001). Its use was demonstrated by Hansen and Ines (2005) to disaggregate monthly rainfall by adjusting input parameters or by constraining output to match target rainfall totals.

Before the weather data could be input into the Weatherman package for daily climate data simulation, the gaps in both daily and monthly records were filled using a correlation technique based on neighbouring stations (DLWC, 1995). Altogether data from 45 stations were employed to determine neighbouring stations to fill gaps. The station providing the data for gap filling must have a continuous record over the gap period. If data from more than one station is available, then the data is taken from the station having the highest correlation with the site of monthly rainfall in the wettest month.

The gaps were filled by adjusting the daily rainfall at the station selected for gap filling by the ratio of mean annual rainfall from the station selected for gap filling and the station with gaps. The annual rainfall of the station with gaps must not exceed the annual rainfall of the neighbouring stations by more than 10% (McCuen, 1989). Long-term monthly rainfall data were calculated for all of the rain gauging stations and wettest months for the stations were detected. Cross-correlation analysis was conducted to determine the neighbouring stations.

4.2.4 Streamflow modelling using IHACRES

Many rainfall/runoff models have been developed for streamflow generation with differing input data requirements. Several were investigated for use in the Lombok project to best accommodate the local conditions and available data. This includes the Sacramento Model (Burnash et al. 1973), SIMHYD (Chiew et al. 2002), AWBM (Boughton 1993; Boughton and Carrol 1993) and IHACRES (Jakeman et al. 1990; Evans and Jakeman 1998) models. The IHACRES (Identification of unit Hydrographs And Component flows from Rainfalls, Evaporation and Streamflow data) model was eventually adopted for this study because of its simplicity and adaptability to limited data and diverse climate conditions. In other studies, IHACRES has been successfully applied to catchments with areas ranging from 500 m2 to nearly 100,000 km2 (Schreider and Jakeman, 2005).

IHACRES allows the simulation of streamflow either continuously or for individual events using discrete time interval data. IHACRES is able to identify unit hydrographs for total streamflow, rather than just for a direct runoff component of streamflow. IHACRES comprises two modules in series. The first module operates nonlinearly to calculate effective rainfall from rainfall and temperature data applying a non-linear loss module. A catchment-wetness-index or antecedent-precipitation-index, representing catchment saturation is calculated for each time step. The second module (the unit hydrograph) operates linearly to

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[4] *More recently developed weather generating software including USCLIMATE (Johnson* et al. *1996), CLIMAK (Danuso* et al. *1997), EARWIG (Kilsby* et al. *2007) and CLIMA (Dontalli* et al. *2008) were not available for consideration during this study.*

convert the effective rainfall to streamflow using a linear routing module. With three parameters in the first module, and typically three in the second, the IHACRES model is parametrically parsimonious. When good model-fits are obtained, the parameters characterize the hydrological response of the catchment.

Due to its minimal data requirements, IHACRES can be applied over many catchments without spending a long time preparing necessary input data. It requires only inputs of rainfall, streamflow and temperature time series and catchment area (no catchment descriptive data such as topography, vegetation, or soils). The model requires only time series of precipitation and temperature to simulate catchment runoff. Observed streamflow data are used for calibration.

The model calibration process is based on the Monte Carlo approach where in each simulation the settings of all model parameters are assigned randomly. Because of this, a large number of simulations are required in order to capture “all” possible parameter combinations. Croke et al. (2005b) reported that in temperate/humid catchments, a two to three year calibration period is usually sufficient.

4.2.5 Water diversion modelling using IQQM

The IQQM Lombok model was developed to estimate irrigation water availability by simulating river streamflows and irrigation diversions (and mercu) at key distribution points in the Lombok irrigation system. The choice of the hydrology and irrigation management model, its methodology and its role in this systems modelling process is based on the experiences of the Australian project team in undertaking similar research in South East Queensland (Abawi et al. 2001). The developed IQQM Lombok model requires two stages of calibration. In the first stage, for each irrigation node, streamflows (total streamflow at the irrigation node) are calibrated by fixing the recorded diversion values at corresponding irrigation weirs. Next the crop and soil moisture model in IQQM is activated to model the crop water requirement and to replicate the observed irrigation diversion flows.

The calibration of streamflow and diversion flows were undertaken using data from 01/01/1995 to 31/12/1999, covering five growing seasons. The calibration period was chosen based mainly on the data availability, and the ENSO occurrences during that period. In the record, 1995/1996 season was a neutral ENSO year, 1996/97 was a weak La Niña year, 1997/98 was an El Niño year, 1998/99 was a La Niña year, and 1999/2000 was a neutral ENSO year. This is to cover the three types of years: dry, wet and neutral years, so the calibration results could be accepted as valid stand-alone results.

Method and guidelines for streamflow (node inflow) calibration

The aim of flow calibration is to match the simulated streamflow (node inflow) with that recorded at each irrigation node. This is done through optimising the flow routing parameter values, tactically deriving the transmission losses and statistically estimating the catchment residual inflows. The detailed procedures for streamflow calibration have been described in the IQQM Reference Manual (NSW DLWC, 1998d). The main steps have been summarised as follows:

1. Assume zero transmission losses, zero initial values for residual catchment inflows and zero diversion outflows and route upstream inflows to the irrigation node.
2. Visually compare the simulated and the recorded hydrographs. Select single peak events (i.e. to obtain a similar-rise time and recession-time shape) and then maximize the r2 value by changing the lag time, storage delay k and non-linearity exponent m routing parameters. These parameters are from the Laurenson’s non-linear routing method, which is described in IQQM Reference Manual (NSW DLWC, 1998d). These parameters are adjusted until the best possible visual match between the

commencement of the rising limbs on the simulated and observed hydrographs is achieved. This produces calibrated routing parameters for each routing reach.

3. Derive the residual catchment inflows. After the water extraction (e.g. irrigation diversion) is subtracted from the flows, the simulated time series at the reach outlet is compared with the recorded values. The subtraction of the simulated and recorded time series is then correlated against the nearby catchment inflows. The best correlation to the new time series is selected as the residual flow. Through further comparison, multiplying factors can be derived and related catchment time series adjusted.
4. Calibrate the transmission losses and derive the loss function following Rob's Optimisation techniques (NSW DLWC, 1998), through successive comparisons of the ranked simulated and recorded time series data.

Appendix 9 presents guidelines for assessing the quality of streamflow calibration which tests the flow frequency of ranked daily streamflow by examining volume ratios (measured/simulated) for all flows, low flows, mid-range flows, and high flows. The match between the simulated and recorded flows is also checked at 5, 50 and 95 percentile levels (spot-checks). In addition, a regression analysis is undertaken to further evaluate the match between the simulated and observed daily flow time series.

Method and guidelines for diversion calibration

In the IQQM model, the irrigation diversion calculations are based on a water balance process. For irrigation demand calculations it is assumed that soil moisture is depleted only by the crop water requirements and is replenished by rainfall and irrigation applications. Other soil moisture losses are ignored. Details of calculations and curves are described in the IQQM Reference Manual (NSW DLWC, 1998d). In Lombok, the irrigation system is an unregulated one where the environmental flow is yet to be considered and water is extracted from the river whenever river flow is available. On-farm storage in Lombok is very rare so in this study the simulation of on-farm storage is not applicable.

In general, diversion calibration includes two steps:

1. Calibrating crop water requirements and diversion intake for each irrigation node using the recorded planting area to replicate actual diversion amounts
2. Removing observed data on planting areas and leaving them to be simulated by the model's own capability.

The parameters required to configure unregulated diversion nodes (IQQM type 9.3) are:

- Representative sites of rainfall and evaporation data.
- Crop-soil interception loss. Rainfall interception loss refers to the initial portion of a rainfall event that is used to fill initial soil moisture store before runoff occurs. It is assumed that this loss is a constant fraction of each rainfall event but may vary at different irrigation nodes due to variations in the physical and hydrological properties of surface soil in different areas. In this study, the method of calibrating initial rainfall loss is adopted from the Border Rivers System: IQQM Implementation (NSW DLWC, 1999a): the value is initially set to 3 mm and varied within a reasonable range (up to 8mm) by comparing each simulated and observed diversion volumes.

- Soil moisture storage depth. Soil moisture store is a determining factor that triggers an irrigation to meet crop water requirements if it is not met from the rainfall in IQQM. The soil moisture is simulated as part of the daily water balance. For example, soil moisture is depleted by crop requirements (evapotranspiration) and is replenished by irrigation and rainfall. When the simulated soil moisture falls below 50% of the soil moisture storage capacity (a function of soil and crop types), irrigation is applied equal to the crop requirement less the effective rainfall amount. In this study, the calibration of initial soil moisture store is adopted from the Border Rivers System: IQQM Implementation (NSW DLWC, 1999b): the calibration started from an initial value (say 330 mm) and then by varying this starting value and comparing simulated with observed diversion volume time series" until the best match was achieved.
- Crop selection, planting date, and area. In Lombok, there are three crops growing in one growing season. In the wetter western regions of Lombok, rice is sown in November and then harvested in February, and a second rice crop is sown in March and harvested in June. From July to October, a dryland crop such as vegetables or legumes is grown due to the low availability of irrigation water. In the drier eastern regions, the first crop grown is rice; however, the second and third crops are usually either vegetables or legumes. The crop mix pattern across the whole island has been listed in Appendix 8. The crop mix for each irrigation area in this calibration is set up based on the recorded proportion in the table.
- Crop efficiency refers to the efficiency of water application for each crop: a higher efficiency signifies that less water is required to meet the water demand of a particular crop, as a result of the lesser on-farm losses. There are variety of crops grown in Lombok, including rice, vegetables, chilli and legumes. Based on the crop efficiency parameters developed in the Murray Darling Basin and suggested in the literature, the anticipated range of crop efficiency for most crops is from 0.6 to 0.9. The calibration of crop efficiency in this study was undertaken following the general trial-and-error approach and by varying the parameter specified within the anticipated range at each irrigation node until the best possible match between observed and simulated total diversion volumes was achieved.
- Crop factors. The crop factors represent the water use patterns of particular crops and in this calibration they were modified from those defined in the Border Rivers System: IQQM Implementation (NSW DLWC, 1999) based on field survey conducted in Lombok in 2005.
- Pattern files for rice ponding depths. The daily ponding depths in this calibration are modified for rice from values presented in the Border Rivers System: IQQM Implementation (NSW DLWC, 1999) based on the field survey conducted in Lombok in 2005.

Parameters such as non-agricultural water extraction and river pumping constraints (which are usually required in implementing IQQM) were not explicitly included in the Lombok study. While water extraction from the irrigation channel for stock, fishing ponds and domestic use exist in each irrigation area they have not been individually recorded and are scattered throughout large areas (they may be reflected in the recorded diversions). In Lombok, town water is supplied from the groundwater resources and the contribution from river flow is not considered. Variables such as pumping threshold and volume cap were not required for the Lombok irrigation system.

The quality of calibration achieved is assessed though a graphical comparison between the observed and simulated annual and monthly diversions and through using the statistical criteria taken from IQQM Practice Notes (NSW DLWC, 1998) shown in Appendix 9. This includes measures of both annual diversion volume ratio (measured/simulated) and month diversion ratios (measured/simulated) in low, mid and high diversion flow frequency ranges.

4.3 Cropping optimisation (LP model)

Development of the Linear Programming (LP) model to maximize the profitability of the Lombok cropping system is one of the primary goals of this ACIAR project. A cropping system defines the pattern of growing crops in terms of crop combination and sequences in time and space, in addition to the practices and technologies with which the crops are produced (Fageria, 1992). Therefore, considerable information gathering was required to benchmark existing cropping practices in Lombok, and the social and political constraints which influence these practices. The local knowledge of the Indonesian project team contributed to identifying and defining these practices and also in translating this information into the LP model form using Microsoft Excel and the inbuilt Solver engine. This also involved developing and parameterising equations for estimating crop yield as a function of soil, water and crop properties using Excel.

4.3.1 Development of the LP model

The decision to use an LP model to optimise cropping choice is based on similar studies in agricultural management using LP and non-LP models to maximize the seasonal benefits of cropping in irrigation command areas (Berbel and Gomez-Limon, 1999). For example, Kodal (1996), Mainuddin et al. (1997), Raju and Kumar (1999), Benli et al. (2001), Singh et al. (2001) and Reca et al. (2001) all developed linear models to optimise cropping patterns to maximize profit. Some have developed nonlinear models to optimise cropping patterns under deficit irrigation (Carvallo et al. 1998; Benly and Kodal, 2003; Nagaraju Kumar et al. 1998) while others have optimized over consecutive seasons to maximize net annual return (Sethi et al. 2006). Others such as Dutta and Carter (1998) and Karya (1995) have focused on optimising water use and allocation for fixed cropping options.

In Lombok, the problem is associated with the irrigation of multiple crops in multiple cropping sequences in which water supply can be predicted using seasonal climate forecasting. None of these existing models were structured for this purpose, so a LP model was developed in this study to optimise cropping strategy for the Lombok requirements. The LP model was originally prototyped in Microsoft Excel using the Solver optimisation tools, before later being incorporated into the CropOptimiser software.

In general, LP models involve the optimization of a linear objective function subject to a series of linear constraints. They provide a means to maximize profit given a list of requirements presented as linear constraints. Mathematically, in canonical form, they can be expressed as:

$$Maximize\left[C^{T}X\right] \qquad (3.1)$$

$$Subject\ to\left[AX \leq B\right] \qquad (3.2)$$

where, Eqn. 3.1 is the objective function and Eqn. 3.2 is the matrix of system constraints. In these equations, X represents the vector of variables to be determined (in this case, crop-areas), C is a vector of objective function coefficients (crop profit factors), A is a matrix of constraint coefficients (water user or land-use coefficients), and B is a vector of constraint limits (land-use or water use limits).

The formulation of the LP model for the Lombok scenario was split into three components: formulating the objective function (maximization of profit); defining the fixed (physical) constraints; and defining the user-defined (social) constraints.

4.3.2 Model parameterisation

Having developed the mathematical formulation, the LP model required parameterising for Lombok conditions. This included parameters of the crops, seasons, climates, regions and water availability. Data and information came from a wide range of sources including government departments, University of Mataram, national and international cropping companies, grower groups, field studies and a survey conducted in 2006 for the planting year of 2004/2005.

In the survey, data were collected through a semi-structured interview with 76 farmers. Farmers were selected using proportional random sampling across irrigation canals (up stream, middle, and down streams). The survey tested the types and areas of crops planted, crop yields, management strategies, and factors that influence farmers' decisions to grow rice (discussed in Section 4.7 Information dissemination).

4.4 Development of decision support software

A key output of this project is the development of decision support software that can be used to analyse relevant data and be made available for building local capacity amongst the Indonesian scientists, engineers and decision makers. The two key software-based decision support tools include:

- FlowCast: to generate and analyse empirically based seasonal climate forecasts for any type of meteorological, hydrological and agronomic time series data.
- CropOptimiser: to optimize regional cropping choice and patterns for different seasonal, climatic, agronomic and social conditions.

The primary goal of the design of these decision support tools is to simplify and interface the science for use by unskilled users while providing the advanced analysis capabilities for specialists.

4.4.1 FlowCast

FlowCast was originally developed to generate probabilistic forecasts of streamflow and irrigation allocations in the project 'A decision support system for improving water use efficiency in the northern Murray-Darling Basin' (Abawi et al. 2001). It had evolved through several versions and by the onset of this ACIAR project, Version 3 was available and being used by the project team in a range of in-house applications and projects. However, even at this stage of its development, it was unsuitable for release to external users and had many limitations including:

- a complicated and non-standard interface design making it unintuitive to use
- it was not robust, and could be easily 'crashed'
- it had limited forecast generation (stratification based) and skill testing (hypothesis testing) functionalities
- it was not designed for performing spatial analyses
- its structural framework was limited (having evolved over several versions) making modification and maintenance difficult.

Therefore, it was decided to completely re-engineer a new version of FlowCast to develop an open stable platform to accommodate the functionality requirements of forecasting in Indonesia, focusing on both point-based ('station') and spatial analyses. This process was simplified through the work that the project team had already undertaken while developing the seasonal prediction software SCOPIC (Seasonal Climate Outlooks in Pacific Island Countries) for Pacific Island Country meteorological services (McClymont et al. 2009). While SCOPIC contained much of the forecasting and skill assessment methodologies required for this project, it was primarily designed for a limited number of predictand data. FlowCast was therefore designed around a structure that could accommodate a large number of predictand data for spatial analysis.

Several key design criteria have been recognized when developing FlowCast including:

- encapsulate the stratification and discriminant analysis algorithms into a standalone, easy to use, and easy to maintain software product
- encapsulate hindcast-based skill testing algorithms
- provide both spatial and temporal forecast generation and assessment capabilities
- input any type of monthly predictor data
- input any type of daily or monthly predictand data, including outputs from the IQQM model
- directly compare results from different predictands, predictors, rule-sets, and output types
- develop a simple graphical user interface tool for adjusting predictor and predictand periods
- provide detailed reporting of results including textural, chart, and GIS-based outputs
- develop a simple graphical user interface using state-of-the-art software engineering practices.

4.4.2 CropOptimiser

CropOptimiser has been continually developed throughout the life of this project from its beginnings as an Excel spreadsheet through to a stand-alone software application with inbuilt LP solver and advanced textural, charting, and spatial outputs. However, the key feature of the software throughout its development cycle is the central component of the LP model.

The LP model was originally prototyped and developed in Microsoft Excel using the inbuilt Solver engine for determining the optimum. Because of the difficulties in visualizing and presenting the outputs in Excel, work began simultaneously on the first version of CropOptimiser to import and automatically display the Excel outputs geographically. This version of CropOptimiser was unable to manipulate the LP model directly, but was designed to coincide with it and to generate and display polygons of different outputs overlaid on to the map of Lombok.

In 2004, CropOptimiser was rewritten to incorporate the LP model directly, including its own solver engine, and graphical user inputs to load, store and edit LP variables and constraints. Over the next four years it was enhanced and modified to simplify its coexistence with its companion decision support tools. For example, the ‘stratification engine’ in FlowCast was embedded into CropOptimiser to remove the need to run FlowCast separately, and to directly link with modelled water allocation and rainfall time series data from the hydrologic models.

During this development, key design criteria have been considered and addressed, in order to arrive at the current version. This includes:

- encapsulate the LP model for optimizing cropping choice and pattern into a standalone software product
- encapsulate a stratification algorithm to generate seasonal prediction information
- input ENSO time series data for input into the stratification algorithm
- input (and link) water diversion and rainfall time series directly from the hydrologic models to calculate available water
- provide a mechanism to simplify the inputting of both physical and social constraints

- develop a simple graphical user interface using state-of-the-art software engineering practices
- provide detailed reporting of results including textural, chart, and GIS based outputs.

4.5 Assessing supplementary irrigation resources

4.5.1 Groundwater extraction

A study was undertaken to determine the extent and potential of shallow groundwater for supplementary irrigation in Lombok. This involves reviewing previous groundwater studies in the region and undertaking a new groundwater survey in 11 shallow wells in Southern Lombok.

The new study is designed to better understand the characteristics of shallow groundwater and to assess the capacity of these wells for irrigating crops. The dug well diameter in the study area is one metre or greater. The water storage in the well influences the drawdown during the pumping test. As pumping continues, more water from the surrounding formation will contribute to the discharge and the drawdown will follow the Theis curve (Mace, 1999). Moreover, a dug well with diameter 1 metre and transmissivity of 1 m2/day will require 62 days of pumping before the drawdown curve will begin to fall on the Theis curve (Papadopulos and Cooper, 1967). Therefore drawdown data during the pumping test will not necessarily produce a good estimate of well yield. It is better to use the recovery data for this analysis, since the water filling the bore is sourced from the aquifer. In our study, we have used the recovery test data to estimate the well yield and rate of percolation.

Pumping and recovery tests were conducted in two different locations, namely Kawo and Tanaq Awu in South Lombok at different times: October 2005 (end of the dry season), January-February 2006 (wet season), and May 2006 (end of the wet season/early dry season). Altogether 11 dug wells were chosen to conduct pumping tests in these wells. However, nine dug wells (five in Kawo and four in Tanaq Awu) were used to conduct the test in October 2005. In January-February 2006 an extra dug well (Tanaq Awu) on the top of the previous list was available to conduct the tests. In May 2006, one dug well was omitted from Kawo but one new one was added from Tanaq Awu. In the end, field measurements were recorded in nine dug wells during October 2005 and May 2006, and seven dugs wells during Jan-Feb 2006.

In order to estimate the transmissivity of the formation, residual drawdown as recorded during the recovery test was plotted in the semi-log format using Microsoft Excel following time-drawdown graph (Theis recovery from Raghunath 1983), as there are practical limitations of using drawdown data. The transmissivity of the aquifer is given by:

$$T = \frac{2.3Q}{4\pi\Delta s} \qquad (3.3)$$

Where T is transmissivity, Q is pumping rate, Δs is residual drawdown per log cycle of time ratio.

Early on in the study, a standalone software package was developed called PumpTestAnalyser which could calculate the transmissivity from the drawdown data. It is mentioned here again that the testing period for drawdown was insufficient for the calculations and the recovery test was used instead. Therefore the software was not used in the final calculations of transmissivity. Also, it was not possible to determine the storage coefficient of the aquifer due to the limited data of drawdown test.

4.5.2 On-farm water harvesting

The potential for on-farm water harvesting was investigated using the HowLeaky (2008 Version, McClymont et al. 2009) water balance model. Simulation studies of in-crop runoff were conducted for the first cropping season (November to March). The meteorological data used in the simulations were for the farming region of Mangkung situated in southern Lombok, where irrigation water is limited and additional water capture from irrigation would be a valuable resource in the second cropping season. Selected crops simulated in HowLeaky were rice, tomatoes, soybeans, chillies, and melons grown in both the first and second cropping seasons. Lombok Black Vertisol and Sodic Brown Vertisol soils were selected for simulation as they broadly represent the range and majority of soils located in the irrigated lands within Southern Lombok.

HowLeaky soil and crop input parameter values were sourced from collaborating researchers in Lombok and referenced literature where available. Runoff results were presented as average yearly runoff values for the range of soils and crops simulated. Time series and probability distributions of in-crop runoff were plotted to demonstrate the annual and inter-annual variability in runoff volumes.

Simulated in-crop runoff from these studies was also imported into the FlowCast software to assess the ability to forecast in-crop runoff for the first cropping season. Sensitivity analyses were also conducted using HowLeaky through analysing each input parameter across the range of plausible values to quantify those input parameters requiring the greatest level of accuracy in terms of model parameterisation.

4.6 Capacity building

The major component of this project consisted of developing and refining the science for using seasonal climate forecasting to improve cropping profitability and water usage in the Lombok agricultural communities. For the implementation of the science to be sustainable in the long-term, strategies are required to transfer this scientific knowledge and capacity over to the Indonesian scientists, engineers and decision makers. It must be recognised that the outputs from this research are unlikely to be beneficial in the short-term (SCF is a long-term decision and risk management strategy) and requires a long-term stability and commitment from local experts.

The methodology adopted to build local scientific capacity centred on conducting a range of workshops and training sessions in both Indonesia and Australia. The goal of these exchanges is to develop enough scientific capacity in the local experts to manipulate, maintain and apply outputs of this research into the local community. It was not intended that local experts be able to internally replicate the science developed in this project, although some individuals could be expected to master certain components.

The decision support tools developed in this project will eventually be transferred to and applied by government agencies. In particular, FlowCast will be used by the Geophysical and Meteorological Bureau (BMG), CropOptimiser will be used by the Department of Agriculture (DOA) and IQQM will be used by the Agency for Public Works (DPW). Therefore the capacity building process needs to consider how to ensure the tools are well adopted by those agencies for their planning purposes, with likely institutional implications. Therefore the benefits of the technologies need to be clearly portrayed, along with the methodologies.

In summary, the key science areas addressed in the capacity building phase are:

- training all key personal in understanding seasonal climate forecasting – local exports can then transfer this knowledge onto the community groups and farms
- training DPW staff in IQQM calibration, modelling and management

- training BMG staff in FlowCast operation, including advanced training in applications of seasonal climate forecasting using the FlowCast decision support software
- training DOA staff in CropOptimiser operation.

4.7 Information dissemination

The information dissemination component of this project has been undertaken by the Indonesian project team utilising their extensive local knowledge to develop and implement a strategy. The focus of the dissemination task was on how best to transfer seasonal climate forecast information to regional, local and farm levels. Four separate tasks were involved:

- understanding the government infrastructure in place to disseminate the scientific outputs and identifying local barriers to dissemination
- identifying how Lombok farmers make decisions
- developing the dissemination plan
- implementing the dissemination plan.

Key tools in the dissemination process include workshops, focus group discussion (especially with farmers), demonstrations, and regular meetings with key stakeholders. Indonesian project personnel will play an important role in training key people in the government organisations, and other regional scientists.

A risk associated with this project is that completion of the scientific components occurs towards the end of the project, leaving insufficient time to fully implement the results in the field. Therefore a wide-scale climate training program to all key stakeholders was undertaken while the dissemination strategy was being developed. This recognises that the adoption of new technology or practice is an ongoing, long-term, dynamic learning process which involves gaining awareness, trialling, adapting, learning from the experience, evaluating, reflecting and making decisions on whether to adapt or continue the practice (Race and Millar, 2006).

5 Achievements against activities and outputs/milestones

Objective 1: Simulation analysis to assist in the use of SCF as an operational tool in water and crop management.

No.	Activity/output	Achievements
1.1	An analysis of how ENSO affects the climate and agricultural production at a regional level	COMPLETED An analysis of the ENSO effects on rainfall, streamflow, irrigation diversions and the onset of the monsoon season has been completed. Analysis of the agronomic impacts of ENSO using the developed LP model was also completed and is formally documented within this final report.
1.2	An information base of climate, hydrological, economic and agronomic data leading to improved risk management	COMPLETED A database was developed for meteorological and other measured data was compiled by the Indonesian team, and is currently being hosted by the Research Centre for Water Resources and Agroclimate (RCWRA) of the University of Mataram, initiated by members of this project in 2006.
1.3	A database containing simulation results covering a range of climate scenarios, allocation decisions and planting options	INCOMPLETE Modifications have been made to the decision support tools which would greatly facilitate completion of this task.

Objective 2: Development (enhancement) of decision support tools

No.	Activity/output	Achievements
2.1	Calibration of the IQQM model to be used in water allocation studies	COMPLETED A calibrated and operational model of IQQM was set up to schematically represent all of the physical features and management rules of the Lombok irrigation system comprising over 64,000 ha of irrigated lowlands, from Jangkok system in the north-west to Jerowaru in the south-east. Up to 51 years of daily streamflow and irrigation diversion data was simulated for input into FlowCast & CropOptimiser.
2.2	Refinement of the LP model developed from previous ACIAR project	COMPLETED Refinement of the LP model was undertaken by the Indonesian team in parallel to the development of the software program “CropOptimiser”. Parameterisation has been completed and limited outputs evaluated in a real-world context. However, full validation outputs weren’t provided for this report and full validation is recommended.
2.3	Development of the CropOptimiser Software	COMPLETED The fully operational CropOptimiser is now a stand-alone software with a simplified graphical user interface and can be use to optimise regional cropping choice and patterns for different seasonal, climatic, agronomic and social conditions. Numerical validation and finalisation of the model occurred in July 2008 after the software and model developers meeting in June 2008.
2.4	Development of the FlowCast software	COMPLETED Updated FlowCast software developed was officially released to BMG in April 2008 and an updated version provided in March 2009. FlowCast has now had extensive debugging, testing and refinement, with new analyses added including a missing-data analysis, new skill assessment analyses, and advanced spatial analysis. A new user interface was also developed with “operational” (for Indonesian users) and “research” modes. Advanced training was provided to key BMG representative under ATSE Crawford scholarship.

Objective 3: Consultation and information dissemination

No.	Activity/output	Achievements
3.1	Conducting 5 workshops explaining the use of climate forecasts in agricultural production and natural resource management	ONGOING A number of workshops for Indonesian local government officials, academics, extension officers, farmers and group leaders have been conducted by Indonesian team. These are summarised in Section 7 of this report.
3.2	Additional 10 to 20 workshops are planned using local funding	

Objective 4: Capacity building

No.	Activity/output	Achievements
4.1	Training of two Indonesian staff in the calibration and application of the IQQM model	COMPLETED Two Indonesian scientists from Public Office were trained on IQQM modelling in Indonesia and Australia by Australian scientist.
4.2	Training of up to twenty staff in the use of FlowCast, and CropOptimiser Tools	COMPLETED Initial training in the use of FlowCast was undertaken; however, repeated training is recommended along with regular assessment of usage to foster its adoption and build local capacity in its operational use in country. Training in the use of CropOptimiser was undertaken with selected staff during the project. More extensive training in its use is recommended.

Objective 5: Farm-level water resource management

No.	Activity/output	Achievements
5.1	Conduct a review of the current and potential extent of groundwater for irrigation in southern Lombok	COMPLETED A review of Lombok's groundwater and reanalyses of dug well testing data was completed and is documented in Section 5.5.1 of this report.
5.2	Conduct a water balance study and crop modelling to independently validate or test the plausibility of the water balance determined in SMCN/1999/005	COMPLETED To accommodate the objectives of project, HowLeaky software has been improved with additional functionality. Simulation modelling with HowLeaky was completed across the range of common crops grown, soil types and management practices undertaken which enabled the testing of plausibility of water balance results determined in SMCN/1999/005.
5.3	Evaluate the potential impact of additional water from the water balance study and assess the impact of water harvesting on the scheme irrigation and water allocation decisions	COMPLETE Simulation modelling to quantify average in-crop runoff volumes and inter-annual variability in runoff capture has been completed and it documented in Section 5.5.2 of this report. Integration of estimated additional on-farm water into scheme irrigation and water allocation decisions is recommended.
5.4	Apply these results in CropOptimiser to determine the best cropping system in different regions and seasons where water harvesting and storage is feasible	INCOMPLETE This work was not possible within the time and skills available.
5.5	Conduct an economic impact study of water harvesting and re-use at the farm and irrigation command level	INCOMPLETE This work was not possible within the time and skills available

6 Key results and discussion

6.1 Seasonal climate forecasting

6.1.1 Review of climate in Indonesia and Lombok

Many studies have been done to identify the effects and drivers of climate in Indonesia. Indonesia experiences a typical monsoonal climate system with distinct wet and dry seasons (Chang 2005). The annual cycle is dominated by the interaction of the complex topography and the austral–Asian monsoon, and is subject to significant inter-annual variability leading to extremes of drought and anti-drought events generated by conditions in both neighbouring oceans (McMahon and Finlayson 2003). Aldrian and Susanto (2003) identified three distinct climate regions across Indonesia (Figure 6.1d). Region A, where Lombok Island is located, experiences a wet NW monsoon during November to March and a dry SE monsoon during May through September (Figure 6.1a). The other regions exhibit quite different rainfall patterns with Region B exhibiting rainfall peaks in October/November and March to May (Figure 6.1b) and a distinctive June/July peak for Region C (Figure 6.1c).

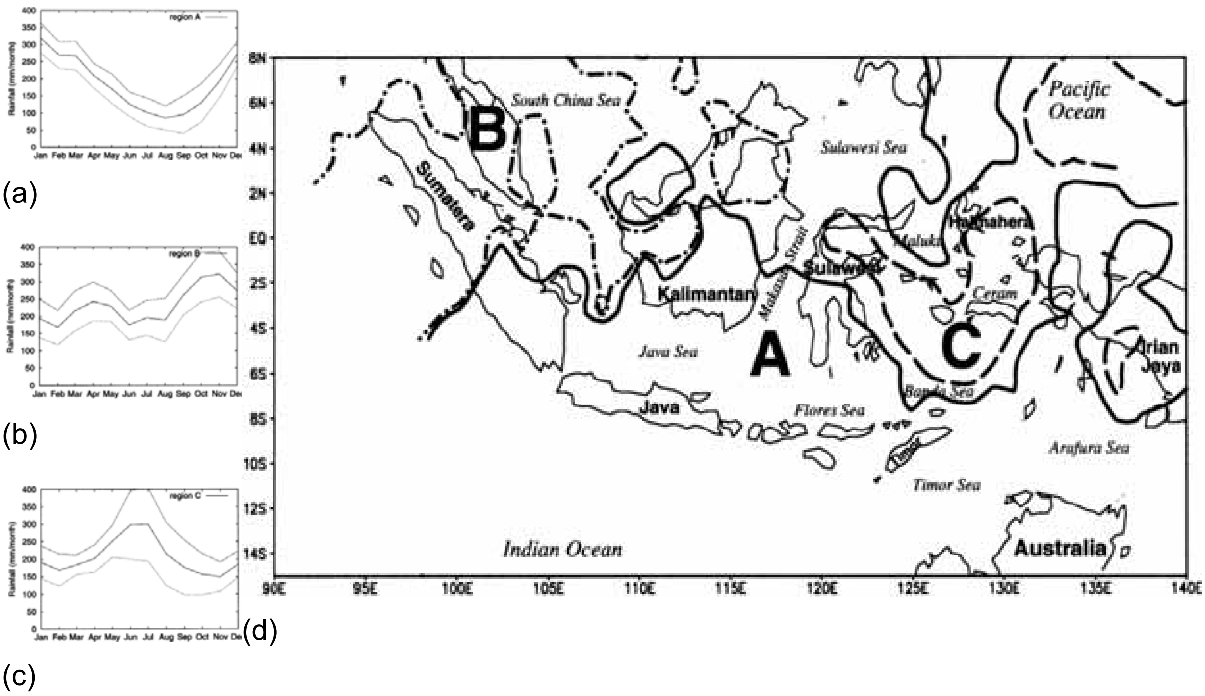
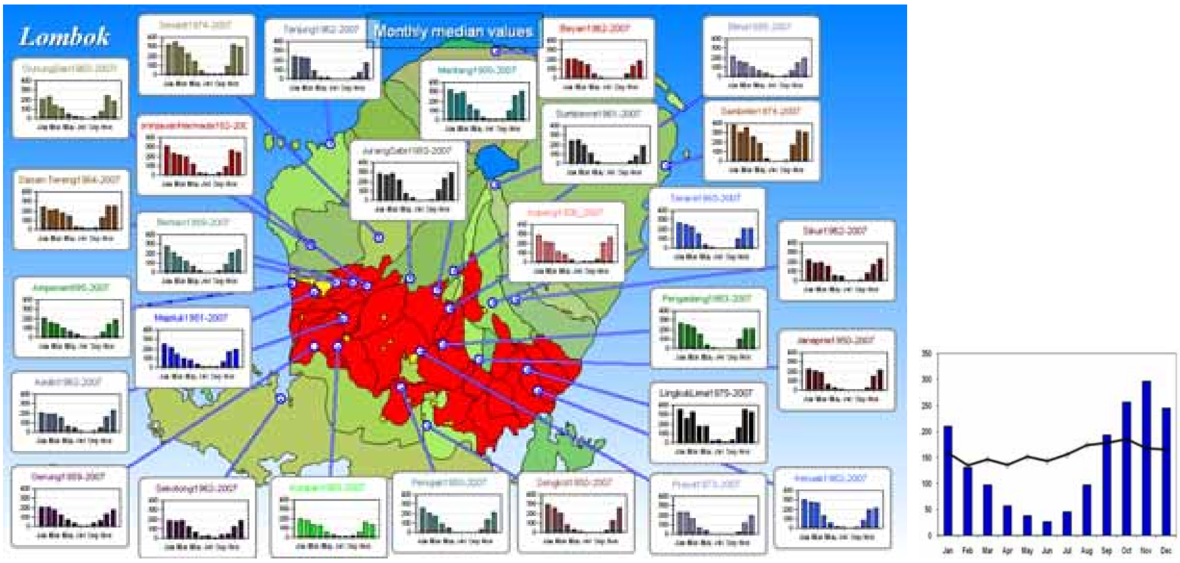


Figure 6.1 Three Indonesian climate rainfall patterns (a-c) and regions (d) according to Aldrian and Susanto (2003, p1438–39). Region A: solid line, Region B: short dashed line and Region C: dashed line.

Despite Lombok's small size, its climate can vary considerably across the island (Figure 6.2a). The annual average rainfall in the study area varies from 1300 mm in the south to more than 2100 mm in the north with an average of 1700 mm. The long-term monthly rainfall and evaporation patterns are shown in Figure 6.2b. This figure depicts that about 80% of the annual rainfall occurs during September to February. The period from April to August is dry, yielding less than 10% of the total annual rainfall. On the other hand, evaporation does not have any significant variation throughout the year. Lombok, being close to the equator, remains warm throughout the year with a mean monthly air temperature of about 27° Celsius and relative humidity of more than 80%.



(a) (b)

Figure 6.2 (a) Monthly median rainfall distribution for different stations across Lombok; and (b) Lombok irrigation region (red area on map) monthly rainfall (bars) and evaporation distributions (line).

The dominant source of inter-annual climate variability in Lombok (and Indonesia) is the El Niño Southern Oscillation (ENSO) global climate phenomenon (Giannini et al. 2007), estimated to account for about two-thirds of the variance (Aldrian and Susanto 2003; Haylock and McBride 2001). The remaining climate variability is driven by Indian Ocean sea surface temperatures (Indian Ocean dipole – IOD) and internal regional processes associated with the monsoon and the Inter-Tropical Convergence Zone (ITCZ). D'Arrigo and Smerdon (2008) suggest that the remaining variance is due to equatorial Indian Ocean zonal winds, local dynamics and and/or orographic effects. Aldrian and Susanto (2003) identified Region C (Figure 6.1) as being most strongly influenced by ENSO, followed by Region A, with Region B being most influenced by the north/south movement of the ITCZ.

Across Indonesia, including Lombok, drought conditions are associated with warm ENSO events (El Niño) and positive IOD episodes. Anti-drought events are associated with cool ENSO events (La Niña) and negative IOD episodes. The coherency between ENSO and Indonesia reaches a maximum during austral spring (Haylock and McBride 2001; Naylor et al. 2007) and greatly influences the onset of the monsoon, impacting greatly on local agriculture. A 30-day delay in monsoon onset is critical to agricultural risk (Naylor et al. 2007). While the onset coincides with the period when ENSO exerts its strongest influence on Indonesian rainfall, the influence of ENSO weakens significantly during the rainy season of December to February (Haylock and McBride, 2001; Aldrian et al. 2007; Giannini et al. 2007). The onset of the austral-Spring monsoon varies across Indonesia with earlier starts in the north-west and later starts in the south-east of the country (Aldrian and Susanto, 2003; Naylor et al. 2007). Depending on the wind movements across the oceans that influence the monsoon events, the effect of the west monsoon may last up to March. To a great extent the length of the wet season depends on the migration of the Asian–Australian monsoon (Chang 2005).

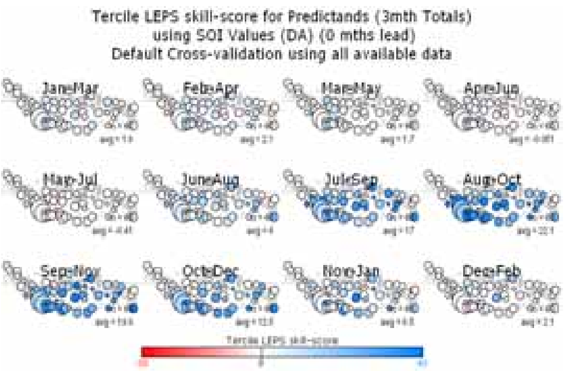
The ITCZ also considerably influences the climate of Lombok. The ITCZ moves southwards during the summer months bringing moist winds from the tropical oceans, and during the winter it moves northwards bringing dry winds (Beture Setame et al. 1992).

Topography has a pronounced effect on the monsoonal rain (Delinom et al. 1983) and strongly influences Lombok's climate. Mountains in the north of the island intercept the monsoon's path, leading to a distinct rain shadow across much of the southern part of the island and delaying onset of monsoon by up to a month further south-east (McDonald and Partners Asia 1985). As a result the central and southern high plateau and southern slopes of Lombok generally receive less rainfall than the northwest and near Rinjani southern slope. Prolonged drought causing harvest failure is prevalent in this part of the island (Team ITB, 1969; Donner, 1987; McDonald and Partners Asia, 1985).

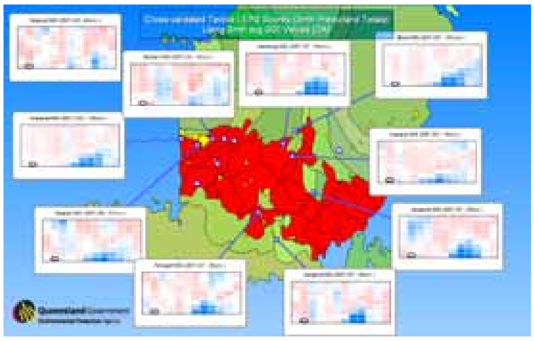
6.1.2 Assessment of forecast skill

The results of the study to assess forecasting skill are presented in Appendices 3 to 6. Four main forms of output are presented including LEPS (Linear Error in Probability Space – See Appendix 2) skill scores shown as spatially overlaid bubble plots (Figure 6.3a) for rainfall, and polygons (Figure 6.3c) for hydrological predictands, LEPS skill tables for different lead-times and forecast periods (Figure 6.3b) for all predictands, and probability distributions of ENSO stratifications (Figure 6.3d) for the onset of the monsoon and different water components in CropOptimiser. All suggested predictive systems are analysed in the rainfall forecast skill assessments presented in Appendices 3 and 4. Here it was found that the SOI Value (DA) based predictive system was the preferred system for an operational forecast system in Indonesia and Lombok. Therefore, only the results for this system (or the similar 3 category SOI Value system when showing stratifications) are presented in the following Appendices.

An important point to reiterate for analysing these results is that scale of the LEPS scores presented varies from chart to chart, from predictor to predictor, and between locations due to the variations in sample sizes and predictor composition. However, the results within each station-based skill-table are (usually) consistent with each other, and the trends between systems can also be distinguished.



(a)



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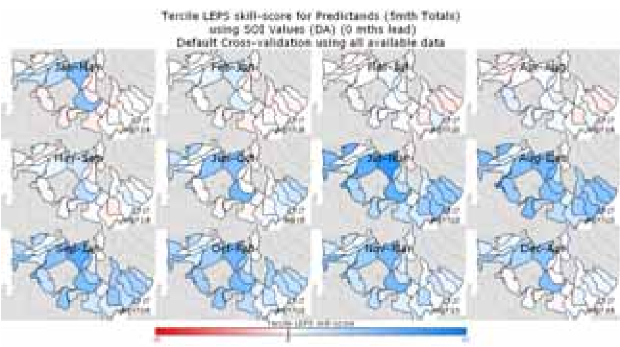
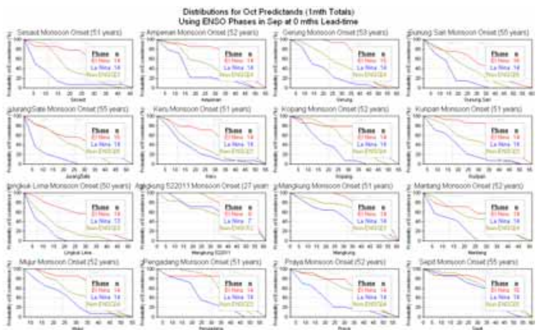


(c)



(d)

Figure 6.3 Sample forecast skill (LEPS Scores) analysis outputs for (a) Indonesian rainfall (Appendix 3); (b) Lombok rainfall (Appendix 4); (c) Lombok streamflow and water diversions (Appendix 5); and (d) onset of the monsoon (Appendix 6).

Rainfall forecast skill

Appendices 3 and 4 present the results of skill testing from all predictive systems for rainfall in Indonesia and Lombok Island. For the Indonesian study, the results are presented for three, six and nine month season lengths. For the Lombok study, only the results for the three month season length are presented. In summary, the results of the study can be described as follows:

- Significant skill exists for all of the ENSO-related predictors (Systems 1–5 and 9–12 Table 4.1) during some periods of the year to justify recommending the use of seasonal climate outlooks.
- Throughout Indonesia and Lombok, the ENSO-related predictor systems for rainfall demonstrate their highest skill for three-month seasonal periods from July–September, August–October, September–November and October–December periods. Skill consistently decreases with season length for all predictive systems tested[5].
- In Indonesia, the regions of highest rainfall skill exist in central southern-hemispherical islands, typically located in Regions B and A defined by Aldrian and Susanto (2003) which includes the island of Lombok. The region of least skill is in the north-west islands of Indonesia located in Region B which Aldrian and Susanto described as having a "suppressed ENSO-related signal".
- In Lombok, predictive rainfall skill appears reasonably consistent throughout the island with the lowest skill in the north-west of the island. The length and quality of the predictand data appears to influence the skill-score results.
- The preferred predictive system for use as an operational forecast system would be the SOI-value system using discriminant analysis. This system demonstrates similar or greater spatial and temporal coverage of skill compared to the other predictive systems analysed, and has twice the amount of training data available than the SST-based systems. Also in its favour is the less deterministic nature (categorising of climate data) of the discriminant analysis methodology over the stratification methodology in relating global climate to Indonesian rainfall[6]. The choice of this system is subjectively based as it is difficult to justify numerically (and visually) because of the differences in sample sizes between this and the other systems.
- The use of SSTaEOF2 (correlated with IOD) as a predictive system shows very limited skill on its own, but when combined with SSTaEOF1, it appears to enhance or modulate the skill of SSTaEOF1.
- Forecasting at longer-lead times (two to four months) may be possible for many locations in Lombok for the August–October and September–November periods. Some of the SST-based systems (SSTaEOFs 1, 1&2, 1&9 and 1&12) demonstrate higher skill at longer lead-times than the preferred SOI Value system.

Hydrological predictands forecast skill

Appendix 5 presents the results of the skill scores for the hydrological variables in Lombok Island including catchment river inflows and irrigation diversion amounts, for the SOI Values (DA) predictive system. In summary, the results of the study can be described as follows:

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[5] A four-month seasonal period was not tested for the rainfall predictands, but was for catchment/river inflows and irrigation diversion, and was found to be the most successful to forecast. It can be assumed that this would also be true for the rainfall forecasts.

[6] Note however, that the stratification methodology must still be used in CropOptimiser *software due its input requirements for stratifications of climate.*

- The skill in predicting catchment river inflows and irrigation diversions is high over most of Lombok during some periods of the year to justify recommending the use of seasonal climate outlooks.
- The skill is higher, and the onset of skill periods is earlier, for predicting streamflow than it is for predicting diverted irrigation water.
- Throughout Lombok, the highest skill for the hydrological predictands occurs during the four-month seasonal periods from August–November, September–December and October–January periods. Skill consistently decreases with season lengths greater than or less than four months. Significant skill exists for over half the stations in Lombok during July–October (the third cropping season in Lombok) for streamflow predictions. Only a quarter of the Lombok stations exhibit the same level of skill for predicting diverted irrigation water during this period.
- Both catchment river inflows and irrigation diversion predictands exhibited irregular spatial uniformity of skill, which could be due to the modelled nature of the input data, but is more likely to be caused by the anthropogenic influences on the river system. That is, in some regions, human intervention in diverting water for irrigation could be causing irregular trends in the data which degenerate the linkages with ENSO.
- Significant triangular block patterns of skill exist in the LEPS skill tables for streamflow predictions which consistently commence in the May to June periods in locations throughout Lombok. This suggests that the predictor periods ending April (February–March–April) and May (March–April–May) are key times to monitor SOI, and four month seasonal outlooks can be made at this time for hydrological predictands for different starting periods over the remainder of the year. This could provide two to three months lead time for streamflow predictions in over half the locations tested, and between four to five months lead time for a quarter of the locations tested.

Onset of the monsoon forecast skill

Appendix 6 presents the results of the monsoon onset analysis for Lombok Island using the 3 month average SOI Values (DA) predictive system. The LEPS skill tables show results only for the period of October, as this is the characteristic of the predictand data (days since October 1). Twelve of the sixteen datasets analysed exhibited very high skill (from 19% for Jurang Sate to 38% for Ampenan) which is significant at lead times of up to four months[7]. That it, the results show that the onset of the monsoon may be forecast with some reliability from as early as June or July each year, and as October is approached, the skill of the forecasts increases. The high skill is evident in the probability distributions of ENSO stratifications (using 3 category SOI Values) which are highly separated indicating distinct characteristics of each stratification.

6.1.3 Effect of ENSO on rice production

The quantity of data on rice production in this project was not sufficient for use in seasonal climate forecasting, and crop modelling to extend the dataset was out of the scope of this project. Therefore, a simple historical analysis was undertaken using anecdotal evidence to interpret the relationship of rice yield with ENSO. It has commonly been observed that the occurrence of El Niño leads to substantial reduction in rice production in Lombok. Water reserves in rivers and springs tend to decrease in some of the main producing areas, and a prolonged shortfall in rainfall has in the past seriously reduced rice yields and production.

[7] *Of the remaining stations, Praya and Mankung (tested twice) still exhibited significant skill, while Sepit exhibited poor skill results, which could be due to the quality of the input data.*

For example, the effects of El Niños in 1982/1983, 1997/1998 and 2006/2007 caused widespread drought that induced crop failures in southern Lombok (Dinas Pertanian, 2007).

Historical rice production data from 1970 to 1998 shows a reduction in rice production during each persistent El Niño event. Figure 6.4 shows disaggregation of annual rice production into the first and second growing seasons. It is evident that El Niño causes reduced rice production across multiple seasons. For example, the drought during the 1982/1983 El Niño led to a reduction in rice production in the second growing season in 1982 and the first growing season in 1983. A similar pattern occurred during the 1997/1998 El Niño. It was found that the decreased rice production was mainly due to reduced harvest areas, with only slight decreases in yield.

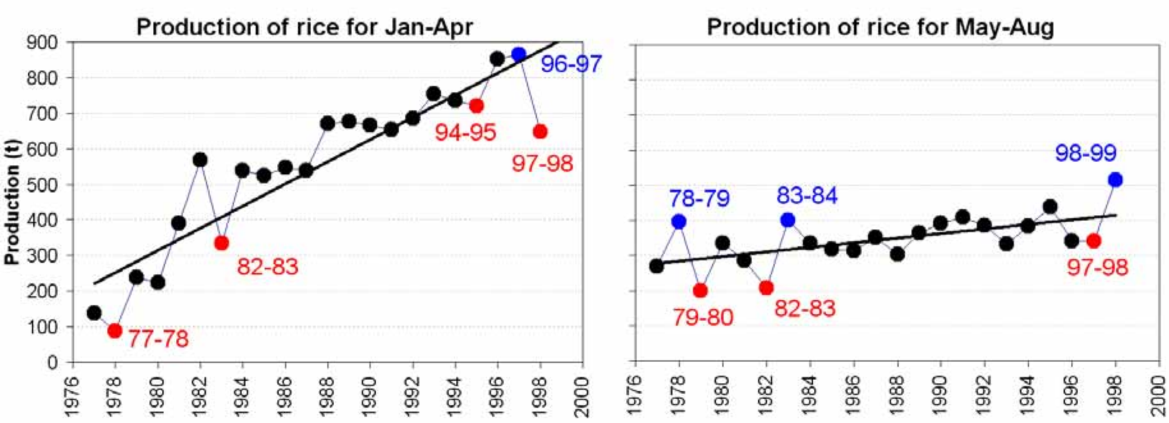


Figure 6.4 Rice production in the rainy (Jan-Apr) and dry (May-Aug) seasons in West Nusa Tenggara (• El Niño event, • La Niña event).

Dinas Pertanian West Nusa Tenggara (2007) reported that the drought during the 2006/2007 El Niño affected 39000 ha of rice with a quarter of this (10,000 ha) experiencing crop failure. Fortunately, significant rainfall early in the following dry season (after March 2007) presented the opportunity for farmers to replant their land and compensate for the cropping failures. The effects of this were not reflected in the annual rice crop production for that year, but through limiting the chance of harvesting non-rice crops during the second growing season.

6.2 Hydrological modelling

6.2.1 River system configuration

To represent the river-irrigation systems in Lombok for the IQQM model, a total of 414 nodes have been used. Among them, there were 137 gauge station nodes that represent the places where the streamflows were measured. Ninety-two inflow nodes were used which include river inflow, tributary inflow, catchment residual inflow and groundwater contribution inflow. There were 57 irrigation nodes that simulate the irrigation/diversion behaviours in 57 irrigation areas ranging from 100 ha to over 10,000 ha. Two nodes were used to simulate operation of Jangkok and Seasaot weirs. There were 86 effluent nodes and 11 effluent return nodes that simulate the transmission loss, effluent diversion and effluent and diversion return. Twenty-nine river confluence nodes were used to represent the river confluence in the system. The flow between the nodes is simulated using routing parameters that are calibrated and parameterised using a “link routing” model. While the geographic locations of the rivers, canals and irrigation areas are shown in Figure 6.5, the completed node-link diagram configured for the IQQM modelling is shown in Appendix 10.

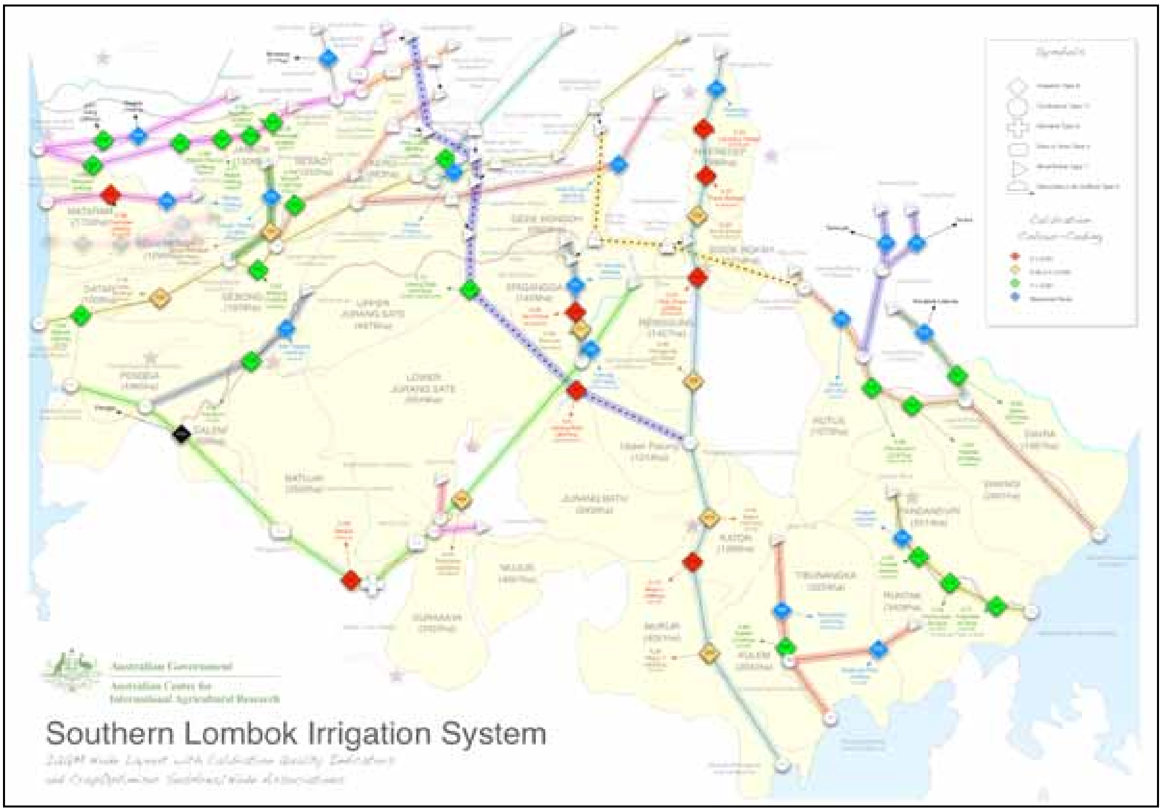


Figure 6.5 Lombok river system configuration for IQQM (See Appendix 10 for larger view).

6.2.2 Data collection

While several agencies were involved in collecting rainfall data in the study catchments, consistent rainfall data were not available in most of the stations. Daily rainfall data from all of the weather stations contained missing records, and other climate data such as maximum temperature, minimum temperature, solar radiation, relative humidity, and wind speed were recorded on an irregular basis. The length of record of daily climate data was not adequate for forecasting or hydrological modelling. However, monthly rainfall data with sufficient length of more than 50 years was obtained from range of sources.

Weather data was collected from six possible sources such as BMG (Badan Meteorologi dan Geofisika), HU (Hydrology Unit), BPTPH (Balai Proteksi Tanaman Pangan dan Hortikultura), CIDA and Crippen, WOC (Water Operation Centre), IWO (Irrigation Watcher Office). Monthly rainfall data covers the period from 1950 to the late 1990s for a number of stations. Longer-term monthly data has been collected for Praya (1914–1998), Kopang (1926–1998) and Ampenan (1895–1998). Daily rainfall data from BMG covers the period from 1989 to 1998 and has limited missing data, while the daily rainfall from the Hydrology Unit spans a longer period (1970–1999) but has more missing data.

Daily climate data such as rainfall, solar radiation, wind speed, maximum and minimum temperature, and relative humidity were collected from five weather stations controlled by BMG, and three stations controlled by HU. Daily rainfall was collected from 22 stations controlled by BMG, 14 stations controlled by HU, and two stations controlled by the Irrigation Watcher Office. As the daily data length was short, monthly rainfall data was sourced from 26 stations controlled by Agricultural Office, nine controlled by CIDA. Moreover, the Water Operation Centre controlled 12 stations where 15-day total rainfall was recorded. Data were collected from as many stations as possible since very few stations maintained regular recording and extra data contributed to gap-filling. Considering the location of the rivers and their proximity to the rain gauging stations we chose 18 out of a possible 39 stations in Lombok.

Monthly rainfall data is available for 104 stations. Most of these stations have data after 1960. Few stations (eight) have records since 1916. There was no rainfall record during 1942 to 1949 which may be due to the Second World War. Daily rainfall data have fewer records compared to the monthly rainfall. Daily rainfall is available for 76 stations. Most of these stations have data records after 1990. Only one station had records since 1961 and another one since 1969.

Irrigation diversion data are available on daily basis for 113 stations/gauges. Most of the stations have records since 1994/1995. There were two stations with data since 1990. The amount of missing data during the 1995–2005 period was on average 3.4 years.

The streamflow records were of very short length, usually from 1992 to 1999. Daily gauged flows were available from the Hydrology Units. Three stations did not have any data. Altogether 23 river gauging stations were covered in this study (Table 6.3). Catchment areas of the rivers at the gauging stations were obtained from published records and research reports (CIDA and Crippen 1975; McDonald and Partners Asia; 1986; Le Group AFH, 1993).

These data are now archived online in their original digital form and managed by the Research Centre for Water Resources and Agroclimate (RCWRA) of the University of Mataram, which was initiated by members of this project in 2006.

6.2.3 Data pre-processing, patching and synthesis

Missing rainfall data and gap-filling

In preparing the rainfall data for input into the Weatherman software, the monthly rainfall data required an initial pre-processing to infill gaps using data from neighbouring stations. It was found during the correlation analysis that using only one neighbouring station was insufficient for gap-filling, requiring second and third neighbouring stations to be analysed (Table 6.1). Fortunately, correlations between neighbouring stations were generally high.

Table 6.1 Neighbouring rainfall stations and correlation coefficients in the study area.

Target station	Neighbouring stations and correlation coefficients					
	1st neighbour	r	2nd neighbour	r	3rd neighbour	r
Ampenan	Majeluk	0.858	Rernbiga	0.854	Gunung	0.756
Batu Kumbung	Kuripan	0.812	Majeluk	0.781	Rernbiga	0.778
Barabali	Mantang	0.802	Pringgarata	0.764	Kopang	0.74
Bertais	Majeluk	0.831	Rembiga	0.817	Gunung	0.8
Gerung	Ketirik	0.848	Kuripan	0.777	Rembiga	0.672
Gunung	Rembiga	0.902	Majeluk	0.902	Bertais	0.821
Janapria	Saba	0.906	Sepit	0.712	Penujak	0.68
Jurang Sate	Keru-Peresak	0.848	Pringgarata	0.801	Mantang	0.801
Kabul	Ranggagata	0.721	Penujak	0.682	Mankung	0.681
Keruak	Tanjung Luar	0.807	Sapapan	0.78	Pengadang	0.632
Keru-Peresak	Sesaot	0.931	Nvurlembang	0.904	Suranadi	0.884
Ketirik	Gerung	0.848	Kuripan	0.734	Bertais	0.653
Kopang	Barabali	0.74	Mantang	0.716	Pengadang	0.698
Kotaraja	Perian	0.835	Timbanuh	0.613	Prava	0.582
Kuripan	Batu Kumbung	0.812	Bertais	0.788	Suranadi	0.787
Lingkok	Perian	0.858	Persil	0.831	Barabali	0.76
Loang Make	Mujur	0.644	Kabul	0.585	Sepit	0.567
Majeluk	Rembiga	0.928	Gunung	0.877	Ampenan	0.858
Mankung	Kabul	0.681	Sengkol	0.622	Penujak	0.618
Mantang	Barabali	0.802	Kopang	0.715	Jurang Sate	0.712

Mujur	Praya	0.711	Rambitan	0.677	Loang Make	0.644
Nvurlembang	Keru-Peresak	0.911	Sesaot	0.9	Suranadi	0.835
Pengadang	Penujak	0.764	Prava	0.746	Kuripan	0.728
Pengondang	Sepit	0.728	Janapria	0.636	Saba	0.589
Penujak	Pengadang	0.764	Kabul	0.682	Janapria	0.68
Peninjoan	Mantang	0.746	Kuripan	0.666	Pringgarata	0.649
Perian	Lingkok	0.858	Timbanuh	0.824	Kotaraja	0.776
Persil	Lingkok	0.853	Sesaot	0.793	Jurang Sate	0.759
Praya	Pengadang	0.746	Mujur	0.711	Barabali	0.663
Pringgarata	Barabali	0.764	Batu Kumbung	0.686	Mantang	0.685
Puvung	Sesaot	0.676	Persil	0.639	Suranadi	0.637
Rambitan	Sengkol	0.795	Mujur	0.677	Sekotong	0.641
Ranggagata	Kabul	0.738	Sekotong	0.707	Penujak	0.704
Rembiga	Majeluk	0.928	Ampenan	0.854	Gunung	0.847
Saba	Janapria	0.906	Sepit	0.694	Penujak	0.636
Sapapan	Keruak	0.78	Tanjung Luar	0.71	Sepit	0.667
Sekotong	Ranggagata	0.728	Sengkol	0.704	Ketirik	0.646
Selong	Sepit	0.597	Janapria	0.575	Keruak	0.575
Sengkol	Rambitan	0.795	Sekotong	0.704	Kabul	0.64
Sepit	Pengondang	0.728	Janapria	0.712	Saba	0.694
Sesaot	Keru-Peresak	0.931	Nvurlembang	0.879	Suranadi	0.866
Sikur	Kopang	0.449	Kotaraja	0.435	Barabali	0.421
Suranadi	Sesaot	0.887	Persil	0.844	Nvurlembang	0.834
Tanjung Luar	Keruak	0.807	Sapapan	0.71	Pengadang	0.588
Timbanuh	Perian	0.906	Kotaraja	0.767	Mujur	0.69

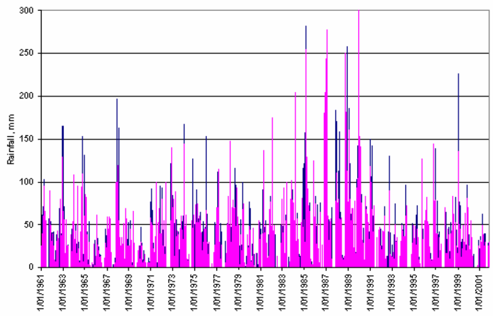
Once the missing data were filled, input data files were prepared for use in the Weatherman package for daily climate data simulations. Each of the monthly climate variables including daily rainfall, solar irradiance, maximum temperature and minimum temperature were disaggregated into three sets of daily realisations. The average of the three sets of RMSE (root mean square error) and MBE (mean bias error) results for each of disaggregated climate variables are presented in Table 6.2.

Table 6.2 RMSE and MBE of generated climate data for the study area.

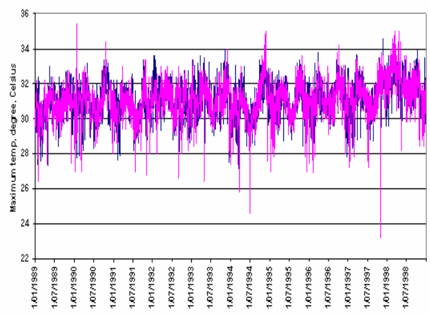
	Rainfall			Solar Irradiance			Max Temp			Min Temp		
	MBE	RMSE	t-test	MBE	RMSE	t-test	MBE	RMSE	t-test	MBE	RMSE	t-test
Ampenan	0.04	14.9	ns	8.2	6.2	ns	0.19	1.18	ns	0.04	1.47	ns
Gerung	0.12	15.4	ns	11	6.2	ns	0.2	1.2	ns	0.26	1.9	ns
Gunung sari	1.04	19.2	ns	7.5	6.1	ns	0.21	1.18	ns	0.25	1.45	ns
Jurang Sate (Perampuan)	0.42	18.1	ns	7.2	6.2	ns	0.23	1.19	ns	0.25	1.45	ns
Keru-Peresak	0.1	15	ns	7.4	6.1	ns	0.22	1.2	ns	0.25	1.44	ns
Kopang	0.15	18.8	ns	1.1	4.6	ns	0.04	1.5	ns	0.32	1.56	ns
Kotaraja	0.04	20	ns	1.3	4.7	ns	0.15	1.5	ns	0.32	1.6	ns
Kuripan	0.19	13	ns	6.8	6.2	ns	0.08	1.2	ns	0.27	1.46	ns
Lingkuk Lima	0.08	23	ns	6.6	6.2	ns	0.2	1.2	ns	0.25	1.46	ns
Mangkung	0.07	13	ns	7.6	5.4	ns	0.8	1.5	ns	0.13	1.46	ns
Mantang	5.3	21	ns	3	4.6	ns	0.05	1.49	ns	0.28	1.56	ns

Mujur	0.72	15	ns	5.8	5.4	ns	0.46	1.7	ns	0.94	1.55	ns
Pengadang	0.09	15	ns	5.9	5.4	ns	0.53	1.64	ns	1.03	1.53	ns
Praya	0.04	18	ns	6.2	5.5	ns	0.74	1.5	ns	0.21	1.51	ns
Rembitan	0.08	13.7	ns	6.5	5.1	ns	0.58	1.62	ns	0.99	1.55	ns
Sepanan-Keruak	0.07	14	ns	13	5.2	ns	0.05	1.5	ns	0.31	1.56	ns
Sepit	0.11	13	ns	18.3	4.7	ns	0.03	1.49	ns	0.32	1.55	ns
Sesaot	0.73	21.8	ns	6.8	6.1	ns	0.22	1.17	ns	0.25	1.45	ns

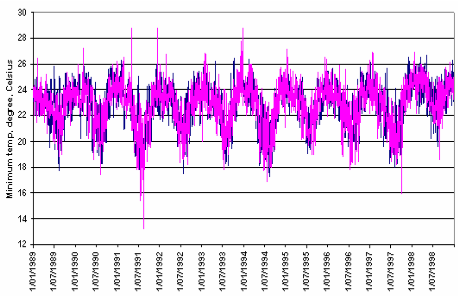
The t-test showed that there is no significant (ns) difference between the observed and simulated data. Minimum and maximum temperatures showed very low values of RMSE and MBE for all the stations. Solar irradiance also showed very low RMSE and MBE except in Gerung and Sepit that may be due to errors occurring in recording solar data for the stations concerned. The MBE of generated daily rainfall was also low for most of the stations except Mantang. The RSME of the rainfall was relatively high for all the stations compared to that of other variables. This might be due to the high level of monthly and annual variability. The daily simulated rainfall (randomly picked up one out of 10) and the observed rainfall for Ampenan has been shown in Figure 6.6a. On a particular date the rainfall may vary significantly, but on a monthly basis there is no difference. The unique feature of the Weatherman package is that on monthly, annual and for the entire length of the record the standard deviations did not show any difference. This is true for other variables too. For instance, the simulated maximum temperature and minimum temperature have been shown in Figure 6.6b and c depicting the pattern of the simulated temperature and observed temperature matching very well. The daily simulated solar irradiance has been shown in Figure 6.6d displaying a similar trend. It may be mentioned here that solar irradiance is not like maximum and minimum temperatures as the radiation variability is comparatively high.



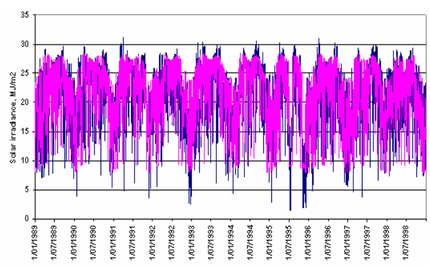
(a) streamflow



(b) maximum temperature



(c) minimum temperature



(d) solar irradiance

Figure 6.6. Simulated and observed daily data for Ampenan. (- Observed, - Simulated)

The weather data including rainfall was not of sufficient length for most of the rain gauging stations. Moreover, accuracy and gaps were very critical issues for their use in the rainfall-runoff model for streamflow simulation. However, the monthly rainfall totals for relevant rain gauging stations provided an opportunity to disaggregate the rainfall into daily values. The WeatherMan package disaggregated the monthly rainfall data into daily values based on climate patterns for the stations in Lombok. This stochastic weather generator provides flexibility in generating synthetic series of rainfall and other climate variables that match target monthly values. As the data are synthetic, better results could be achieved through a number of realizations meeting the target monthly values. We found that the Weatherman package generated maximum and minimum temperatures that were very close to the observed values as the variability in temperature for Lombok is not that significant throughout the year. However, rainfall and solar irradiance were found to vary significantly throughout the year and that is why observed and generated values for rainfall and solar irradiance did not demonstrate as close agreement.

6.2.4 Streamflow modelling (IHACRES)

The IHACRES model was calibrated to adjust parameters to match the simulated streamflow data to the observed flow data for the river gauging stations. For each of the river gauging stations we calibrated the flow using each set of three generated time series of rainfall and temperature data using a number of calibration periods. Based on measures of model efficiency (r2) and bias, calibration parameters were accepted for simulation of flow for the entire period. Simulations with an efficiency coefficient of 0.6 are generally considered to be satisfactory and simulations with coefficient 0.8 are always considered to be acceptable for hydrological studies (Chiew and McMahon 1993). The calibration exercise was carried out in order to achieve the highest possible efficiency coefficient but it was found that that level of efficiency could only be achieved for few rivers. This is mainly due to errors in recorded streamflow data for different gauging stations. Four stations were ungauged and we used catchment area ratio with another neighbouring station. Amongst the stream gauging stations, Sesaot at Kelling produced the highest level of efficiency which was 0.75 and the lowest level 0.16 was found for Kelambu-Separu River at Parung (Table 6.3). If the bias is negative, it dictates that the runoff produced over the year was higher than rainfall (Sesaot) which was due to the fact that there were numerous springs in that area contributing to the streamflow throughout the year. The relative bias was less than 15% for all the stations.

The Lombok catchment is strongly influenced by the baseflow component as rainfall falling on the catchment enters into the soil very quickly and infiltrated water contributes to the flow over a long period of time. The groundwater store configuration in this catchment can be defined as two exponential stores in parallel (Croke et al. 2005).

Table 6.3 Calibration of streamflow for river gauging stations in the study area.

River	Calibration period	R-squared	Bias (mm/yr)
Babak at Lantan Daya	01/10/1993 - 01/10/1996	0.637	15
Bekanga at Simbe	15/11/1993 - 15/01/1997	0.332	95
Lower Lenek at Gede Bongoh	01/01/1993 - 31/12/1995	0.179	325
Ranget***	01/06/1994 - 15/11/1997	0.340	317
Remining at Batu Kantar***	01/06/1994 - 15/11/1997	0.340	317
Upper Lenek***	01/10/1993 - 01/10 1996	0.637	15
Pande at Karang Makam	01/01/1993 - 31/10 1996	0.302	193
Blendung at Suradadi	01/01/1993 - 31/12/1995	0.179	325
Gading at Terera	01/01/1993 - 31/12/1995	0.330	101
Gambit at Pelapak	01/04/1994 - 28/02/1998	0.198	16
Ganti at Tibunangka	01/04/1994 - 30/04/1998	0.418	46
Kermit at SakraWeir	01/01/1993 - 31/12/1995	0.352	107
Ancar at Bertais***	01/06/1994 - 15/11/1997	0.340	317
Jangkok at Aik Nyet	01/08/1993 - 31/07/1996	0.633	11

Sekot at Montang	01/06/1994 - 15/11/1997	0.340	317
Sesaot at Kelling	01/08/1993 - 31/07/1996	0.753	-82
Midang at Gegetu	01/04/1991 - 31/03/1994	0.530	-55
Rutus at Rutus weir	01/07/1993 - 31/10/1996	0.309	264
Brembung*	01/03/1996 - 30/06/1999	0.163	217
Kelambu Semparu at Parung	01/03/1996 - 30/06/1999	0.163	217
Lajut-Desa*	01/03/1996 - 30/06/1999	0.163	217
Renggung at Punggung	01/06/1995 - 31/05/1999	0.588	396
Sade*	01/03/1996 - 30/06/1999	0.163	217

** Based on catchment area proportion with Kelambu_Semparu River at Parung*
*** Based on catchment area proportion with Babak River at Lantan Daya*
**** Based on catchment area proportion with Sekot River at Montang*

IHACRES allows choosing the calibration period (Appendix 11 Figure A11.1) displaying each data set of rainfall, streamflow and temperature. Several calibration periods were chosen to ascertain that the best possible model efficiency was achieved. The calibration exercise provided the parameters (Appendix 11 Figure A11.2) that were used for simulation. From the calibration statistic summary (Appendix 11 Figure A11.3), the parameter set that gave the highest efficiency coefficient (r2) was used for simulation. The simulation summary (Appendix 11 Figure A11.4), provided the modelled streamflow for each year together with rainfall, runoff, efficiency coefficient and other statistics. Finally, the simulation run of the program gave the simulated streamflow (Figure 6.7). It was found that for Sesaot River at Kelling, the modelled streamflow was very close to the observed streamflow. Similar results were also obtained for Babak, Jangkok, and Renggung rivers in the study area. IHACRES was run to simulate three sets of streamflow data for each of the river gauging stations and finally these data were processed to be used in the water allocation model.

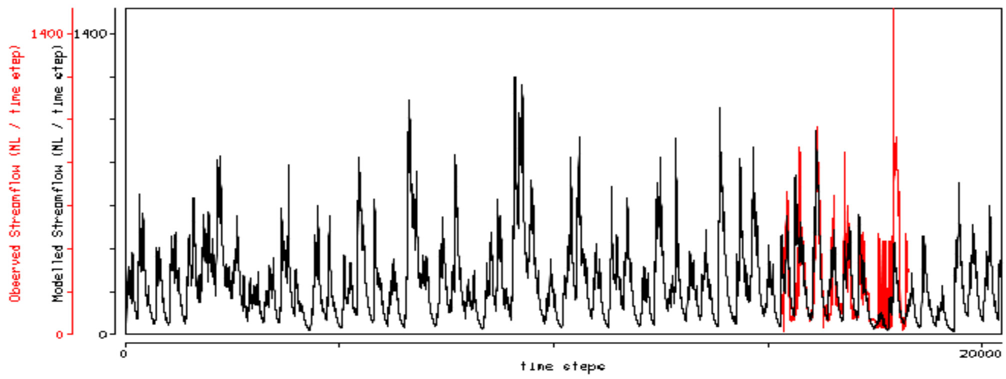


Figure 6.7 Observed and simulated streamflow data for Sesaot River at Kelling.

Streamflow is dependent on many factors, amongst which rainfall is the most sensitive factor. Therefore, in order to simulate an acceptable data set for streamflow, it is suggested that more realizations of rainfall and temperature data sets should be used in the hydrological model to capture the variability in the daily streamflows.

By and large, the model efficiency coefficient for the rivers was not within the satisfactory level. This has occurred due to poor recording of streamflow and rainfall. The Indonesian Bureau of Meteorology (BMG) should provide more effort to maintain the accuracy of climate data. At the same time Hydrology Unit and other organisations who are engaged in collecting streamflow data should maintain coordination amongst them to maintain authentic data.

6.2.5 Water diversion modelling (IQQM)

The Lombok IQQM model was developed in two parts: model configuration based on field survey and published maps and data (Section 6.2.1), and a two-stage model calibration process by comparing the simulated streamflows and irrigation diversion flows against the limited measured data. After calibration the model is able to simulate streamflow, irrigation diversions and mercu flows by activating the internal crop water model. The Lombok IQQM model can now simulate more than 50 years of daily streamflow and irrigation diversion data for the 57 irrigation areas in Lombok for use in the FlowCast and CropOptimiser software. This work was presented at the ANZ Climate Forum in Canberra, Australia in 2006.

Detailed outputs of the streamflow and irrigation diversion modelling component of this project are presented in Appendix 12, showing comparisons of simulated and measured streamflow flow frequencies and values for several nodes at selected sub-basins. Also shown are individual calibration quality indicators for those nodes, which have been summarised in

Table 6.4.

Table 6.4 Statistical indicators of calibration for total and irrigation diversion flows in Lombok. (Note: in the calibration, the total flows in some irrigation weirs are the river inflows. In this case the total flow calibration is not needed, hence the missing results)

Irrigation weir	Flow frequency – volume ratio (%)							Time series match (y=mx+b)			Annual divn. (volume ratio %)	Monthly diversion - volume ratio (%)		
	Whole range	Low range	Middle range	High range	5%ile point	50%ile point	95%ile point	m	b	r2		Low range	Mid-range	High range
Montang	-	-	-	-	-	-	-	-	-	-	1.1	53.4	1.1	1.2
Nyurbaya	102%	109%	100%	103%	111%	98%	124%	0.75	115.1	0.6	106.8	18.9	136.2	156.9
Mencongah	101%	125%	99%	100%	103%	113%	101%	0.85	49.8	0.78	97.9	19.9	121.2	147
Majeli	101%	102%	99%	103%	101%	90%	86%	0.92	41.8	0.77	95	21.6	107.9	119
Repok Pancor	101%	100%	101%	101%	100%	85%	112%	0.85	92.7	0.68	96.8	18.7	121.2	147
Mataram	101%	85%	104%	96%	97%	101%	91%	0.81	77.6	0.69	96.8	33.4	97.5	143.4
Gegutu	-	-	-	-	-	-	-	-	-	-	96.8	20.6	117	131.3
Ireng Daya	98%	87%	101%	98%	101%	100%	80%	0.79	23.6	0.61	101.2	30.1	111.3	169.9
Bertais	-	-	-	-	-	-	-	-	-	-	100	87.6	103.8	108.7
Pamotan	102%	99%	102%	105%	119%	98%	103%	0.6	53.1	0.28	99.4	25.1	113.5	136.3
Keru	101%	98%	102%	101%	99%	104%	81%	0.87	39.7	0.69	98.3	20.3	116.3	141.2
Gede Bongoh	-	-	-	-	-	-	-	-	-	-	97.3	36.6	106.3	133.7
Simbe	-	-	-	-	-	-	-	-	-	-	100.2	89.5	101.9	105.3
Sesaot	100%	99%	100%	101%	100%	98%	80%	0.8	72	0.63	104.3	18.9	122.5	169.3
Dasan Tereng											102.3	16.7	122	187.7
Juwet Bangkel	100%	90%	100%	109%	107%	95%	100%	0.75	36.4	0.38	98.5	29.4	115.3	142.8
Gebong	101%	99%	107%	88%	86%	108%	96%	0.71	124	0.62	100.5	31.2	110	148.3
Datar	96%	103%	98%	92%	88%	96%	97%	0.58	78.7	0.39	100	31.2	116.7	121.9
Baturiti	101%	106%	98%	105%	121%	102%	112%	0.75	60.2	0.6	100.6	29.2	111.7	146.3
Bun Topeng	-	-	-	-	-	-	-	-	-	-	99.7	26.8	111.7	129
Pesongoran Kuripan	100%	106%	100%	100%	122%	106%	100%	0.91	8.6	0.87	99.4	28.9	107.5	146.5
Jurang Sate	99%	101%	99%	98%	101%	100%	88%	0.82	38.7	0.75	94.1	84.5	94.8	102.4
Jurang Batu	100%	96%	101%	99%	98%	94%	100%	0	140	0	88.7	68.4	92.3	90.5
Paok Dengkel	-	-	-	-	-	-	-	-	-	-	100.7	87.7	99.2	111.2
Parang	-	-	-	-	-	-	-	-	-	-	100.9	74.3	100.3	111.6

Surabaya	99%	125%	101%	94%	90%	113%	100%	0.63	40	0.44	99.6	0	101.8	127.8
Batujai	100%	134%	77%	99%	118%	96%	100%	0.36	283.8	0.07	110.5	138.8	97.3	100
Nyeredep	-	-	-	-	-	-	-	-	-	-	103.2	60	97.9	0
Lendang Telgae	91%	93%	89%	101%	117%	98%	96%	0.19	15.1	0.03	104.5	97.7	99.2	190
Paok Rengge	100%	104%	99%	99%	104%	90%	105%	0.51	8.8	0.24	118.1	75.4	107	190
Bisok Bokah	101%	102%	101%	97%	103%	103%	91%	0.49	8.7	0.23	118.9	80.3	115.5	0
Otak Desa	100%	101%	100%	102%	101%	96%	109%	0.49	55	0.24	96.2	72.2	100.5	111.4
Renggung	102%	93%	102%	107%	104%	101%	86%	0.64	37.6	0.36	100.1	43.5	115.4	104.1
Katon	101%	104%	98%	106%	110%	100%	116%	0.71	34.6	0.46	100.3	60	91.6	153.7
Mujur 1	102%	89%	104%	103%	101%	98%	117%	0.38	11.2	0.13	93	89.8	95.6	86.9
Mujur 2	97%	123%	92%	102%	107%	100%	100%	0.61	47.9	0.38	100.8	0	90.2	150.2
Tibunanka	-	-	-	-	-	-	-	-	-	-	100.7	67.5	96.1	133.8
Kulem	105%	90%	102%	109%	110%	103%	100%	0.91	3.3	0.6	100.3	61.2	102.3	109.9
Embung Pare	-	-	-	-	-	-	-	-	-	-	92.5	51.4	94.3	100
Pelapak	-	-	-	-	-	-	-	-	-	-	99.6	89.8	98	104.9
Tundak	102%	82%	102%	103%	104%	116%	75%	0.83	8.3	0.65	99.7	41.7	97.6	147.2
Penendem	103%	76%	102%	106%	102%	99%	125%	0.91	5.4	0.76	100.2	43.9	94.9	131.4
Pelambik	106%	95%	110%	101%	100%	100%	100%	0.88	2.1	0.71	92.6	58.3	94.2	97.8
Rutus	-	-	-	-	-	-	-	-	-	-	99.8	63.5	103	133.4
Termusik	-	-	-	-	-	-	-	-	-	-	100.7	60	105.3	126.8
Terara	-	-	-	-	-	-	-	-	-	-	100.9	60	102.2	134.3
Pandanduri	103%	111%	102%	102%	105%	94%	101%	0.81	45.4	0.65	99.4	50.8	101.5	140
Swangi	103%	105%	103%	104%	103%	108%	112%	0.97	8.2	0.91	102.8	57.2	105.4	130.7
Kangkek Lepung	-	-	-	-	-	-	-	-	-	-	100.2	71.8	95.3	126.1
Sakara	101%	100%	99%	104%	110%	100%	100%	0.78	13.2	0.6	100.6	64.5	92	126.1

These results show the performance indicators of the calibration which cover systematic and random error tendencies between the simulated and measured time series. The systematic errors indicate the overall bias of the simulations against the measurements, while the random errors represent the extent and scatter of the differences. Five classifications were used here to categorise the calibration quality. Among them, ‘adequate’ indicates an acceptable calibration for agricultural and irrigation management purposes. For irrigation diversion, the quality of calibration achieved is assessed by comparing the simulated annual and monthly diversions with the observations.

Overall, the calibration to the volume ratio between the simulated and measured streamflows at 50 irrigation weirs in Lombok has achieved ‘adequate’ quality or better. However for the daily flow time series replication, quality indicators for 14 weirs were ‘inadequate’ or ‘poor’. This means that caution should be exercised when planning irrigation management using the IQQM simulation output in those 14 weirs. For irrigation diversion, ‘adequate’ or better quality results have been achieved for the annual diversion for all irrigation weirs. However, for the monthly diversion some irrigation weirs are associated with the ‘inadequate’ or ‘poor’ indicators for the low flows (flows below the 70%ile exceedance rate) or high flows (flows over the 10%ile exceedance rate). This indicates that using annual diversion simulations for irrigation planning is more reliable than using monthly values, especially for the months with extremely low or high flows.

It is reassuring to note the there is little effective variation between the three sets of simulations produced from IQQM relating back to each set of stochastically disaggregated rainfall data. Figure 6.8 shows the envelopes of probability distributions of simulated annual streamflow results for Majeli Weir for different climate types.

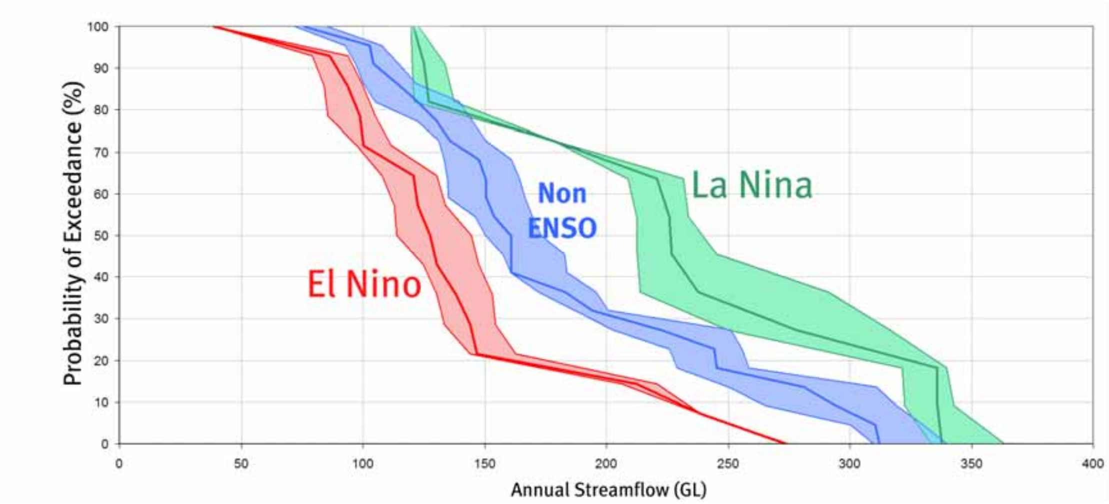


Figure 6.8 Distribution of Annual Streamflow at Majeli Weir, Indonesia for El Niño, La Niña and Non-ENSO years

The calibration results have shown that the calibrated model is adequate for strategic planning purposes for most irrigation weirs in Lombok. However, it has also been noticed that some aspects of the calibration process can be addressed to improve the calibration quality. Firstly, obtaining better quality inflow data for some rivers is essential to improve the calibration. Currently the inflows for several rivers (e.g. Lekong River, Renggung River) are either unavailable or of poor quality. Secondly, measurement or accurate estimation of the groundwater contribution to the hydrological system will improve the calibration. In the current IQQM Lombok model, measurements of groundwater are not available for calibration purposes. Thirdly, refining and obtaining quality soil moisture, planting area and irrigation management data (e.g. ponding depth in rice field) can improve the irrigation diversion calibration. Finally, enhancing the IQQM model to enable the simulation of water requirements from the paddock with different soil types, cropping and irrigation management regimes will improve the calibration quality on a monthly basis.

6.3 Cropping optimisation (LP model)

Developing an LP model for optimising Lombok's cropping systems was a time-consuming and complex task led by the Indonesian team in Mataram. The objective function and constraint equations had to be developed from first principles, and then later parameterised to reflect the local conditions. The parameterisations include the soil and crop characteristics, socio-economic data such as farmers' crop preference, the price of crop yields and local cropping regulations, as well as water supply data both from rainfall and irrigation diversions from IQQM.

6.3.1 Formulation of the LP model

Objective function

The objective of this LP model is to maximize the annual (cropping year) fiscal profit, or annual gross margin, across an irrigated (or rainfed) agricultural system. The annual gross margin is defined as the gross income of the crops minus the cost of production over different seasons, subject to a range of physical (land-area and water-availability) and social constraints. The objective function depends upon the irrigation system being broken up into a series of irrigation command areas, or "sub-areas", for which data on crop water supply is available and optimal crop type and proportions will be determined. Annual cropping cycles must be predefined through designated cropping "seasons", along with the types of crops that can be planted in each season. Climate information is captured through separate optimisations. Therefore, for a predefined climate condition (such as El Niño or La Niña), the objective function can be defined mathematically as:

$$PROFIT = Maximize\left[\sum_{i=1}^{No.Seasons}\sum_{j=1}^{No.Areas}\sum_{k=1}^{No.Crops} X_{ijk}\left(Yield_{ijk} \times \Pr ice_{ijk} - Costs_{ijk}\right)\right] \quad (5.1)$$

where, for any crop k, at sub-area j and season i, Xijk represents the planted-area in hectares; Yieldijk is the potential yield in t/ha; Priceijk is the unit price of marketable yield per hectare; and Costsijk are the total costs per hectare of agricultural production for that crop.

One limitation of this function is that it assumes a fixed unit-price for crops regardless of the quantity produced. In reality, the unit price of each crop will reduce non-linearly with increase in regional crop yield. This would make the objective function non-linear, requiring a much more complex non-linear solution process. However, in all practicality, it can be assumed that the unit price of crops remains constant over the range of system constraints defined by the user. This means that the user has direct control of the constraints to ensure that this assumption is not violated.

Yieldijk is calculated simply by:

$$Yield_{ijk} = PotentialYield_i \times ProductivityIndex_{ijk} \quad (5.2)$$

where, PotentialYieldi is the maximum achievable yield for a crop in t/ha; and ProductivityIndexijk is a productivity factor combining a range of soil, season and crop variety factors[8] with values ranging from 0 to 1.

This yield function is limiting in practice, since crops can still be grown when water supplies are scarce, with an associated reduction in yield. Therefore a modified yield function can be

[8] In early version of the LP model, the $ProductivityIndex$ was equivalent to the more commonly known soil productivity index (SPI) used to express the relative capability of soil of producing a crop yield relative to its potential yield (Khiddir,1986). In recent versions of the LP model, SPI was modified to include cropping and seasonal factors.

included (through the user-defined constraints) based on the methodology of Doorenboss and Kassam (1979), and FAO (1982). The modified yield function $Yield^{*}_{ijk}$ is defined as:

$$Yield^{*}_{ijk} = Yield_{ijk}\left[1 - Ky_i\left(\frac{WS_{ijk}}{WD_{ijk}}\right)\right] \qquad (5.3)$$

where, Kyi is a production coefficient with typical values ranging form 0.7 to 1.3; and WSijk represents the water supplied to the crop k; and WDijk is the water required by the crop. A limitation of using this function is that the optimized parameters may not reflect the true optimum conditions since the WSijk/WDijk component is fixed at the start of the optimization with no adjustment during iterations.

Fixed constraints

The maximization of fiscal profit is subject to various physical land-area and water-availability factors. These can be categorized into four types of constraints: crop-area limits, crop-area synchronization constraints; crop water-use limits; and crop water-use synchronization constraints. These will now be defined in turn.

Crop-area limits

For any given cropping season, sub-area and crop type; individual cropping areas must be greater than or equal to zero, and less than the total arable land available in that sub-area:

$$0 \le x_{ijk} \le Area_{ij} \qquad (5.4)$$

Crop-area synchronization

For any given cropping season, and sub-area; the sum of all cropping areas (for each crop) in that sub-area, must be less than or equal to the total arable land available in that sub-area:

$$\sum_{k=1}^{No.Crops} x_{ijk} \le Area_{ij} \qquad (5.5)$$

Crop water-use limits

For any given cropping season, sub-area and crop type; the total crop water-use for each type of crop must be greater than or equal to zero, and less than the total available water in that sub-area for that season:

$$0 \le \left(x_{ijk} \times WaterUsePerHa_{ijk}\right) \le WaterSupply_{ij} \qquad (5.6)$$

In the model, crop water-use (per ha) shall be defined as the crop water-use factor (mm) minus the effective rainfall (mm) in that sub-area, and converted to ML/ha:

$$WaterUsePerHa_{ijk} = \left(CropWaterUseFactor_{ijk} - EffectiveRainfall_{j}\right) \times 10.0 \qquad (5.7)$$

Crop water-use synchronization

For any given cropping season, and sub-area; the sum of all crop water-use (for each crop) in that sub-area, must be less than or equal to the total water available in that sub-area for that season:

$$\sum_{k=1}^{No.Crops} \left(x_{ijk} \times WaterUsePerHa_{ijk}\right) \le WaterSupply_{ij} \qquad (5.8)$$

6.3.2 Season and climate parameterisation

The LP model has been developed to optimise cropping for three seasons and three climate types (in fact any number of each can be used). The seasonal period needs to be defined in the LP model for allocation of cropping sequence, and in the calculation of available water. For Lombok, the following seasonal definitions have been used:

- Season 1 – November to February
- Season 2 – March to June
- Season 3 – July to October

The onset of cropping season for irrigation supply in southern Lombok may occur later (up to four weeks) compared to northern regions. In this case seasonal water requirement is calculated from the beginning until the end of the season.

The three climate types are ENSO-stratifications based on the definition of Allen et al. (1996) in which they are defined on an annual basis during the April to March period:

- El Niño
- La Niña
- Neutral

6.3.3 Water supply parameterisation

In the LP model, the seasonal water supply for a crop is the total gross irrigation supply entering the irrigation area plus total effective rainfall in the cropped area during growing season. This data comes directly from the IQQM model and is calculated on a sub-area basis from the probability distributions for each season and climate type, usually at the fifty percentile level.

6.3.4 Crop parameterisation

The expertise and local knowledge of the Indonesian team was utilised in identifying the Lombok specific crop parameters for input to the LP model. These were derived for the six common forms of crops including rice, legumes, corn/maize, vegetables, chillies and tobacco. This required parameters included:

- Potential yield (t/ha): Estimated from Lombok local data.
- Fixed price($/t): Estimated from Lombok local data.
- Crop water demand (mm): Calculated from methodology described from Doorenboss and Pruitt (1997). See Appendix 13 for an overview of the calculations used in the Lombok study.
- Productivity index: Calculated based on soil, crop and seasonal characteristics including crop type, inundation, climate, soil texture, soil depth, soil waterlogging, soil nutrients, elevation, slope, fragmentation, pH and salinity. (See Appendix 13)
- Production costs ($/ha): Estimated from Lombok local data.

The characteristics of each crop and their subsequent parameterisation will now be discussed in turn.

Rice

Rice is the most important crop in Indonesia. West Nusa Tenggara produces about 1.3 million tonnes of unhusked rice annually, sixty percent of it contributed from Lombok Island. Based on Biro Pusat Statistik data, the average rice cropping intensity in Lombok is 1.46

crops/yr (Biro Pusat Statistik, 2007), with 46% of rice planted in the second cropping season. Traditionally in Lombok, the first cropping season (October to February) will be planted to almost 100% rice. However, there are a few areas (less than 1% of irrigation area) such as in the Mataram irrigation area, where farmers may grow corn, tomatoes or chillies in the first season to achieve a better income with an added risk of over-watering. Rice cropping intensity is different for each irrigation area. Based on figures from Water Operation Centre (1997), in the northern irrigation areas, farmers typically plant two rice crops per year while in the south (the tail of the irrigation system) it is often only one crop per year. Planting rice in the second season depends on both irrigation availability and rainfall during March and April (Mahrup et al. 2005). In general, the areas with good irrigation facilities can support two rice crops per year (1.75 to 2.25 crops/yr from Biro Pusat Statistik, 2007), while other areas will support one rice crop followed by a secondary crop.

Table 6.5 Rice crop parameterisation for CropOptimiser

Parameter	Entisols	Inceptisols	Alfisols	Vertisols
Potential Yield	8 t/ha			
Fixed Price	Season 1: 166 $/t Season 2: 178 $/t Season 3: 206 $/t			
Crop Water Demand	1500 mm	1400 mm	1100 mm	950 mm
Productivity Index	Season 1: 0.72 Season 2: 0.69 Season 3: 0.54	Season 1: 0.71 Season 2: 0.69 Season 3: 0.54	Season 1: 0.72 Season 2: 0.69 Season 3: 0.54	Season 1: 0.72 Season 2: 0.7 Season 3: 0.55
Costs	340$/ha	350 $/ha	Season 1: 369 $/ha Season 2: 297 $/ha Season 3: 369 $/ha	Season 1: 375 $/ha Season 2: 300 $/ha Season 3: 300 $/ha

Legumes

Leguminous crops including soybean, peanut and mungbean are the second most important crop in West Nusa Tengara. Legumes are simple to grow and require little maintenance during the growing season and usually don't require irrigation. They are mainly planted during the dry season (>60%) primarily in drier regions including central Lombok, and are commonly grown in the neighbouring islands. Farmers traditionally broadcast the seeds over the moist soil just a few days after the rice harvest. Leguminous crops are typically given little care during the growing season and as a consequence, yields are often low (< 1 t/ha). However, better management may provide yields in excess of 2 t/ha. In West Nusa Tenggara the annual production of these crops has fluctuated in the past, being affected by government policy. In the 1980s and 90s, soybean production increased when the government provided incentives to farmers through the soybean intensification program. When this program finished, farmers reverted back to other crops instead. The national demand for these crops is very high, and production is insufficient to meet this demand. Unfortunately, the free trade movement has meant that these crops are not profitable for farmers to grow.

Table 6.6 Legume crop parameterisation for CropOptimiser

Parameter	Entisols	Inceptisols	Alfisols	Vertisols
Potential Yield	2.5 t/ha			
Fixed Price	Season 1: 544 $/t Season 2: 532 $/t Season 3: 520 $/t			
Crop Water Demand	390 mm			
Productivity Index	Season 1: 0.79 Season 2: 0.76 Season 3: 0.63	Season 1: 0.76 Season 2: 0.74 Season 3: 0.62	Season 1: 0.75 Season 2: 0.72 Season 3: 0.61	Season 1: 0.75 Season 2: 0.72 Season 3: 0.61

Costs	111$/ha	120 $/ha	139 $/ha	Season 1: 146 $/ha Season 2: 140 $/ha Season 3: 140 $/ha

Corn/Maize

Corn/maize is the second most important grain crop in Indonesia after rice. However, in West Nusa Tenggara it ranks third after leguminous crops as it is less profitable to grow. The price is controlled by the bigger companies and farmers are forced to agree with a fixed price. Farmers usually have very few market choices and sell their corn for a low price. Corn is the staple food choice when there is a shortage of rice, but is used mainly for feeding poultry when rice is plentiful. Corn is mostly planted in the first growing season (wet season) predominantly in the non-irrigated areas. Only about 30 ha is planted in the irrigated areas of western Lombok during the first season and is used for fresh consumption. During dry seasons some area such as the Batujai irrigation area are usually planted with corn.

Table 6.7 Corn/Maize crop parameterisation for CropOptimiser

Parameter	Entisols	Inceptisols	Alfisols	Vertisols
Potential Yield	7.5 t/ha			
Fixed Price	Season 1: 99 $/t Season 2: 100 $/t Season 3: 104 $/t			
Crop Water Demand	440 mm			
Productivity Index	Season 1: 0.77 Season 2: 0.68 Season 3: 0.51	Season 1: 0.76 Season 2: 0.67 Season 3: 0.51	Season 1: 0.77 Season 2: 0.67 Season 3: 0.51	Season 1: 0.77 Season 2: 0.68 Season 3: 0.51
Costs	158$/ha	160 $/ha	Season 1: 172 $/ha Season 2: 158 $/ha Season 3: 172 $/ha	Season 1: 175 $/ha Season 2: 160 $/ha Season 3: 160 $/ha

Vegetables

Vegetable crops such as cabbages, Chinese cabbages, longbeans, eggplants, cucumber and tomatoes can be grown throughout Lombok but require more input than the other crops. They are labour- and resource-intensive requiring applications of fertilizer, pesticides and irrigation. Irrigation is crucial during the early stages of crop development to promote vegetative growth. The price of production is relatively stable and decreases slightly during the drier seasons. The risk involved with growing these crops comes from water logging due to excessive rainfall, especially during the wet season (season 1). Therefore good drainage is required to reduce the risk.

Table 6.8 Vegetable crop parameterisation for CropOptimiser

Parameter	Entisols	Inceptisols	Alfisols	Vertisols
Potential Yield	13 t/ha			
Fixed Price	Season 1: 258 $/t Season 2: 196 $/t Season 3: 224 $/t			
Crop Water Demand	465 mm			
Productivity Index	Season 1: 0.6 Season 2: 0.74 Season 3: 0.59			
Costs	Season 1: 536 $/ha Season 2: 251 $/ha Season 3: 251 $/ha	Season 1: 540 $/ha Season 2: 260 $/ha Season 3: 260 $/ha	Season 1: 579 $/ha Season 2: 294 $/ha Season 3: 294 $/ha	Season 1: 585 $/ha Season 2: 300 $/ha Season 3: 300 $/ha

Chillies

Chillies (including 'hot chilli', 'big chilli' and 'curl chilli') require similar growing conditions to vegetable crops and are susceptible to excessive rainfall. They are a high-risk crop to grow and are also subject to price fluctuations in the market. The price of chillies in the wet season could be as much as triple the price in dry seasons. Micro climate modification through drainage, plastic mulching is required for growing this crop in the rainy season.

Table 6.9 Chillies crop parameterisation for CropOptimiser

Parameter	Entisols	Inceptisols	Alfisols	Vertisols
Potential Yield	3.6 t/ha			
Fixed Price	Season 1: 940 $/t Season 2: 620 $/t Season 3: 500 $/t			
Crop Water Demand	625 mm			
Productivity Index	Season 1: 0.68 Season 2: 0.71 Season 3: 0.51	Season 1: 0.68 Season 2: 0.70 Season 3: 0.50	Season 1: 0.68 Season 2: 0.70 Season 3: 0.50	Season 1: 0.68 Season 2: 0.71 Season 3: 0.51
Costs	Season 1: 699 $/ha Season 2: 414 $/ha Season 3: 414 $/ha	Season 1: 720 $/ha Season 2: 420 $/ha Season 3: 420 $/ha	Season 1: 785 $/ha Season 2: 499 $/ha Season 3: 499 $/ha	Season 1: 790 $/ha Season 2: 510 $/ha Season 3: 510 $/ha

Tobacco

Lombok Island is the centre of the tobacco growing area in West Nusa Tenggara (WNT) (Hamidi, 2007). Cropping areas and total tobacco production have increased exponentially since 1977 resulting from increased profitability for the farmers, as well as the introduction of many facilities provided by the tobacco companies (PT Jarum, 2006). Several international and national companies have established themselves to support the tobacco plantations and trade such as PT British American Tobacco (BAT), PT Jarum, and PT Sadana Arif Nus, all having branches in Lombok. These companies act as farmers' partners who provide facilities and extension services for growing tobacco. In 2007, the estimated total area of tobacco held by these companies was 20,000 ha with an estimated production of about 40,000 tonnes of dry leaves (Dinas Perkebunan, 2007).

Lombok Virginian tobacco (reputed to be one of the highest quality tobacco products in the world) has the potential to double its planted area in Lombok (pers. comm. PT Jarum, 2008). However, due to the high level of care required during the growing period, not every farmer has the capacity to grow this crop. Farmers consider this to be a high-risk crop, requiring a high level of maintenance and being very sensitive to overwatering. While tobacco requires regular irrigation, over-irrigating, excessive rainfall, and shallow watertables can seriously impact on crop production. Prices may also fluctuate significantly at harvest time.

The Virginian tobacco is the most important secondary crop in some irrigation areas in the middle and east of Lombok Island. In East Lombok it comprises 60% of the total irrigated land while in other areas it ranges from 20 to 30%. Typically, more than 20% of cropping area in Gde Bongoh, Srigangga, Renggung, Rutus, Pandanduri, Swangi and Sakra is used for growing tobacco.

Table 6.10 Tobacco crop parameterisation for CropOptimiser

Parameter	Entisols	Inceptisols	Alfisols	Vertisols
Potential Yield	30 t/ha			
Fixed Price	Season 1: 108 $/t Season 2: 120 $/t Season 3: 108 $/t			
Crop Water Demand	455 mm			

Productivity Index	Season 1: 0.52 Season 2: 0.59 Season 3: 0.54	Season 1: 0.52 Season 2: 0.64 Season 3: 0.54	Season 1: 0.52 Season 2: 0.65 Season 3: 0.54	Season 1: 0.52 Season 2: 0.61 Season 3: 0.54
Costs	Season 1: 950 $/ha Season 2: 750 $/ha Season 3: 750 $/ha	Season 1: 900 $/ha Season 2: 760 $/ha Season 3: 760 $/ha	Season 1: 1107 $/ha Season 2: 821 $/ha Season 3: 821 $/ha	Season 1: 1200 $/ha Season 2: 725 $/ha Season 3: 725 $/ha

6.3.5 Prototype LP model

The principle of the LP model is matching available water to types of crops. Since every crop has a different water demand and economic value then the optimization of cropping can be done through combining high-water-demand and high-economic-value crops with low-water-demand crops. Also, in some locations, particular crops can be prioritised for social or political reasons despite low economic values or high water demands.

The setup of the LP model for Lombok has some distinguishing characteristics for each season. Firstly, during the first growing season (November to February rainy season) rice cropping is prioritised over other crops, using as much land and available water as possible. Only when water supplies are insufficient will rice areas be reduced and replaced with higher income and less water-dependent crops. During the second cropping season (March to June), rice cropping is preferential, but will be augmented with more profitable and farmer-preferred cropping. In many areas where tobacco growing is common, the model will be constrained to plant tobacco to at least 20% of the available area. During the third season (July to October), the only constraints in the model are those that prohibit rice and tobacco cropping in all areas.

The results from the prototype LP model have been used for validation against what is known to have occurred in the past, with the expectation that the optimised outputs will be significantly improved over the historical practices. Validation involves choosing a year of known water availability (such as a severe El Niño year) and using these values for each region in the LP model to compare the optimised results against the known cropping practices for that year. This has been undertaken by the Indonesian team using their extensive local knowledge but has not yet been documented. It is recommended that this information be provided for future reference.

Instead the Indonesian team have provided a generalised summary of results for each climate type (El Niño, La Niña, Non-ENSO) grouped in areas of surplus, sufficient and deficit water supplies (Figure 6.9) where the regions are defined as:

Surplus water supply region comprises those areas where the water supply is greater that that required for cropping in the area. The surplus water is then diverted to the water-deficit area in the south. In a surplus water supply region, cropping can be done three times a year with the first two seasons planted to rice, while the total water supply from irrigation is greater than that in rainy season. Since there is less rainfall during the second growing season, irrigation water demand is greater compared to that in the rainy season.

Sufficient water supply region comprises those irrigation areas that have sufficient water supplies for planting 100% rice in the first season and at least 50% rice in the second season. The water supply during the second growing season is about the same as that in the rainy season, so therefore the water is sufficient to service rice crops in about 50% of irrigation areas. The rest of irrigation area is cropped with non-rice crops.

Deficit water supply region comprises those irrigation areas where the discharge during the second growing season is less than that in the rainy season. It is evident that in the southern Lombok, rice cropping can be done only once. Since irrigation water is only available during the rainy season, the cropping pattern is typically rice/palawija/palawija or rice/palawija/fallow cropping pattern.

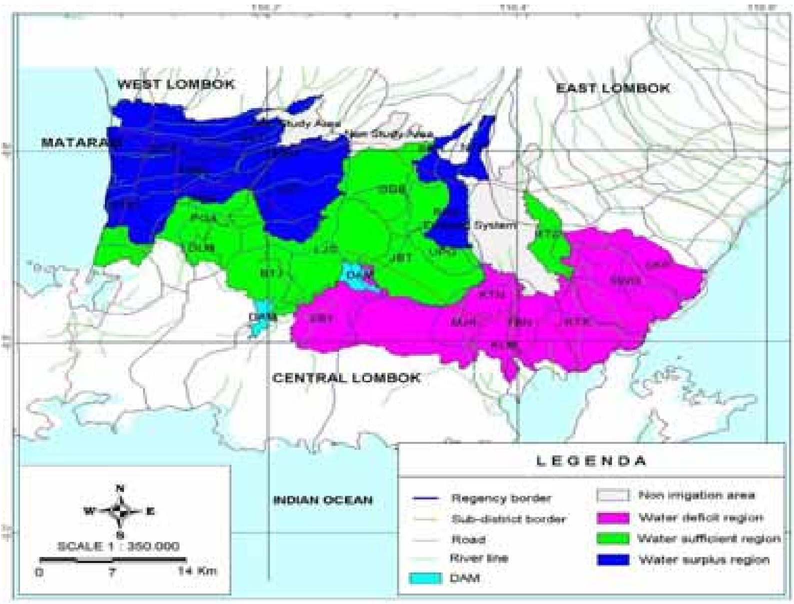


Figure 6.9 Categorisation of irrigation sub-areas into areas of surplus, sufficient and deficit water supply regions.

The results of the analysis (Table 6.11) show that cropping composition in the water surplus regions is not significantly affected by the ENSO phenomenon. In these regions, farmers may fully cultivate rice in the first and second growing seasons, regardless of the current climate conditions. In the third growing season the dominant crops that suit the lower water availability are leguminous and vegetable crops. In contrast to water surplus region, rice cropping in the water deficit areas is significantly affected by current climate conditions. During La Niña events, only 73% of total irrigation areas can be planted to irrigated-rice, which reduces to 65% of the area during El Niño events. The remaining areas must be allocated to non-irrigated crops. If all available land is planted to rice in these regions, crop failure may occur during El Niño events. Therefore, the most useful function of the LP is for developing cropping strategies in these water deficit regions. Strategies can be formulated during droughts to divert more water from the water surplus regions or to select alternative cropping practices.

Table 6.11 Crop composition (in %) for surplus sufficient and deficit water supply regions.

Name	Area	Crop	Land-use Season 1			Land-use Season 2			Land-use Season 3		
			El Niño	La Niña	Neutral	El Niño	La Niña	Neutral	El Niño	La Niña	Neutral
Surplus	18147	Rice	99%	100%	96%	82%	85%	84%	0%	0%	0%
		Corn	0%	0%	0%	4%	4%	4%	10%	10%	10%
		Legumes	0%	0%	0%	6%	3%	4%	50%	50%	50%
		Chillies	0%	0%	4%	1%	1%	1%	0%	0%	0%
		Vegetable	1%	0%	0%	0%	0%	0%	40%	40%	40%
		Tobacco	0%	0%	0%	7%	7%	7%	0%	0%	0%
Sufficient	23651	Rice	76%	86%	78%	45%	56%	50%	0%	0%	0%
		Corn	0%	0%	0%	5%	5%	5%	0%	5%	2%
		Legumes	2%	0%	0%	35%	24%	32%	11%	32%	22%
		Chillies	0%	14%	22%	3%	3%	3%	0%	0%	0%
		Vegetable	22%	0%	0%	2%	3%	1%	33%	37%	34%
		Tobacco	0%	0%	0%	10%	10%	10%	0%	0%	0%
Deficit	23244	Rice	65%	73%	64%	16%	23%	19%	0%	0%	0%
		Corn	0%	0%	0%	2%	2%	2%	0%	0%	0%

		Legumes	21%	2%	0%	37%	48%	41%	4%	9%	4%
		Chillies	0%	0%	33%	2%	2%	2%	0%	0%	0%
		Vegetable	1%	14%	3%	2%	1%	1%	16%	25%	19%
		Tobacco	0%	0%	0%	6%	6%	6%	0%	0%	0%

6.4 Development of decision support software

Both FlowCast and CropOptimiser have been developed in C++ as a Win32 application with a multi-threaded object-oriented design structure under Microsoft Windows using Borland C++Builder and the Visual Class Library (www.codeweavers.com). XML (extensible Mark-up Language), and XSLT technologies (www.w3.org/xml) were chosen to develop the reporting and storage components of the software while prototyping was undertaken using XML Spy Suite software (www.altov.com). Several third-party libraries including TeeChart (www.teemach.com) and VirtualTreeView (www.delphi-gems/VirtualTreeview) feature predominantly throughout both software applications while CropOptimiser also uses the GIPALS32 linear programming library (www.optimalon.com).

6.4.1 FlowCast

FlowCast was officially released to BMG in April 2008. This represented the first ‘refined’ and ‘stable’ version of the software.

Program functionality

The program structure, interface design, and operational direction are focused around four principal functionalities:

- Organising the project: This allows maps, predictors, predictand and rule-sets to be imported into the project, with project information available as reports.
- Exploring the time series data: Allows the linked time series data to be inspected, compared and explored using a suite of graphical and textural viewers. It is intended that this functionality will be used when any new data is imported to check on the quality and characteristics of the data.
- Performing “station” analyses: Used to generate and analyse forecasts for individual stations. Provides many detailed analyses exploring temporal variability.
- Performing spatial analyses: Provides GIS-based outputs for dozens of forecast and skill test variables. Provides limited temporal analysis capabilities.

Several ‘comparison modes’ have been developed for the different program functionalities. For example, when analysing station data, FlowCast can be configured to simultaneously compare and display results of multiple analyses of predictands (default), predictors, rulesets, output types and seasons. These options make FlowCast very flexible, but are potentially dangerous in the hands of inexperienced and untrained users, as results can easily be misinterpreted. Therefore, FlowCast has been developed with two ‘user-operational modes’; a “basic mode” with only the default comparisons accessible by the user and restricted spatial analysis functionality; and an “extended mode” that is password protected and permits all program functionality.

Graphical user interface

The graphical user interface has been designed to be as modern, attractive and simple as possible. It has been developed around several key principles including:

- simultaneous display of inputs and outputs
- reducing modal behaviour

- separating outputs through tabs
- presenting inputs in 'tree-view' controls (rather than dialogs) to support progressive disclosure of details
- performing actions/calculations in the background (threaded) with visual indication of status.

The current version presents the graphical user interface in a vertically split two-panel layout (Figure 6.10): the left panel contains the user input (tree-view) controls; and the right (main) panel contains textural, chart and GIS based analysis outputs. A custom designed 'forecast period setter' control for adjusting the predictor and predictand periods is located at the bottom of the outputs panel. Calculation status and progress are displayed in a footer bar at the bottom of the program window.

Figure 6.10 Example user interface layouts from FlowCast including project setup, browser analyses, station analyses; and spatial analysis outputs.

Input tree-view controls

FlowCast displays all of its input data in 'tree view' controls (Figure 6.11) within the left hand panel. Multiple tree-view windows are displayed according to the current program functionality and 'user operational mode'. Each tree node contains a check box (or radio-box, depending on the 'comparison mode') for selecting/deselecting analysis elements, and an icon indicating status. Clicking on the predictor or predictand icons opens the linked time series data files in external editors. Stratification-based predictor nodes can be expanded to show available stratification types.

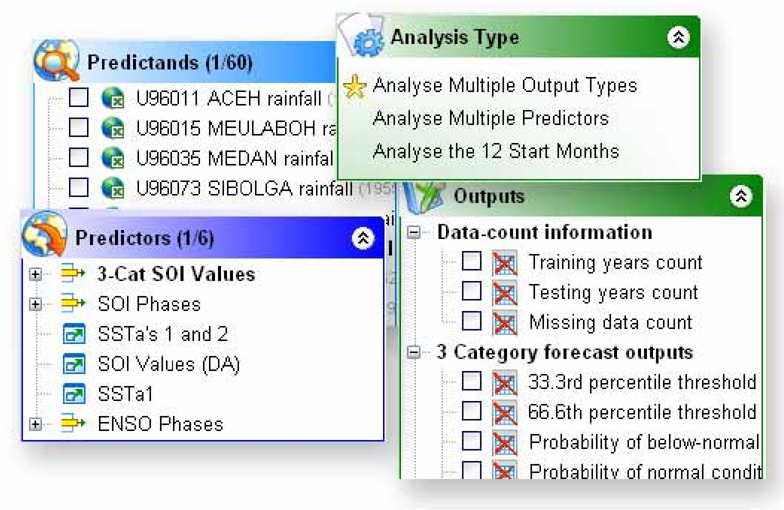


Figure 6.11 Input tree views for different input elements

Forecast period setter

The 'forecast period setter' is a custom-designed user-interactive tool that is presented when performing station and spatial analyses (Figure 6.12). This is a time-line-like control with Gantt bars representing the predictor and predictand periods. The user can move and resize the Gantt bars to adjust individual predictor and predictand periods, or drag the bottom axis or 'lead-time' indicator to adjust both periods in unison.

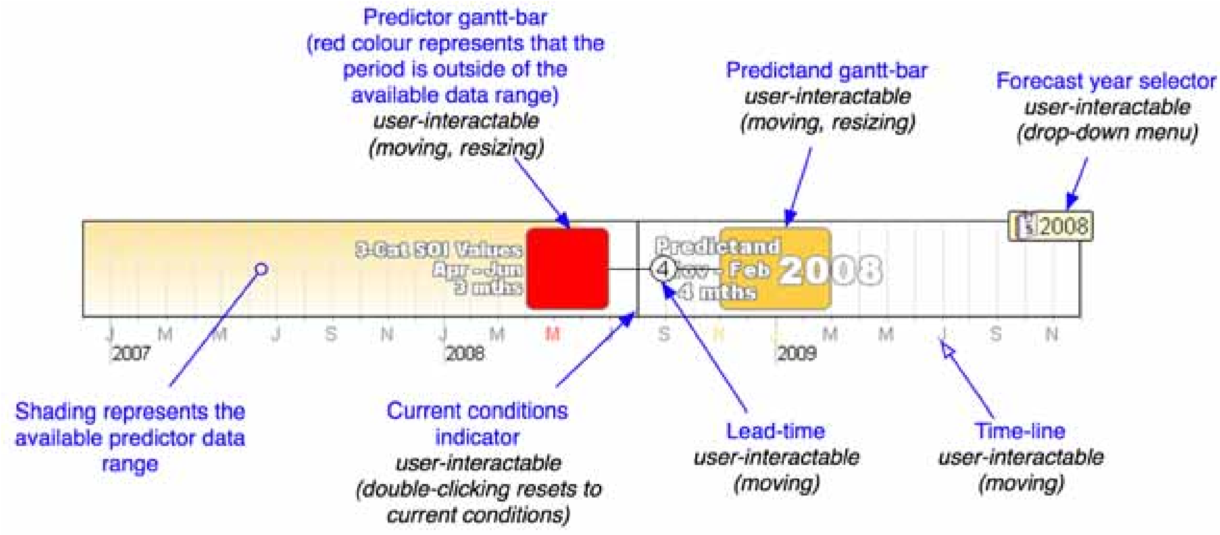


Figure 6.12 Forecast period setter tool showing user-interactive components.

Analyses and outputs

All program outputs are displayed from a range of analyses derived from the 'Browser' analysis toolkit. This toolkit has been developed in parallel with FlowCast and has been used in other software including SCOPIC (McClymont et al. 2009), Browser (McClymont et al. 2009), CropOptimiser, HowLeaky2008 (McClymont et al. 2009), and FIDO (McClymont, 2007). A key feature of this platform is the speed, efficiency and flexibility that it provides the user in interacting with graphical outputs. For example, it provides a simple yet powerful way of synchronizing the zooming and panning of multiple time series or map-based outputs. Chart outputs also have many display layouts and interactive capabilities, while map outputs allow geographical overlaying of chart-based outputs, plotting bubble-series at station locations, fitting contours of results, or combinations of each. Text-based outputs provide Microsoft Excel compatible spreadsheets for viewing and exporting (no editing). The abstract base class provides a consistent mechanism throughout the software to switch between chart, map, and tabular outputs, as well as providing titling, legend, and exporting capabilities. The three output modes are enabled in most analyses, although FlowCast's chart-based outputs have been disabled during spatial analysis due to the potential for high chart counts. Examples of the analyses in FlowCast are presented in Appendix 16.

Forecasts in Bahasa

In addition to the graphical outputs, FlowCast has recently been modified to provide local forecasts in the Bahasa language (Figure 6.13). The capability was originally developed for the SCOPIC software and transferred to FlowCast. Combined XML and XSLT technologies are used to transform the program results into rich-text outputs which can be transferred directly to a public-access website. Any number of "stylesheets" can be developed and loaded into FlowCast to create a range of output presentations.

Laporan ini dikeluarkan pada tanggal : 18 March 2009 (14:43:31), menggunakan FlowCast v4.4.11 (Beta)

FlowCast Prakiraan Dengan 3 Kategori

BMKG

Prakiraan Musim Wilayah Lombok

Maret - Mei (2008)

Berdasarkan nilai rata - rata "SOI Values (DA)" (Southen Oscillation Index (SOI) values) bulan Desember sampai bulan Februari.

Prakiraan Musim Untuk Wilayah Ampenan

Berdasarkan nilai rata-rata 3 bulan Southen Oscillation Index (SOI) values dari bulan Desember sampai dengan bulan Februari (SOI Values=16.600), Ada peluang 35% untuk terjadi hujan dengan sifat "Atas Normal" mulai bulan Maret sampai dengan akhir Mei untuk wilayah Ampenan. Peluang terbesar pada kondisi ini adalah hujan dengan sifat "Bawah Normal" dengan peluang 48%. Dan untuk terjadi hujan dengan sifat "Normal" peluangnya sekitar 16%.

Cara lain untuk melihat kondisi hujan yang terjadi sekarang adalah: Bahwa pada setiap 10 tahun selama periode Maret sampai dengan Mei secara umum di wilayah ini terjadi 5 kali sifat hujan"Bawah Normal"; terjadi 2 kali sifat hujan"Normal"; dan terjadi 4 kali sifat hujan"Atas Normal" (Note: Rounding Errors Occurring).

Note: "Bawah Normal" jika jumlah curah hujan pada bulan Maret sampai dengan bulan Mei di wilayah Ampenan jumlahnya kurang dari 259.7 mm. "Atas Normal" jika jumlah curah hujan selama periode tersebut lebih besar dari 389.3mm. "Normal" jika jumlah curah hujan selama periode tersebut berkisar antara 259.7 dan 389.3mm.

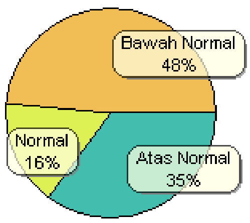


Figure 6.13 Sample forecast report in Bahasa language

Avoiding misuse

There is a real danger of this software being misused by users who have little understanding of climate and interpret results based on correlation alone without consideration of the associated driving mechanisms. The software makes it easy to ‘troll’ for best results and to seasonally alternate between predictive systems, violating conventions on spatial and temporal consistency. This can result in artificially inflated forecasting skill leading to overconfidence in the results and poorer decision making. Therefore, it has always been intended that FlowCast be used only by those with an understanding of these implications, and it is not intended for release to the general public. A significant part of the software’s design is in providing temporal and spatial evidence to minimize artificial skill and to empirically support the assumptions of the driving predictor/predictand mechanisms.

6.4.2 CropOptimiser

CropOptimiser was officially released to the University of Mataram in December 2008. This represented the first 'refined' and 'stable' version of the software.

Graphical user interface overview

The graphical user interface has been designed to be as modern, attractive and simple as possible. It has been developed around several key principles:

- simultaneous display of inputs and outputs
- reduce modal behaviour
- key outputs separated through tabs
- inputs presented in "Trees" (rather than dialogs) to support progressive disclosure of details
- actions/calculations to perform in background (threaded) with progress updates.

The current version is presented with a three-panel layout (Figure 6.10); with a top panel containing menus and status bar; the left panel containing the user controls (for inputs and outputs); and the right (main) panel containing textual, chart and GIS outputs, selected through a tab control.

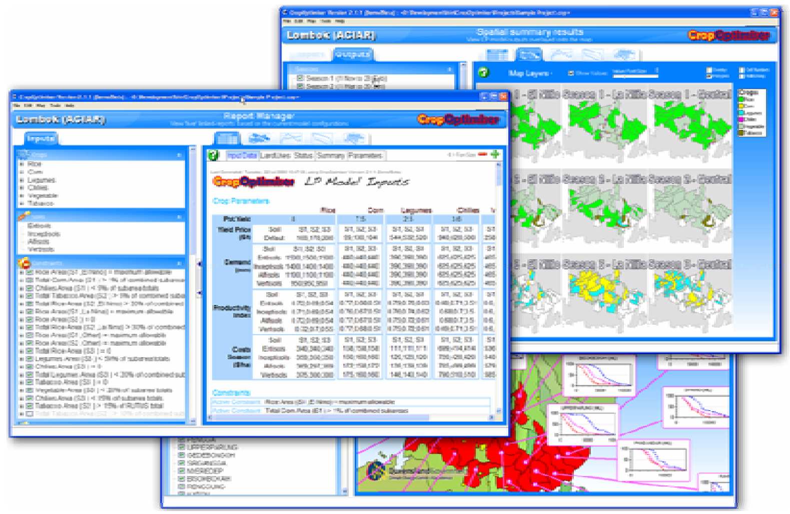


Figure 6.14 Sample screenshots from CropOptimiser including reporting analyses, GIS mapping of results, and geographic overlaying of probability distribution outputs.

A significant part of the interface is formed from the Browser analysis tools, as were used in FlowCast. These tools provide a polymorphic graphing and GIS platform for deriving analyses central to the CropOptimiser requirements. A key feature of this platform is the speed, efficiency and flexibility that it provides the user in interacting with graphical outputs. For example, it provides a simple yet powerful way of synchronizing the zooming and panning of multiple time series or map-based outputs, as well as displaying chart-based outputs as geographical overlays.

Program inputs

There are seven forms of input data that are required by CropOptimiser, including a map of the study area, season information, climate information, crop data, soil information, sub-area data, and user-defined constraints (Table 6.12). These data are stored within the 'project' object, and saved and loaded using an XML data format. The user interacts with these data using several VirtualTreeView components presented in the left-hand panel, which progressively discloses more data detail through expanding/contracting nodes. Some modal dialogs are also used for linking sub-area information (Figure 6.15).

Figure 6.15 Examples of input controls including (from left to right) crop inputs, sub-area inputs, and special sub-area linking dialog.

Table 6.12 Summary of Input data for required by CropOptimiser.

Input data type		Description	Notes
Map		GIS component that is converted from an ArcView 'shape-file' and saved in the TeeChart format.	Future versions will support GML and KML map formats.
Season-objects		Defines the cropping time-period for calculating available water and effective rainfall. Modifies the crop and sub-area data objects requesting additional season-specific information	Typically define 2-4 seasons Contains start-date and end-date fields.
Climate	Climate-objects	Defines the climate types for the stratification engine when calculating available irrigation water and effective rainfall. Defines the number of optimisations that the LP model will solve. Modifies the sub-area data objects by adding climate-specific input fields for irrigation water and effective rainfall.	Typically define 3-5 climate types. Links to the climate-date file.
Climate	Climate phase file	Monthly time series data file, which defines climate states, typically based on the ENSO phenomenon.	Default file is based on Allen's ENSO index (Allan et al. 1996)
Crop data	Potential yield (t/ha)	Defines the maximum yield achievable by a crop when the productivity index equals 1.	
Crop data	Fixed yield price ($/t) [season]	Vector of yield prices for each season.	
Crop data	Water-use factors (mm) [season] [soil]	Vector of water-use factors for each season and soil type. Implemented in Equation 7.	
Crop data	Productivity index [season] [soil]	Vector of productivity indices for each season and soil type. Implicitly includes soil productivity index information.	Ranges from 0-1 where a value of 1 means that crop production will be equal to the potential.
Crop data	Production costs ($/t) [season] [soil]	Vector of seasonal production costs which includes labour, management, water and agricultural costs.	
Soil data		Placeholder used to link productivity indices for crops grown in this sub-area.	Does not contain any data.
Sub-area	Map Code	Code which links the sub-area to a polygon on the map.	User-defined using special editor.

	Area (ha)	The total arable land area (for irrigation) within the sub-area.	
	Delivery efficiency (%)	Represents the percentage of available irrigation water that can be used by the crops.	
	Soil type	Reference to the area-specific soil data placeholder.	
	Available irrigation (ML)	Vector of total irrigation water available for different seasons and climate types. For example, 3 seasons and 3 climate types will require 9 inputs (vector size=9) for this data.	Can be entered manually or automatically from the outputs of the stratification engine.
	Available irrigation data files	Daily or monthly time series data files – as output from the IQQM model. Multiple files can be linked to each sub-area, and will be averaged or summated (depending on data nature) to produce a single representative time series for calculations.	Optional. Averaging will take place for data representing different simulations of the same source.
	Effective rainfall (mm)	Vector of effective rainfall for different seasons and climate types. Represents the amount of rainfall that is usable by the crops. As above, the vector size is determined by the number of seasons and climate types.	Can be entered manually, or automatically from the outputs of the stratification engine.
	Effective rainfall data files	Daily or monthly time series data files. Multiple files can be linked to each sub-area, and will be averaged to produce representative time series for calculations.	Optional.
User-defined constraints		Constraints are edited through selecting constraint type (crop area, water use, costs), crop type, sub-area type, season type, climate type, relationship type, and constraint RHS value.	

User-defined constraints

One of the more challenging issues in developing CropOptimiser was designing and interfacing a mechanism to allow the user to define social and management constraints, and subsequently incorporate them into the LP model. While user-defined constraints may be easy to formulate in words, translating these words into their equivalent algebraic representation required by the LP model is much more complex, given the range of constraint formulations possible and the need to automate this process within the software application.

The key factor in automating this translation is recognizing the underlying patterns accounting for all possible types of constraint formation. Central to this is identifying the effect of the constraint on each of the fundamental seasonal, sub-area and cropping elements. This includes:

- identifying whether the constraint affects ALL seasons simultaneously or just SELECTED seasons (or each season individually)
- identifying whether the constraint affects ALL sub-areas simultaneously or just SELECTED sub-areas (or each sub-area individually)
- identifying whether the constraint affects ALL crops simultaneously or just SELECTED crops (or each crop individually).

A total of eight patterns were recognized based on all possible combinations of the ‘ALL’ and ‘SELECTED’ element states. They typically involve breaking down the user-defined constraint into many individual algebraic statements. Examples of these patterns are presented in Appendix 14 and are accompanied by their algebraic formulation and sample matrix representation. The ordering of iterations of seasonal, sub-area and cropping elements is also presented to simplify the matrix-building process when automating the translation process.

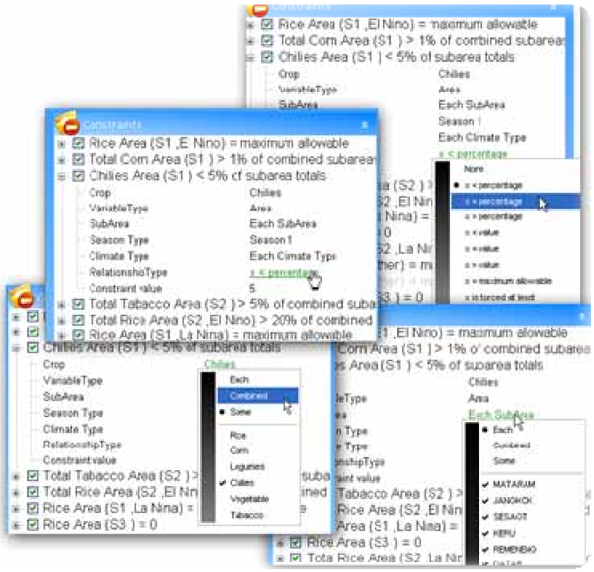


Figure 6.16 Example of the user-defined constraints editor, showing different menu options for equality type and crop and sub-area selection using "SELECTED" and "ALL" notation.

To allow the user to compose and apply these constraints, specially designed 'tree-based' constraint objects (Figure 6.16) were developed. These objects are designed to interface the eight constraint patterns by presenting the user with SELECTED and ALL options through drop-down menus, in key fields of "Crop Type", "Sub-area Type", and "Season Type". For the SELECTED case, the drop-down menus show all available options for that constraint element allowing the user to preferentially select the desired inclusions for the constraint. Users can define constraint limits through both absolute or percentage values, using a range of equality options. An important feature of this interface is the verbalization of the constructed constraint options as the displayed constraint name.

Program outputs

There are four types of program outputs in CropOptimiser including reports, GIS outputs, Browser outputs, and probability distributions. These analyses represent different visualizations of the LP model inputs, and optimised results including planted area of each crop, water supply and use, yields, costs and profits (Table 6.13). Results are calculated in terms of both totals and on a per-hectare basis.

Table 6.13. Result types from CropOptimiser. All results are calculated in total and on a per-hectare basis, which is required for displaying spatially.

Result type	Description	Calculated using…
Planted area	Area in hectares for each crop in each sub-area.	LP engine
Crop yield (t & t/ha)	Crop yield for each crop in each sub-area.	LP engine and post-processing
Crop water demand (ML & ML/ha)	Crop water use for each crop in each sub-area.	LP engine and post-processing
Total water use (ML & ML/ha)	Total water use in each sub-area.	LP engine and post-processing
Available water (Irrigation) (ML & ML/ha)	Total irrigation water available in each sub-area.	Stratification engine or user input
Available water (rainfall) (ML & ML/ha)	Total rainfall available in each sub-area.	Stratification engine or user input
Available water (total) (ML & ML/ha)	Total water available in each sub-area.	Stratification engine or user input

Water use/available ratio	Ratio of total water use to total water available.	Post-processing
Planted area ratio	Ratio of land area planted to land area available.	Post-processing
Costs ($ and $/ha)	Costs of production for each crop in each sub-area	LP engine and post-processing
Gross income ($ and $/ha)	Total revenue income in each sub-area	LP engine and post-processing
Gross margin ($ and $/ha)	Total profit margin in each sub-area	LP engine and post-processing

All four types of outputs are displayed in the right-hand panel in the main form. They interact with the application through individual task managers (report-manager, spatial analysis manager, browser manager, and stratification analysis manager) and all contain a range of tools to help manipulate and coordinate the outputs. Special selection tools are displayed in the inputs panel to allow fast selection and comparison of outputs. For example, these tools allow the user to simultaneously compare specific outputs across selected optimizations, or alternatively multiple outputs from a single optimization. These program outputs will now be discussed in turn.

Report outputs

CropOptimiser presents report outputs using XML and XSLT technologies, in the same way the reports in the Bahasa language are presented in FlowCast. Outputs are prepared in XML format in memory before transforming using a XSLT-based template into HTML. There are no limits on the number of reports that can be incorporated into CropOptimiser. One benefit of this technology is that it allows new reports to be generated without changing the software code, and can be undertaken by a graphic designer (with XSLT experience) rather than a software engineer. Five reports that are preinstalled with CropOptimiser including a summary of LP model inputs, optimised cropping area results, detailed LP model outputs, and parameter and sensitivity analysis results (Figure 6.17).

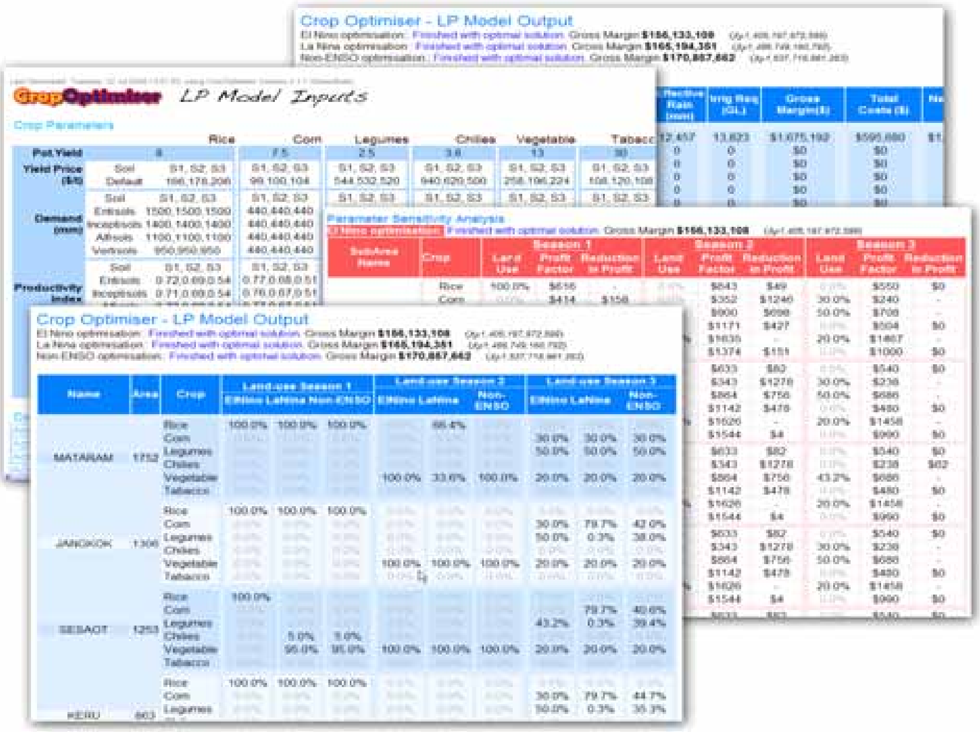


Figure 6.17 Reporting outputs based upon external XSLT templates.

GIS outputs

Displaying cropping patterns geographically is an important visual output of the software. This involves translating crop areas for each sub-area into different coloured polygons representing individual crop proportions. This is a holistic regional-level representation (as opposed to a farm-level representation) of cropping that should only be interpreted scheme-wide. Therefore, geographical cropping boundaries must not be interpreted literally within each sub-area, as the boundaries are defined arbitrarily (but methodologically) based on estimated proportions.

The methodology used to define these boundaries aims to group like crops together across neighbouring sub-areas, minimising the number of colour groupings across the map. This provides a more natural looking and easy-to-interpret output as opposed to generating linear boundaries or randomly allocating crop polygon pieces throughout each sub-area. To develop this, different approaches were trialled by hand, using graph paper and coloured pencils for some sample crop proportions (Figure 6.18).

In the adopted methodology, a grid is overlaid across the cropping regions, and crop types or fallow are allocated to individual grid cells in each sub-area in accordance with individual crop proportions, and based upon the importance of each sub-area to each crop's production. For example, sub-areas with the highest individual crop proportions are allocated cells first, followed by those sub-areas of lesser importance. Within each sub-area, outer cells that are closest to neighbouring dominant sub-areas are allocated crops first to ensure that the biggest cropping areas are grouped together. Once all cells have been allocated a crop, polygons are generated around the cropping groups and sub-area boundaries, using complicated mapping algorithms that were specifically developed for this purpose.

Browser outputs

CropOptimiser also contains three of the standard Browser time series analyses to compare and investigate any input time series data. This includes a time series viewer, monthly statistical analysis, and annual plots of seasonal totals. These are important tools to check and compare the quality of input data.

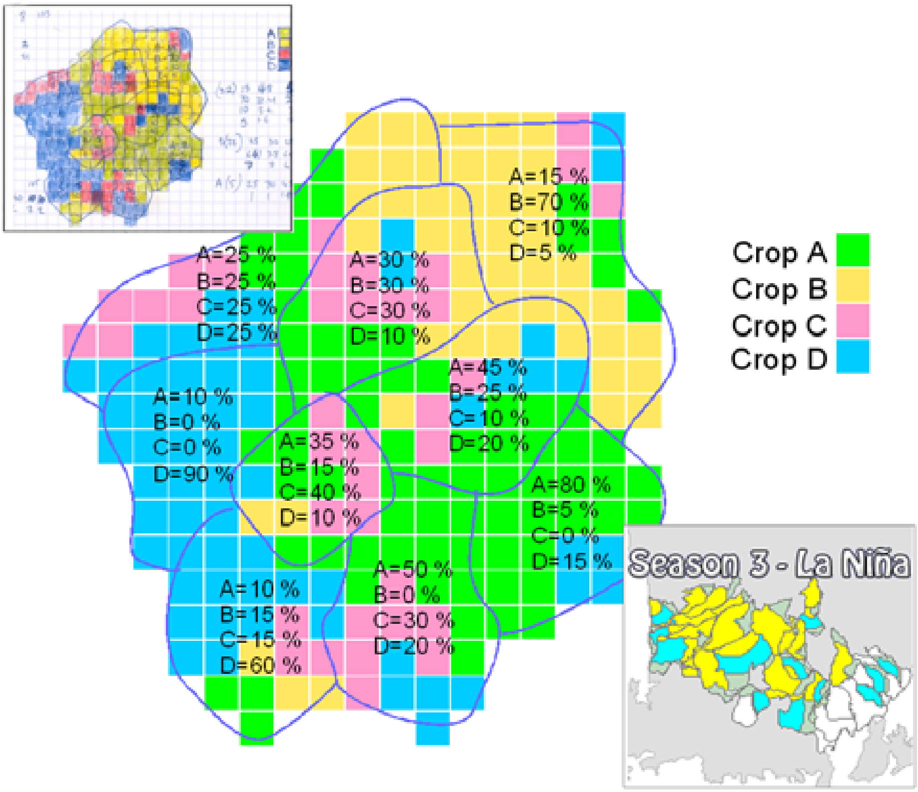


Figure 6.18. Methodology for assigning crop portions to geographically overlaid polygons. Top insert shows a preliminary hand-calculated output, while the bottom insert shows a final output from CropOptimiser.

Numerical validation of results

The output of CropOptimiser was validated numerically against the prototype LP model developed in Microsoft Excel through an interactive process of adding constraints and comparing numerical results. This was done to verify that the mathematical algorithms in the model are behaving correctly, rather than to justify the physical validity of the results provided (the physical validation was undertaken by the Indonesian team in prototyping the LP model and as described earlier, and was not provided for inclusion in this report). Appendix 15 presents the results of the mathematical validation which show identical results between the two models.

Barriers to operational use

Despite the availability and repeated training of key personnel in the use of the CropOptimiser software, the Indonesian team has continued to use and rely on the results from the prototype spreadsheet-based LP model that they had developed themselves. This partly reflects the late completion date of the development of CropOptimiser, and also the ‘teething’ problems that occurred in the initial versions of the software which eroded confidence in its use. The experience of this project has been that small problems, minor bugs and intermittent crashes in the software became insurmountable barriers against its use. While these issues have now been addressed in the software development, further training and education is required to push for the software’s adoption in real-world applications.

6.5 Assessing supplementary irrigation resources

6.5.1 Groundwater extraction

Previous studies

Delinom et al. (1992) described the geological condition of Lombok using a geological map scaled 1:400,000 (Matrais et al. 1972) and field observations. Hydrogeology of Lombok was divided into six forms, namely alluvium, young volcanic ash, mature volcanic ash, limestone, sedimentary rock and igneous rock. South Lombok has volcanic ash that contains less water with lower permeability. CIDA and Crippen (1975) conducted major investigation into the water resources potential of Lombok. Their groundwater program consisted of 32 boreholes and 12 pumping tests in Lombok and they found that sufficient quantities of water exist in Rembiga (north of Mataram) and on the east coast near Lembar Lombok and on the north coastal fringe.

The next investigation was carried out by ELC-Electroconsult (1986) focusing on four different sites: Sekotong in the southwest, Sengkol in the south, Bayan in the north, and Priggabaya in eastern Lombok. Le Groupe AFH international (1993, 1996) reviewed the hydrogeology of Lombok and it was reported that in most parts of the island the groundwater is found in shallow aquifers. The geological formations of the aquifers in Lombok are Ash and Lahar volcanic in the northern mountain area, alluvium in the west, northeast and northwest Lombok, fault zone and Karstic limestone in south Lombok, and ancient beach deposits to the coastline of east and west Praya. The alluvial deposits are a good aquifer, whereas the Ash and Lahar make an excellent aquifer. On the other hand, fault and Karstic limestone aquifers produce insignificant amounts of groundwater. Ancient beach deposits could be a good aquifer provided that there is adequate recharge.

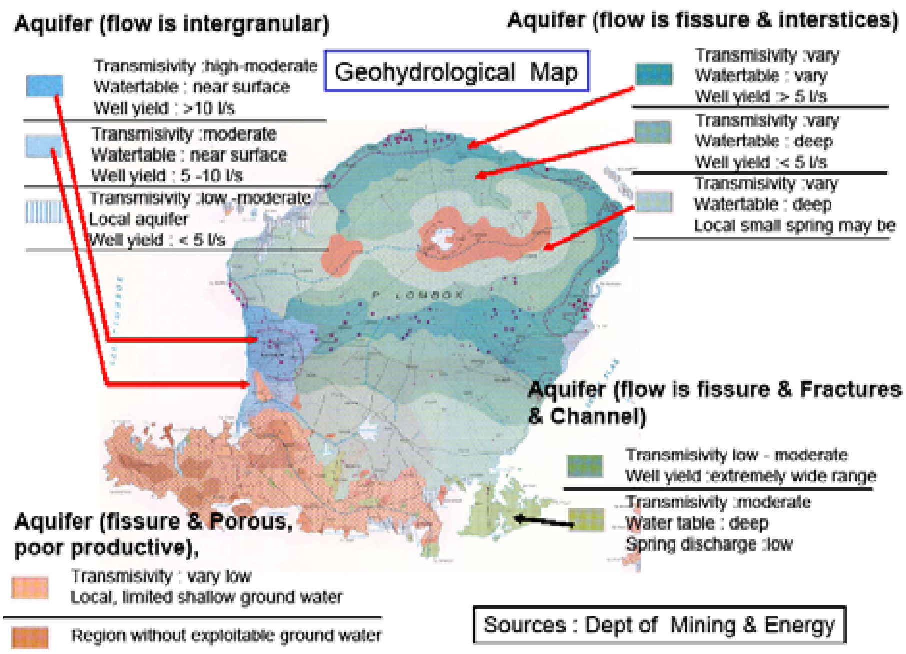


Figure 6.19: Aquifer characteristics in the study area.

Munawir et al. (2003) reported that in the north-west part of Lombok, the lithological composition of the downstream part of the Segara basin, along the coast and up to +100 m mean sea level, is sedimentary rock such as alluvium, gravel, fine gravel, sand, clay, peat and coral split. There is an aquifer layer, which has a medium to high transmission capacity and medium productivity. The groundwater level is shallow, with discharge varying from 5 to 10 litres per second. According to the Department of Mining and Energy (Indonesia) the water level is very near to the surface in Mataram and is ideal for construction of shallow dug wells.

Dug wells (Figure 6.20) are holes in the ground dug by shovel or backhoe. A dug well is excavated below the groundwater table and the well is then lined (cased) with stones, brick, tile, or other material to prevent collapse. Typically, they are only 3 to 10 metres deep depending on water level and geology of the aquifer and 1 to 2 metres in diameter. A shallow dug well is perceived as an appropriate water-harvesting technology to support irrigation covering approximately 3 ha of horticulture crops in some areas at Lombok Tengah. In 1973 Crippen conducted a study on the status of water levels of the dug wells in Lombok and they reported that only 4 out of 10 wells maintained a reliable water supply in the dry season (Le Groupe AFH international, 1996).

Figure 6.20 Shallow dug well in Lombok Tengah.

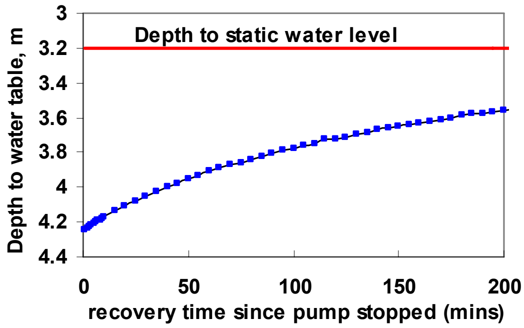
New study

Table 6.14 shows the field measurements recorded for the 11 wells located in Kawo and Tanaq Awu in southern Lombok in October 2005, January 2006 and May 2006. The recovery test for a representative dug well (K1) in Kawo is shown in Figure 6.21a to depict the watertables in relation to static water level. It shows that after the pump was stopped, the recovery was taking place at an accelerating rate at the beginning before gradually slowing. It was shown that about 65% of the depressed head was recovered within 3½ hours. The shallow aquifer is dominated by limestone and depending on the fractures and fissures present the properties may vary. The residual drawdown during the recovery test for this dug well is shown in Figure 6.21b. It shows that the residual drawdown per log cycle was 0.48 m. It was not possible to verify the transmissivity under recovery test with that under drawdown test because of poor quality data. The same dug well was also used in the second phase of the study in Jan-Feb 2006. The nature of the recovery of the water level and the time-drawdown curve are shown in Figure 6.21c and d to show that the well showed similar characteristics that reconfirmed the transmissivity of the aquifer.

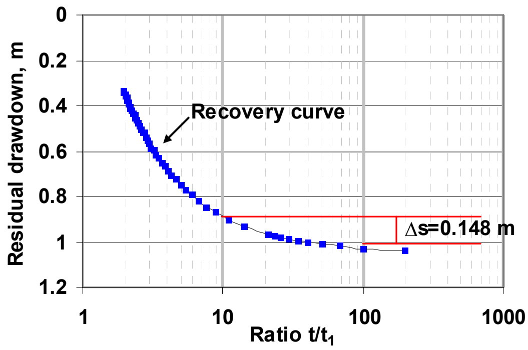
Table 6.14 Dug wells in South Lombok used for pumping and recuperation tests.

Well owner	Location	Well code	Well depth (m)	Well diam. (m)	Oct 2005		Jan-Feb 2006		May 2006	
					Depth to water table (m)	Water depth (m)	Depth to water table (m)	Water depth (m)	Depth to water table (m)	Water depth (m)
A Sandi	Kawo	K1	5.7	1.8	3.16	2.64	2.93	2.77	Na	Na
A. Nuri	Kawo	K2	5.72	1	4.03	1.69	3.21	2.51	1.27	4.43
A. Chai	Kawo	K3	5.3	1	4.4	0.9	Na	Na	0.65	4.65

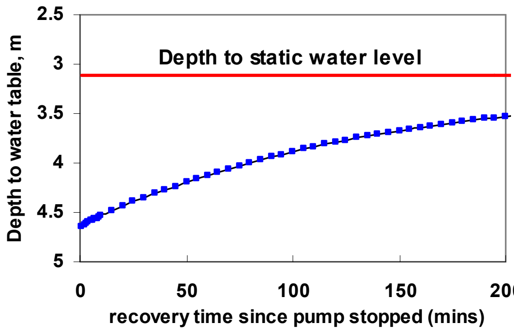
A, Laut	Kawo	K4	4.6	0.8	3.62	0.94	0.98	3.58	0.76	3.71
Utama Desa	Kawo	K5	6.11	1	5	1.11	4.37	1.74	1.89	4.24
A. Akil	Tanaq Awu	T1	3.64	1	3.02	0.62	2.34	1.3	0.82	3.11
H. Halidi	Tanaq Awu	T2	4.39	1	2.96	1.43	0.6	3.79	0.33	4.06
Mq. Haeruman	Tanaq Awu	T3	4.94	1	3	1.94	0.77	4.17	0.68	4.26
L. Sukri	Tanaq Awu	T4	3.25	1	3.02	0.23	0.84	2.41	0.71	2.54
Abdul Hanan	Tanaq Awu	T5	3.3	1	Na	Na	0.91	2.39	0.65	2.65
L. Rupawan	Tanaq Awu	T6	3.89	1	na	na	na	na	0.69	3.2



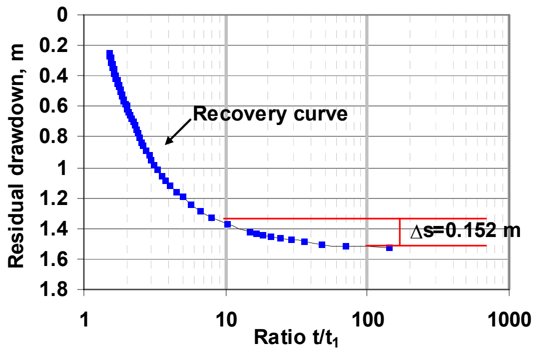
(a) Depth to watertable October 2005



(b) Time-drawdown October 2005



(c) Depth to watertable Jan-Feb 2006.



(d) Time-drawdown Jan-Feb 2006.

Figure 6.21 Sample pumping test results at Kawo (well code K1) including (a) depth to watertable from ground surface during recovery test conducted in October 2005; (b) time-drawdown graph during recovery test in October 2005; (c) depth to watertable from ground surface during recovery test conducted in Jan-Feb 2006; and (d) time-drawdown graph during recovery test conducted in Jan-Feb 2006.

In October 2005, reliable data could be collected from only two dug wells in Kawo for calculating aquifer properties including transmissivity. It was found that the transmissivity was around 45 m3/day/m thickness of the aquifer. The percolation rate during the recovery tests varied from as low as 0.005 l/sec to as high as 0.19 l/sec. The average yield of the well varied from 0.006 to 0.17 l/sec (Appendix 17 Table A17.1).

In Jan-Feb 2006, the transmissivity varied from 20 to 46 m3/day/m thickness of the aquifer (Appendix 17 Table A17.2). The percolation rate and corresponding working head are also reported in the table. The percolation rate and yield did not vary widely as compared to those in October 2005. Similar results were also obtained in the third phase (Appendix 17 Table A17.3) with the exception that the transmissivity increased quite significantly in some new areas. This requires further verification as drawdown tests might have influenced the results. Le Groupe AFH International (1996) revealed that the transmissivity in the water-bearing stratum comprising limestone could vary from 70 to 90 m3/day/m. Considering the field conditions and the difficulties in collecting data in the field we may consider that the results we have found are reasonable. This type of field experimentation requires further verification, with longer pumping tests and automation of the data collection.

The percolation rates of the dug wells were derived considering that the working depression head will be within safe limits so that there is no loosening of the soil particles beneath the concrete lining. If the pumping rate is higher than the percolation rate then it is unlikely that the wells will be sustainable. Some dug wells were found to yield a very significant amount of groundwater compared to others, but precaution must be taken so that the pumping of the groundwater does not exceed the percolation rate.

Maximum pumping rate is useful to calculate the potential of shallow groundwater for supplementary irrigation. For illustration, the area that could be irrigated was calculated for such a pumping rate for a specific crop (watermelon). The amount of water required for watermelon is about 300 mm (3000 m3/ha) for one season. Watermelon is an important secondary crop in South Lombok. It is normally irrigated using hand-held pouring systems that maximizes the irrigation efficiency. The average yield of the dug wells ranged from 0.034 l/s in May to 0.088 January to February. However, the average safe yield of these dug wells as interpreted from the percolation rate is 0.08 l/s, that can be translated to 622 m3 considering a season of 90 days. This will allow growing 0.2 ha of watermelon for each dug well.

6.5.2 On-farm water harvesting

Appendix 18 presents the HowLeaky parameterisations of the cropping, soil and tillage options simulated in this study. Water balance simulation results using HowLeaky (Ver. 1.36) found the average in-crop wet season runoff for Mangkung varied substantially for the combinations of crop, soil and management practices simulated (Tables 6.15 and 6.16). For all three of the wet season crops simulated (tomato, chillies and rice), there was little difference in in-crop runoff across the plausible range of values in residue cover, and on the two soil types parameterised. In comparison, conceivable field changes in soil drainage rates displayed the most significant impact on simulated in-crop runoff volumes.

For a Black Vertisol soil, results showed a range of average in-crop runoff volumes from as low as 99 mm to 197 mm across the simulation scenarios range (three crop types, with and without crop residue, two soil drainage rates). The same simulation scenarios conducted for the Lombok Sodic Brown Vertisol showed increases in runoff volumes (compared to the Lombok Black Vertisol) ranging from 130 mm to 218 mm. These are associated with the reduced drainage rates and soil structure.

The error which can be made by only considering the average in-crop runoff volumes is demonstrated by plotting a probability distribution of in-crop runoff volumes. Figure 6.22 presents these results for a rice crop grown in the first season on a Lombok Black Vertisol soil. Although the average in-crop runoff was calculated at 120 mm, this shows that approximately less than 94 mm of in-crop runoff occurs in only 50% of years simulated.

Table 6.15. Simulated average in-crop water balance parameters for Mangkung (Lombok Black Vertisol) for a range of scenarios.

Simulation Scenario	Rainfall	Irrigation	Runoff	Drainage	Soil Evap.	Transp.
1. Rice (PRB), maximum drainage rate 5 mm/day, 0kg residue reset	632	124	120	159	99	324
2. Rice (PRB), maximum drainage rate 1 mm/day, 0kg residue reset	632	108	191	59	99	323
3. Rice (PRB), maximum drainage rate 5 mm/day, 5000kg residue reset	632	113	123	163	86.9	327
4. Rice (PRB), maximum drainage rate 1 mm/day, 5000kg residue reset	632	96.5	197	59.5	86.8	326

Net change across simulations (1 to 4)	**-**	**27.5**	**77**	**104**	**12.1**	**4**
5. Tomatoes (PRB), maximum drainage rate 5 mm/day, 0kg residue reset	583	108	107	152	127	244
6. Tomatoes (PRB), maximum drainage rate 1 mm/day, 0kg residue reset	583	92.6	173	55.1	127	244
7. Tomatoes (PRB), maximum drainage rate 5 mm/day, 5000kg residue reset	583	93.8	111	154	113	246
8. Tomatoes (PRB), maximum drainage rate 1 mm/day, 5000kg residue reset	583	83.8	182	56.3	113	246
Net change across simulations (5 to 8)	**-**	**24.2**	**75**	**98.9**	**14**	**2**
9. Chillies (PRB), maximum drainage rate 5 mm/day, 0kg residue reset	562	116	99	154	161	194
10. Chillies (PRB), maximum drainage rate 1 mm/day, 0kg residue reset	562	103	167	57.5	160	194
11. Chillies (PRB), maximum drainage rate 5 mm/day, 5000kg residue reset	563	105	103	159	143	196
12. Chillies (PRB), maximum drainage rate 1 mm/day, 5000kg residue reset	563	92.7	176	58.3.	143	196
Net change across simulations (9 to 12)	**-**	**23.3**	**77**	**101.5**	**18**	**2**

Table 6.16 Simulated average in-crop water balance parameters for Mangkung (Lombok Sodic Brown Vertisol) for a range of scenarios.

Simulation Scenario	Rainfall	Irrigation	Runoff	Drainage	Soil Evap.	Transp.
1. Rice (PRB), maximum drainage rate 3 mm/day, 0kg residue reset	627	103	151	120	98.6	323
2. Rice (PRB), maximum drainage rate 0.6 mm/day, 0kg residue reset	627	90.5	210	37.2	98.6	323
3. Rice (PRB), maximum drainage rate 3 mm/day, 5000kg residue reset	627	93.9	155	126	87.2	326
4. Rice (PRB), maximum drainage rate 0.6 mm/day, 5000kg residue reset	627	80.9	218	38.9	87.1	326
Net change across simulations (1 to 4)	**-**	**22.1**	**67**	**88.8**	**11.5**	**3**
5. Tomatoes (PRB), maximum drainage rate 3 mm/day, 0kg residue reset	583	88.1	139	115	127	243
6. Tomatoes (PRB), maximum drainage rate .6 mm/day, 0kg residue reset	583	72.2	193	34.9	127	243
7. Tomatoes (PRB), maximum drainage rate 3 mm/day, 5000kg residue reset	582	76.5	146	119	113	246
8. Tomatoes (PRB), maximum drainage rate .6 mm/day, 5000kg residue reset	582	63.5	206	35.8	113	246
Net change across simulations (5 to 8)	**-**	**24.6**	**67**	**84.1**	**14**	**3**
9. Chillies (PRB), maximum drainage rate 3 mm/day, 0kg residue reset	558	95.7	130	117	160	195
10. Chillies (PRB), maximum drainage rate 0.6 mm/day, 0kg residue reset	558	83.9	189	36.7	160	194
11. Chillies (PRB), maximum drainage rate 3 mm/day, 5000kg residue reset	560	86.8	137	122	144	196
12. Chillies (PRB), maximum drainage rate 0.6 mm/day, 5000kg residue reset	560	74	198	36.4	144	196
Net change across simulations (9 to 12)	**-**	**21.7**	**68**	**85.6**	**16**	**2**

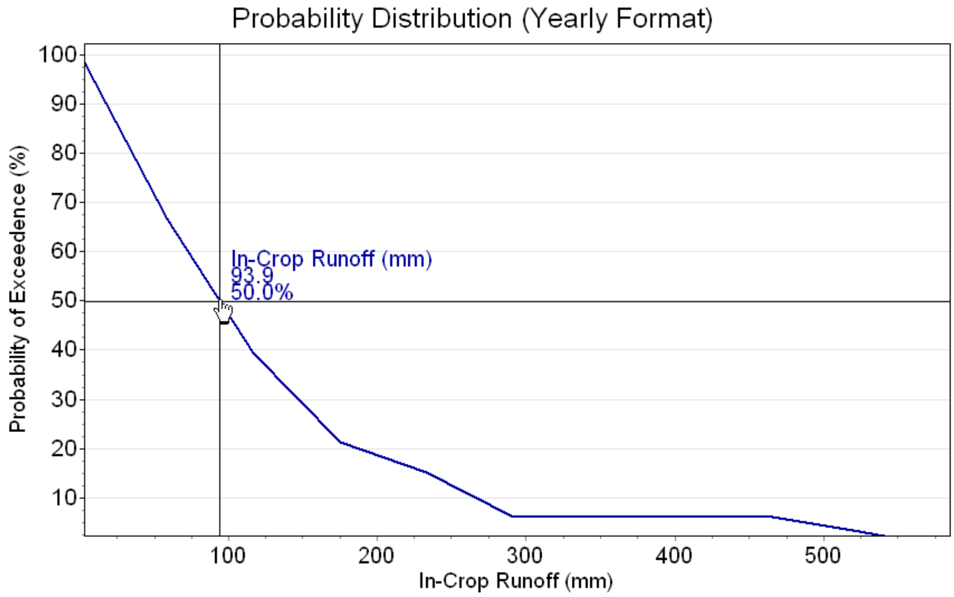


Figure 6.22 Probability distributions of in-crop runoff simulated for rice growth on Lombok Black Vertisol (Simulation 1).

In-crop runoff was found to be highly variable for each of the simulation scenarios conducted. Figure 6.22 shows the strong association between inter-annual variability of in-crop runoff and wet season rainfall. This shows that a rainfall threshold exists where rainfall greater than the soil's infiltration rate must be received before runoff will occur. For the period of 1987 through to 1991, although rainfall did occur, there was no daily rainfall event contributing to runoff for over four years. Along with the probability distributions, this has important implications for farm storage design and the yearly management of these structures in terms of the trade-off between possible increased dry season yields (from the use of stored irrigation water when it exists), and the reduction in cropping area from land-used to host the water storage (embong).

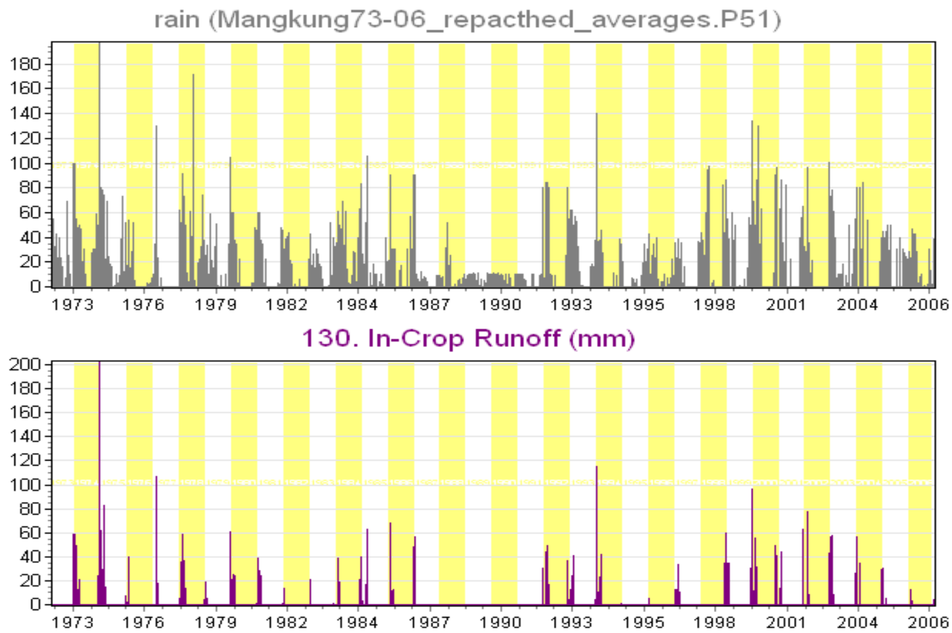


Figure 6.23 Daily rainfall and simulated daily in-crop runoff for rice grown on a Lombok Sodic Brown soil (Simulation 130).

The probability distributions of annual in-crop runoff further demonstrates the variability in runoff volumes from year to year and emphasises the importance of being able to predict the seasonal in-crop runoff in water harvesting and storage management. However, skill-testing of ENSO-based seasonal predictions of in-crop runoff (Figure 6.24) indicated that this is not feasible during the first cropping season. The LEPS skill scores for the September to November (and subsequent) periods (as output from FlowCast) were similar to 'climatology' (poor skill).

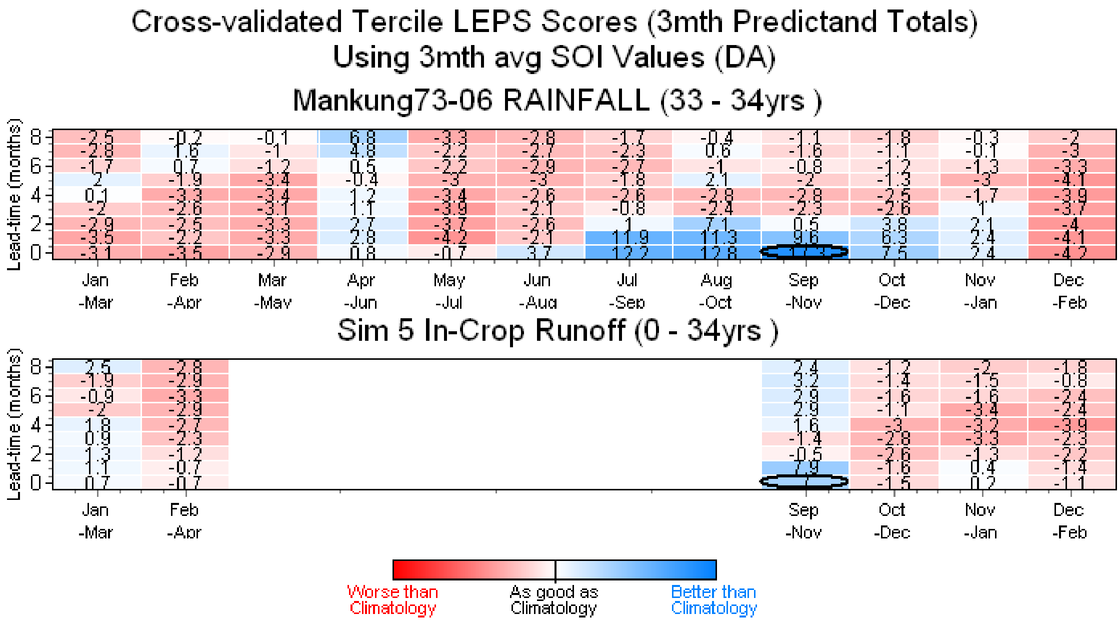


Figure 6.24 LEPS skill testing for rainfall and in-crop runoff for Mangkung using 3 month SOI values (Simulation 1).

Results of the sensitivity analysis conducted across the range of plausible input parameter values found those parameters with the greatest influence on in-crop runoff were those associated with infiltration and drainage. This highlights the importance of in-situ field measurements over the use of text book or reference values in conducting well validated simulation modelling.

Farm water balance modelling undertaken with HowLeaky (Ver. 1.36) involved the parameterisation of 9 Soils, 10 crop by season combinations, 7 tillage types, 6 irrigation methods and various model options for residue cover amounts and reset dates. This work provided operational use in the software, a repository of input variable values and the process to enable future simulation modelling of in-crop runoff to be undertaken more extensively across Indonesia. Although there was found to be poor skill in forecasting in-crop runoff during season 1, with further support the use of HowLeaky as an investigative and education tool can play a pivotal role in quantifying local in-crop runoff volumes and aid farmers' understanding of what impact management practices can have on the capture and efficient utilisation of season 1 in-crop runoff.

6.6 Capacity building

Throughout the duration of this project, efforts were made to build regional scientific capacity in the areas of hydrological modelling, seasonal climate forecasting and operation of the decision support software, and to build local capacity at the field level to implement project recommendations.

At project-end, not enough scientific capacity has been developed to internally replicate the work of this project; however, the Indonesian project team now have the capability to manipulate and apply outputs into the local community, albeit on a limited level. Some individuals do have a high level of proficiency in key project areas including agricultural management, linear programming, seasonal climate forecasting, and operation of the decision support software, with some undertaking higher education as a part of this project. However, in the absence of these individuals, there is a risk that the application and dissemination process will fail.

Agencies such as BPTP, WOC, Dinas Pertanian, BMG and UNRAM have been specifically targeted in training workshops in both Indonesia and Australia. Computer packages such as FlowCast and CropOptimiser have been demonstrated as tools for policy-makers during such events. Many informal meetings with policy-makers, farmers' group leaders and water user association leaders have occurred promoting the importance of the technology.

Several intensive high-level training workshops were undertaken during the project including:

- Workshops on the calibration and application of the IQQM Lombok model which were run in Indonesia and Australia for two key participants.
- Several training courses were run in the operation of FlowCast in both Indonesia and Australia involving up to ten participants. Also, an advanced FlowCast training course was conducted for a key BMG officer (Adi Ripaldi) in March 2009 under an ATSE Crawford scholarship program.
- One key staff member (Ismail Yasin) obtained a high level of training in the use of CropOptimiser, and was actively involved in its development through tasks of parameterisation, validation and testing.

Training in the use of the HowLeaky software was not provided during this project.

At the field level, capacity building has been primarily focused on promoting the importance and background theory of climate in agricultural management. While it appears that at least the messages are getting through to stakeholders, there still seems to be a general reluctance to change practices. To build capacity and facilitate change, a 'field school of climate' has been up and running for over five years, attended by field extension officers, water gate and water user associations and farmer group leaders. This is a week-long course promoting better understanding of management of irrigation, cropping planning, cropping pattern and cropping systems related to unexpected weather conditions and climate variability.

6.7 Information dissemination

6.7.1 Local governance and extension development

Agricultural planning and policy under the current Indonesian government is highly decentralized, with large and complex agricultural research and extension systems including both government and non-government based services. Appendix 19 presents an overview of the current state of institution and policy in Indonesia and what this means for extension and dissemination in Lombok. This includes information regarding local planning and governance as well as Indonesian agricultural extension services.

Relevance, responsiveness and sustainability are key criteria in developing an information dissemination program. While 'decentralization' of Indonesia's extension systems does seem to offer particular hope for improving relevance and responsiveness of advice, many problems and solutions are location-specific. In terms of relevance this should give a clear advantage to the local provision of guidance. However, administrative boundaries rarely coincide with agro-ecological zones (or with socio-economic situations). There may be a large diversity of situations within the purview of a local government, while the capacity to adjust the advice to local conditions (or to specific groups) may be negatively affected by decentralization.

In particular, good linkages with agricultural research may be difficult to establish at the local level if there is no research facility in the region. Similarly, responsiveness to farmer problems may not automatically result from decentralization. Extension managers become closer to the client but not necessarily more attentive to their problems. Staff attitudes need to change, and farmers need to get organized to make themselves heard (Malvicini, 1996).

It is already apparent that decentralization of extension is unlikely to fulfil the extremely high expectations it has aroused. Meanwhile in Indonesia, decentralization is ongoing and will take some years before the dust settles and an objective and well-informed picture emerges. It has yet to be seen how the relationships with other services are taken into account when extension is decentralized.

In West Nusa Tenggara Province, some problems and issues have already been identified under this governance which may hamper the effectiveness of dissemination and extension processes, including:

- a large number of extension specialists and field agents are still under central administration and financing, but some new ones (since 2004/2005) are under BPTP's administration
- agencies handling agricultural affairs and extension among district levels are diverse in terms of name, coverage, and affairs
- some districts have special agencies for food crops (BUKPD, which are in Bima and Western Lombok districts) reflecting that some agricultural affairs are handled in different agencies
- facilities and resources for extension activities after the World Bank left are lacking
- field extension officers (PPL) are limited, one PPL per working area of agricultural extension (WKPP) comprising one or two villages – their capacity to handle climate matters may be limited
- local planning and policy frameworks appear to be ineffective with no scientific methods/models being used to develop local agricultural policy.

In relation to the state of human resources in extension Institutions in this region, there are some persisting problems faced by agricultural and extension officers in this region including:

- the distribution of agricultural extension workers is concentrated in the food crop sector
- efforts to improve the competency of agricultural extension staff have not been optimised
- non-government and private extension workers need further development
- the function of agricultural extension at the province level is hampered because the mandates for running agricultural extension services are not clear
- institutional form and arrangement of rights and responsibilities in the district and provincial levels are diverse due to district autonomy
- not all sub-districts in NTB provinces have an agricultural extension unit/agency (BPP) and buildings and those which have offices struggle to run effectively
- most BPPs do not have experimental fields for demonstration purposes
- some BPP buildings have been converted to other uses and do not have enough facilities for agricultural extension.

6.7.2 Farmer's decision-making survey

The results of a field survey conducted in 2006 (for the planting year of 2004/2005) revealed that a quarter of respondents (26%) found government advice to be the highest factor in influencing their decision to crop rice. Water availability was the main factor, followed by following other farmers (32 %), yield price (31 %), and crop productivity (8%). In terms of water source for cropping irrigation, the study shows that 55% of respondents (41) used diverted irrigation water, 25% (19) used water from other sources (such as wells) and 20% (15) failed to respond.

Farmers in the SLIA still very much rely on a traditional approach called pranata mangsa in their efforts to estimate the rainy season, which is then used in formulating cropping strategies including crop varieties and planting dates. Results of the 2006 study showed that the majority of farmers (88%) still use the traditional approach in deciding plantation time and climate condition and only few farmers (8%) followed recommendations from the DOA, and 4% did not comment. This implies that great effort is required to convince farmers to adopt new information or policies, given the current social and economic conditions of farmers.

Table 6.17 Number and percentage of respondents who affiliate with rural institutions Source: primary data 2006 survey.

No	Rural Institution	Number	Percentage
1	Village cooperative unit	11	15%
2	Farmers' group	32	43%
3	Social neighbourhood group (Banjar)	35	47%
4	Social gathering group (arisan)	43	57%
5	Water user association of farmers	38	50%

Involvement and participation of farmers in local rural institutions in this area may become a crucial factor in extension and dissemination processes based on the previous experience. Adopting new information and technology through local organizations may be more effective, and past experience with extension programs has been very much outside of local institutions.

All ministries in Indonesia have their own targeted groups in the local villages where its programs are executed and developed. However, in the case of the agricultural sector, the kinds of groups and organizations that are closely related to agriculture are farmers' groups (KOPTAN); village cooperative units (KUD); and water user associations (P3A). The involvement of farmers in those agricultural-related institutions is not very high. Therefore, a proper approach for disseminating seasonal climate forecast application results by the Department of Agriculture should closely consider this condition and establish alternative mechanisms to deliver the cropping strategies to be adopted by farmers.

6.7.3 Development of a dissemination strategy

The final dissemination strategy was focused on three different levels including: government organisations and scientific academics; field extension and water gate managers; and village leaders and farmers. Considering the lack of resources and SCF-based expertise in targeted agencies, the dissemination strategy was developed to ensure the SCF tools are adopted in institutional planning with agencies such as the Geophysical and Meteorological Bureau (BMG), the Department of Agriculture (DOA), and the Agency for Public Works (DPW). This took into account common operational problems such as those defined by Smink (1985), including identifying target groups, defining content, communication, and incentives. Since dissemination is an ongoing process, it is important to develop some monitoring and evaluation to ensure their use and dissemination impacts on formulation of their developmental planning (

Table 6.18).

Table 6.18 Some operational problems, possible solutions, and dissemination strategies.

Some operational problems with dissemination (Smink, 1985)	Possible solution	Dissemination strategy
Poorly identified target groups	Clear targets	Develop research groups
Poor content and form of information	Software to come with operational guidelines	Free CDs and operational guideline booklet and assistance
A reliance on one-way communication	Two-way communication	Participatory workshops In-house training
A limited structure for between-group sharing	Appropriate work mechanism should be developed	Users have been integrated in research team and need good coordination: In house training
Weak incentives for use among practitioners	Software provides excellent output for agencies	Provision of software with technical and analysis assistance
Insufficient evaluation of the quality of information	Regular evaluation and monitoring on the application of the software	Need regular evaluation of results and implications
Limited local development and training	Some capacity building on the pat of agencies should be introduced	Should be incorporated in district planning

In summary the key features of the information dissemination strategy have been defined as:

1. Recruiting and organizing a transfer mechanism among stakeholders led to the decision to ask each party (agency) to formally apply to be part of the project.
2. Piloting and revising the original mechanism by asking the partner participants to pilot the existing programs which serves two important purposes: to introduce DSS tools and interpretation of their results in designing farming policies; and to provide crucial feedback to the project about required changes, which would then be compiled and used to revise the existing guidelines, and to guide the development of the new programs.
3. Using workshops to introduce the software. The third phase focused on conducting a series of workshops in SCF technologies and encouraging their use. Staff time was allocated to provide six hours of workshops within each of the partner agencies. The people who attended the initial workshops were expected to conduct additional workshops to introduce more people within their agencies.
4. Utilizing grant resources. Each agency will be given free software and training, so this phase involves each agency deciding how to use these free CDs and guidelines. They must decide when SCF technologies are to be applied and used for agricultural planning.
5. Using SCF technologies in agricultural planning. The ultimate goal of the dissemination plan was the widespread use of SCF technologies and continued training opportunities led by local staff within each participating agency.
6. Conducting an evaluation on the impact of dissemination to the adoption of SCF applications for agencies' decision-making processes. Some questions were properly asked: (1) how did the context of the individual agency impact on the dissemination process? (2) what were the strengths and weaknesses of the dissemination plan and process?; and to what extent did the project dissemination meet its goals? To answer these questions about the process of the dissemination, several sources of data were required. These included: the dates and agendas of meetings; the dates, places, participation and descriptions of the SCF workshops; detailed information from the SCF Team about the process and its evolution; specific information from each participating agency about the context and activities in their agency, and reported uses of SCF technology within each agency.

7. Development of workshops, focus group discussion (especially with farmers), demonstrations, and other meetings to ensure better adoption of the scientific outputs in cropping decision process. This will involve conducting field days and workshops for local farmers on climate, and information visits to farmers' group associations.

6.7.4 Results of dissemination strategy

Throughout the life of this project, dissemination of the projects outputs did occur to a limited extent at the three different levels including: scientific academics and government officials; field extension and water gate managers; and village leaders and farmers. National workshops were held in Jakarta (PERHIMPI) and Bali (related to United Nations Framework Convention on Climate Change (UNFCCC)) where papers were presented on the impacts of climate variability on agriculture and the use of FlowCast as a tool for seasonal climate forecasting in Lombok. At the regional level, workshops and training programs were conducted to increase officer understanding of climate variability to introduce the concepts of decision support systems. Informal meetings and consultations took place with the head of Bappeda Provincial Office and the head of the Department of Agriculture for the district of Central Lombok, on adopting the decision support tools for strategic cropping management. Officers from Dinas Pertanian (Department of Agriculture) conducted field days and workshops for local farmers on climate, while the Indonesian project team also visited some farmers' group associations to lecture on the local impacts of climate variability and climate change.

7 Impacts

7.1 Scientific impacts

A significant focus on this project was in developing the science relating climate to agricultural and irrigation management in Lombok, in order to procure effective strategies at the local level. As a result of this, several powerful decision support tools have now been developed which have application both within and outside of the project boundaries.

A vast amount of historical meteorological, hydrological and agronomic data has been assembled and is archived online. This will provide an ideal platform for future research in agricultural and water resources management in the region. Quantification and measurement of current agricultural performance and resource potential is seen as an essential first step in effecting useful change.

The development of the hydrologic simulation model was a significant challenge, and the methodology developed to facilitate the model though data collection, patching and synthesis will be of much interest to the wider scientific and engineering community. Finalisation of the model now allows different management scenarios to be assessed.

The software-based tools such as FlowCast, CropOptimiser, and HowLeaky (used in the water balance study) are now generalised software applications containing no project-specific functionalities. They all implement powerful user interfaces developed to simplify the interaction between the science and the user, and are readily available for other scientific applications including analysis of different types of agricultural and climatic conditions.

The redevelopment of the FlowCast software also benefits the wider Indonesian community in that BMG now have an operational tool for implementing seasonal climate forecasts at local and national (spatial) scales. This includes new tools to assess the reliability of these forecasts.

The assessment of alternative water sources has achieved a significant scientific impact in terms of quantifying the volume of runoff and groundwater extraction available for irrigation purposes, as well as the variability which exists in these alternative water sources due to seasonal variability and land-use practices. Benefits to the wider scientific community have also been achieved through the process of assessment of land-use practices on runoff water for irrigation, storage efficiencies and the impact seasonal climate variability can have on the volume of water available from year to year.

7.2 Capacity impacts

Success for a project such as this requires building local capacity to understand and use the developed technologies. Therefore education and training has been a key objective targeting key scientific individuals, government officials, extension officers and rural community leaders and farmers. This was undertaken on two levels including training key local scientists and engineers in developing and applying specific components of the decision support technologies, and promoting climate-based agricultural management at the government, rural and field levels.

During the project, local scientific capacity was developed to have a limited but useful understanding of the hydrological modelling, seasonal climate forecasting and decision support component. Inexperience in applying these new technologies will mean that careful guidance will be required after the final project review. Some individuals do have a high level of proficiency in key project areas including agricultural management, linear programming, and climate applications, with some undertaking higher education as a part of this project.

The project has not built enough scientific capacity to internally replicate the work of this project, but it should be sufficient to manipulate and apply outputs into the local community.

Capacity building to implement and incorporate the developed science at the field level has been primarily focused on promoting the importance and background theory of climate in agricultural management. Unfortunately at this stage, there is not sufficient capacity at the field level to implement project recommendations on agricultural management strategies. Ultimately there is still a reluctance to change practices.

This was addressed at a workshop in Toowoomba (during August 2007), which facilitated the development of new communication and capacity building plans. It is recognised that the low level of schooling of farmers (<25% have ever attended) poses special difficulties implementing new practices, although this is compensated by the strong role of government agencies in agricultural decision making. Therefore agencies such as BPTP, WOC, Dinas Pertanian, BMG and UNRAM have been specifically targeted in training workshops in both Indonesia and Australia. Computer packages such as FlowCast and CropOptimiser have been demonstrated as tools for policy makers during such events. Informal meetings with policy makers, farmers' group leaders and water user association leaders are also seen as an important mechanism in promoting an understanding of technologies.

Despite the reluctance to change, it appears that at least the messages are getting through to stakeholders. For example, a precursor to effective change at the field level has been through the 'field school of climate', attended by field extension officers, water gate and water user associations and farmers' group leaders. This is a week-long course which has run for the last five years, promoting better understanding of management of irrigation, cropping planning, cropping pattern and cropping systems related to unexpected weather conditions and climate variability.

7.3 Community impacts

Local communities have received little tangible benefit from the project outputs. While the theoretical benefits of the project have been extensively documented (both in the project proposal, and through the findings of the results that have already been published), significant real impacts are yet to be seen due to a general reluctance to change practices. This is also reflected in the 'systems nature' of the project whereby better quality results were provided only on finalisation of all of the scientific components.

Indirectly, the communities will have already received some benefits from the increased exposure to trained officers at experimental sites, and in focus group discussions and village level workshops conducted with local farmers, village leaders and traditional elites. At least stakeholders should now have greater climate awareness, and an increased agricultural support network. An example of this increased awareness of climate variability is, that although it has been assessed that substantial runoff water may provide a viable irrigation water source in some seasons, it is recognized that the variability of this runoff water may result in potential lost production due to a reduction in the potential cropping area which is used to host the storage.

Given the significant attempts at introducing change, it is hoped that the implementation of the finalised communication and capacity building plans will promote effective change with real benefits, with the initial efforts proving to be a 'softening-up' period.

7.4 Communication and dissemination activities

During the reporting period, the following communication and information dissemination activities have been conducted.

No.	Detail	Information
1.	Activity:	Seminar on natural disaster (drought) in cropping season 2006/2007 In West Nusa Tenggara
	Location and date:	Hall of Dinas Pertanian NTB Mataram; 17 February 2008
	Attendances:	Ir. Ismail Yasin, M.Sc. (Presenter) and Dr. Muhamad Husni Idris (Participant)
2.	Activity:	Training of trainer (TOT) Climate Field School (Sekolah Lapang Iklim (SLI) se – NTB in relation to improvement of human resource for field officer to climate risk
	Location and date:	Balai Diklat Pertanian Narmada; 29 April to 3 May 2007
	Attendances:	Ir. Ismail Yasin, M.Sc. (Presenter), Dr. Muhamad Husni Idris (Presenter)
3.	Activity:	Project Workshop: ACIAR ”Seasonal Climate Forecasting For Better Irrigation System Management in Lombok”
	Location and date:	Bappeda NTB Mataram; 1 November 2007
	Attendances:	Dr. Yahya Abawi (Presenter) and Ir. Ismail Yasin (Presenter)
4.	Activity:	Seminar on Climate data Analysis in West Nusa Tenggara – Dinas Pertanian WNT
	Location and date:	Hotel Mareje Mataram; 1 December 2007
	Attendances:	Ir. Ismail Yasin (Presenter) and Dr. Muhamad Husni Idris (Presenter)
5.	Activity:	International Symposium and Workshop on Current Problems in Groundwater Management on Related Water Resources Issues
	Location and date:	Kuta Bali; 3rd - 8th December 2007
	Attendances:	Ir. Ismail Yasin (Presenter) and Prof. Ir. Mansur Ma’shum
6.	Activity:	Workshop on Eastern Indonesia’s Responses to Climate Change
	Location and date:	Renon Denpasar Bali; 6th- 7th December 2007
	Attendances:	Ir. Ismail Yasin (Presenter) and Prof. Ir. Mansur Ma’shum, Ph.D
7.	Activity:	Seminar on global climate change and seasonal climate forecasts.
	Location and date:	Faculty of Agriculture University of Mataram; 24th- 25th February 2008
	Attendances:	Ir. Ismail Yasin (Presenter)
8.	Activity:	Seminar on increasing capacity of national adaptation to climate change through inter-sectoral collaboration
	Location and date:	Jakarta; 15th- 16th January 2008
	Attendances:	Ir. Ismail Yasin (Presenter) and Prof. Ir. Mansur Ma’shum
9.	Activity:	Dissemination of FlowCast and CropOptimiser
	Location and date:	Station of Climatology Kediri; 5th April 2008
	Attendances:	Dr. Yahya Abawi (Presenter), Ir. Ismail Yasin (Presenter) and Adi Ripaldi (Presenter)
10.	Activity:	Signing of Memorandum of Understanding (MoU) between UNRAM BMG Jakarta on capacity building in climate forecast
	Location and date:	BMG Jakarta; 10th April 2008
	Attendances:	Prof. Ir. Mansur Ma’shum and Dr. Yahya Abawi
11.	Activity:	National Workshop on Adaptation Programme on Climate Change in Indonesian
	Location and date:	Skyline Business Centre Jakarta; 10th- 12th March 2008
	Attendances:	Prof. Ir. Mansur Ma’shum, Ph.D
12	Activity:	Advanced FlowCast Training
	Location and date:	QCCCE Buildings, Toowoomba, 16th February – 16th March 2009

	Attendances:	Mr Adi Ripaldi
13	Activity:	Phd Research Sponsorship
	Location and date:	University of Southern Queensland, Toowoomba, 2006 -2010
	Attendances:	Mr Ahmad Suriadi

8 Conclusions and recommendations

8.1 Conclusions

8.1.1 Seasonal climate forecasting

Both the literature review of Indonesia's climate, and the assessment of seasonal climate forecasting skill, support the hypothesis that ENSO is the main driver of seasonal climate in both Lombok and most of Indonesia. The literature review suggested that ENSO explains about two-thirds of Indonesia's climate variability while the skill analysis suggested that any one of the ENSO related predictors (SOI, SSTaEOF1 and Nino3.4) could be used as part of an operational forecast system for Indonesia. The SOI based predictor using discriminant analysis has been recommended for an operational forecast system. While the Indian Ocean Dipole was also found to be another significant contributor to Indonesia's climate, sea surface temperate anomalies in the central Indian Ocean were not found to be useful in seasonal prediction generation.

Both analyses supported the findings of LWR2/1996/215 which showed that Lombok rainfall is predictable outside of the January to April wet season using ENSO-based predictors. Streamflow and irrigation water availability were also predictable outside of the wet season, especially in the south-east of the catchment, although in certain periods, the skill of the forecasts was less than that of rainfall, possibly due to the anthropogenic influences on streamflow extraction and diversion. The onset of the monsoon was found to be highly predictable as it occurs when ENSO's influence is strongest.

8.1.2 Hydrological modelling

The data collection, patching and synthesis of meteorological and hydrological data was completed over the first two years of this project. The raw data was mostly undigitised and of poor quality and quantity requiring significant pre-processing for use in the hydrological models. However, the quality indicators of the calibrations of the IQQM hydrological model indicate that the results are adequate for strategic planning purposes for most irrigation regions in Lombok. More than fifty years of daily and monthly streamflow, irrigation diversion and rainfall data are now available for input into the FlowCast and CropOptimiser software. Several factors were identified that could improve the quality of the hydrological model calibrations, including obtaining extra measured streamflow data (especially for locations with no data), accounting for groundwater contributions of the hydrological system, and obtaining data on soil moisture, planting area and irrigation management practices. The raw collected data and modelled outputs are now available for future research in the region.

8.1.3 Cropping optimisation (LP model)

Development of the prototype LP model was undertaken in Microsoft Excel using the inbuilt Solver algorithms and involved formulating the objective function, types of constraints and parameterisation of seasonal, climatic, and cropping behaviours. The model was set up for rice, legumes, corn, vegetable, chillies and tobacco production for 29 irrigation sub-areas in southern Lombok. To simplify validation of the results, these sub-areas were later grouped into water surplus, sufficient, and deficit regions. Only limited validation results were provided by the Indonesian team showing that rice can be safely grown in the first two seasons in the water-surplus regions irrespective of the current climate conditions. In contrast to this, rice cropping in the water-deficit areas is significantly affected by the drought conditions potentially leading to rice-crop failure during El Niño events. Therefore, the most useful role of the LP model is for developing cropping strategies in these water-deficit regions to divert more water from the water-surplus regions or to select alternative cropping practices.

8.1.4 Development of decision support software

Development of the FlowCast and CropOptimiser decision support systems has been completed and has met (and exceeded) all original design criteria. FlowCast has been developed with two operational modes (simple and advanced) to accommodate different user skill and climate knowledge levels. CropOptimiser has been developed to allow investigation of different social and political rules and constraints. Given the power and flexibility of both software packages, they have great potential for use in other projects and in other locations around the world. It is expected that both packages will be further developed and refined in the future with funding sought from a range of organisations including ACIAR.

8.1.5 Assessing supplementary irrigation resources

Groundwater in Lombok plays an important role in irrigating highly valuable horticultural crops. However, the studies showed that it is contained in shallow Karstic limestone aquifers with poor transmissivity, typically 20 to 97m3/day/m with a safe yield of 0.08 l/s. Yields may vary depending on recharge quantity in different seasons, well dimensions and aquifer properties. In order to maintain a sustainable small-scale groundwater irrigation system, the yield should not exceed one-third of the available water depth at any time. However, it was found that the safe yield could be increased quite significantly depending on the available drawdown, well dimensions and lining conditions, provided that the yield does not exceed the percolation rate.

Irrigation infrastructure design and management requires careful consideration, especially where there is high inter-annual variability in rainfall, as is the case in Lombok. Although there was found to be poor skill in forecasting in-crop runoff during the first cropping season, the use of HowLeaky as an investigative and education tool can play a useful role in helping farmers understand the impacts that management practices can have on the capture and efficient utilisation of runoff. For example, the HowLeaky modelling confirmed the plausibility that in-crop runoff can occur during the first cropping season (as determined in SMCN/1999/005) and the opportunities this presents as an irrigation source in the second season. However, it also highlights the inter-annual variability in runoff which may occur. This poses an important consideration for scheme-water irrigation allocations and water harvesting planning. In addition to this, under land-limited situations there is also a trade-off between increased dry season yields (from the use of stored irrigation water), and the reduction in cropping area from the land-used to host the water storage. Determining a suitable storage size and management strategy is complicated by the impacts that variations in soil parameters, cropping type and management practices can have on annual runoff volumes, farmers’ differences in adversity to risk and individual economic circumstances. Due to these complexities and delayed staff resourcing, project objectives 5.4 (Applying the results of modelling simulation to CropOptimiser to determine the best cropping system regionally and seasonally) and 5.3 (Conduct an economic impact study of water harvesting and re-use at the farm irrigation demand level) were undelivered.

8.1.6 Capacity building

Efforts were made to build regional scientific capacity in the areas of hydrological modelling, seasonal climate forecasting and operation of the decision support software, and to build local capacity at the field level to implement project recommendations. While not enough scientific capacity has been developed to internally replicate the work of this project, the Indonesian project team now have the capability to manipulate and apply outputs into the local community, albeit on a limited level. Agencies such as BPTP, WOC, Dinas Pertanian, BMG and UNRAM have been specifically targeted in training workshops in both Indonesia and Australia. Computer packages such as FlowCast and CropOptimiser have been demonstrated as tools for policy makers during such events. Advanced training of the software has been provided to key project staff. At the field level, capacity building has been primarily focused on promoting the importance and background theory of climate in agricultural management. While it appears that at least the messages are getting through to stakeholders, there still seems to be a general reluctance to change practices.

8.1.7 Information dissemination

Considerable effort was invested by the Indonesian team in developing an information dissemination strategy, but due to the delays in delivering the scientific components of the project, this never had the chance to be fully tested. Developing the strategy involved defining and understanding the current and historical governance and extension development infrastructure in Lombok. A survey was conducted in 2006 to assess factors influencing farmers' decisions to crop rice, with over a quarter of farmers relying on government advice while water availability, peer advice and yield price were major influencing factors. The final dissemination strategy focused on three different levels including: government organisations and scientific academics; field extension and water gate managers; and village leaders and farmers. Key features of the strategy included recruiting and facilitating stakeholder participation, initiating pilot projects, using workshops to introduce technologies, utilizing grant resources, using SCF technologies in agricultural planning, and evaluating the impacts of dissemination processes.

8.2 Recommendations

This research has provided a clear framework for conducting further studies on the impacts of climate variability and climate change in the region. The objectives which could not be met during this study should be followed up in subsequent projects to ensure the benefits of this research are maximized. We recommend that ACIAR consider the following options to further build on the achievements of this project using remaining funds:

- Developing a database containing simulation results covering a range of climate scenarios, allocation decisions and planting options. This will provide a simple information repository and generic guidelines which are more readily accessible than direct operation of the decision support software, and will be critical to the adoption process.
- ACIAR should encourage further capacity building and dissemination activities in the project region using the finalised decision support tools from this project. It is recommended that a range of workshops on climate awareness, seasonal climate forecasting, and climate risk management should be undertaken across Lombok (and Indonesia) using the FlowCast and CropOptimiser software. These workshops should target a wide range of user groups including government agencies, academics, and managers at the regional level. ACIAR may consider the further development of training materials and potentially the development of E-Learning toolkits, similar to that developed for the SCOPIC software and used in the Pacific.
- A small research activity could examine the operational use of CropOptimiser over three cropping seasons to ensure the validity of the model. Since delays have meant that the validation of the LP model was only rudimentary, the suggested operational validation is necessary for the methodology and the software to attain scientific credibility.
- There is an opportunity for the HowLeaky water balance model to be promoted to agricultural researchers in the region to evaluate and compare water balance and water quality impacts of different land-uses and cropping systems. This software can be used to supplement or even replace traditional field trials to efficiently quantify water balance and quality information. A number of key Indonesian project team members have already expressed enthusiasm for using the software in their work.

- Consideration should be given to apply the technologies developed in this project to other regions of South East Asia. Great effort has been made in the project to ensure that the developed decision support software can be easily configured for other regions. For example, the FlowCast software has already been used operationally for studies in South East Queensland. The methodologies developed for patching, synthesising, and modelling the hydro-meteorology data can also be transferred to other regions.
- Finally, it is recommended that the current progress made in implementing change in the Lombok region is monitored and encouraged in the forthcoming years. There is a great risk that the enthusiasm will stagnate and practices will revert back to traditional methodologies, should significant on-ground benefits from the project not be experienced in the near future. SCF-based planning is a long-term management strategy requiring around ten years of implementation to fully appreciate the benefits.

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9.1 List of publications produced by project

Published

Robinson, BR, McClymont, DJ, Abawi Y and Rattray, D (2007) Irrigation Practice and Infrastructure Design in the Variable Monsoonal Climate of Lombok (Indonesia). Proceedings of MODSIM 2007 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2007, pp. 101-108. ISBN : 978-0-9758400-4-7. http:/www.mssanz.au/modsim07/Papers/2_s44/IrrigationPractice_s44_Robinson_.pdf

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In preparation

Dutta, SC, McClymont, DJ, Zhang, X, and Abawi, GW (2009) An integrated modelling approach to develop ENSO-based streamflow forecasting for a large irrigation system with limited records in Lombok, Indonesia: I. Generating long-term daily hydroclimatic data. Target publication: Not yet identified.

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McClymont, DJ and Abawi, GY (2009) FlowCast: Software for the generation and analysis of empirically based seasonal climate forecasts. Target publication: Environmental Modelling and Software.

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White S.C., Abawi, Y., McClymont, D., Robinson, B and Suriadi, S (2009) Assessing field runoff from land-use practices under a variable climate to improve food security in Southern Lombok, Indonesia. A simulation study. Target publication: Journal of Agricultural Systems.

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Zhang X, Abawi Y, McClymont, D (2009). Modelling a large irrigation system in Lombok, Indonesia: II. Simulating and forecasting streamflow and irrigation allocation based on ENSO. Target publication: Envrionmental Modelling and Assessment

10 Appendixes

10.1 Appendix 1: Rainfall predictand data used in seasonal skill assessment

Table A1.1 Indonesian rainfall predictands used in skill assessment

Name	Period	Quality	Latitude	Longitude
U96011 ACEH	Jan 1952–Apr 1999	47yrs @ 100%	5.52	95.42
U96015 MEULABOH	Jan 1953–Apr 1999	46yrs @ 100%	4.07	96.31
U96035 MEDAN	Jan 1948–Apr 1999	51yrs @ 100%	3.57	99.07
U96073 SIBOLGA	Jan 1953–Apr 1999	46yrs @ 100%	2.31	99.28
U96091 TANJUNGPINANG	Jan 1951–Apr 1999	48yrs @ 100%	-1.31	104.52
U96109 PEKANBARU	Jan 1953–Dec 1986	33yrs @ 100%	0.46	101.43
U96163 PADANG	Jan 1950–Apr 1999	49yrs @ 100%	-1.27	100.34
U96195 JAMBI	Jan 1964–Apr 1999	35yrs @ 100%	-2.03	104.04
U96221 PALEMBANG	Jan 1950–Apr 1999	49yrs @ 100%	-3.30	105.10
U96237 PANGKALPINANG	Jan 1953–Apr 1999	46yrs @ 100%	-2.16	106.13
U96249 TANJUNGPANDAN	Jan 1950–Apr 1999	49yrs @ 100%	-3.15	108.15
U96253 BENGKULU	Jan 1968–Apr 1999	31yrs @ 100%	-4.27	102.33
U96295 REJOSARI	Jan 1951–Apr 1999	48yrs @ 100%	-5.24	105.18
U96509 TARAKAN	Jan 1948–Apr 1999	51yrs @ 100%	3.33	117.57
U96557 NANGAPINOH	Jan 1950–Apr 1999	49yrs @ 100%	-1.00	112.07
U96581 PONTIANAK	Jan 1947–Apr 1999	52yrs @ 100%	-0.01	109.37
U96595 MUARATEWE	Jan 1951–Apr 1999	48yrs @ 100%	-1.30	115.30
U96615 KETAPANG	Jan 1950–Apr 1999	49yrs @ 100%	-2.24	110.37
U96633 BALIKPAPAN	Jan 1948–Apr 1999	51yrs @ 100%	-1.27	117.30
U96645 PANGKALANBUN	Jan 1947–Apr 1999	52yrs @ 100%	-3.04	112.12
U96685 BANJARMASIN	Jan 1951–Apr 1999	48yrs @ 100%	-3.45	115.15
U96745 JAKARTA	Jan 1864–Apr 1999	135yrs @ 100%	-6.16	107.22
U96783 BANDUNG	Jan 1953–Apr 1999	46yrs @ 100%	-7.31	108.00
U96791 JATIWANGI	Jan 1904–Mar 1999	95yrs @ 100%	-7.15	108.27
U96797 TEGAL	Jan 1951–Apr 1998	47yrs @ 100%	-7.24	109.15
U96805 CILACAP	Jan 1952–Apr 1999	47yrs @ 100%	-8.07	109.01
U96839 SEMARANG	Jan 1947–Apr 1999	52yrs @ 100%	-7.37	110.37
U96853 YOGYAKARTA	Jan 1951–Apr 1999	48yrs @ 100%	-8.18	110.43
U96881 MADIUN	Jan 1951–Apr 1999	48yrs @ 100%	-8.03	111.52
U96925 BAWEAN	Jan 1961–Apr 1999	38yrs @ 100%	-6.27	113.04
U96973 KALIANGET	Jan 1951–Jan 1999	47yrs @ 100%	-7.04	114.37
U96987 BANYUWANGI	Jan 1950–Apr 1999	49yrs @ 100%	-8.21	114.37
U97014 MANADO	Jan 1947–Apr 1999	52yrs @ 100%	1.52	125.31
U97048 GORONTALO	Jan 1974–Apr 1999	25yrs @ 100%	1.04	123.22
U97072 PALU	Jan 1954–Apr 1999	45yrs @ 100%	-1.07	120.13
U97086 LUWUK	Jan 1975–Apr 1999	24yrs @ 100%	-1.15	123.18
U97096 POSO	Jan 1974–Apr 1999	25yrs @ 100%	-1.37	121.13
U97146 KENDARI	Jan 1947–Apr 1999	52yrs @ 100%	-4.09	122.43

U97180 UJUNGPANDANG	Jan 1948–Apr 1999	51yrs @ 100%	-5.06	119.55
U97192 BAU-BAU	Jan 1961–Apr 1999	38yrs @ 100%	-5.46	123.01
U97230 DENPASAR	Jan 1949–Apr 1999	50yrs @ 100%	-9.15	115.16
U97240 AMPENAN	Jan 1951–Apr 1999	48yrs @ 100%	-8.52	116.07
U97260 SUMBAWA	Jan 1961–Apr 1999	38yrs @ 100%	-8.42	117.42
U97340 WAINGAPU	Jan 1949–Apr 1999	50yrs @ 100%	-10.06	120.33
U97372 KUPANG	Jan 1947–Apr 1999	52yrs @ 100%	-10.16	124.07
U97390 DILLI	Jan 1952–Apr 1999	47yrs @ 100%	-8.57	125.57
U97502 SORONG	Jan 1950–Apr 1999	49yrs @ 100%	-0.55	131.10
U97530 MANOKWARI	Jan 1955–Apr 1999	44yrs @ 100%	-0.54	134.04
U97560 BIAK	Jan 1955–Apr 1999	44yrs @ 100%	-1.18	136.12
U97580 SARMI	Jan 1974–Apr 1999	25yrs @ 100%	-2.22	139.13
U97600 SANANA	Jan 1974–Apr 1999	25yrs @ 100%	-2.07	126.00
U97682 NABIRE	Jan 1970–Apr 1999	29yrs @ 100%	-3.33	135.49
U97686 WAMENA	Jan 1957–Apr 1999	42yrs @ 100%	-4.06	139.37
U97690 SENTANI	Jan 1947–Apr 1999	52yrs @ 100%	-2.49	140.48
U97724 AMBON	Jan 1950–Apr 1999	49yrs @ 100%	-4.09	128.07
U97748 GESER	Jan 1969–Apr 1999	30yrs @ 100%	-4.19	131.22
U97760 KAIMANA	Jan 1956–Apr 1999	43yrs @ 100%	-4.03	134.12
U97810 TUAL	Jan 1966–Apr 1999	33yrs @ 100%	-6.07	133.19
U97900 SAUMLAKI	Jan 1962–Apr 1999	37yrs @ 100%	-8.37	131.30
U97980 MERAUKE	Jan 1952–Apr 1999	47yrs @ 100%	-8.46	140.37

Table A1.2 Lombok rainfall predictands used in skill assessment

Name	Period	Quality	Latitude	Longitude
Ampenan	Jun 1895–Dec 2007	112yrs @ 92.7%–3 gaps	-8.59	116.08
Bayan	Jan 1962–Dec 2007	45yrs @ 84.8%–6 gaps	-8.20	116.42
Bertais	Jan 1959–Dec 2007	48yrs @ 91.8%–1 gap	-8.58	116.16
Bima	Jun 1895–Dec 2004	109yrs @ 91.6%–5 gaps	-8.57	116.35
Dasan Tereng	Jan 1964–Dec 2007	43yrs @ 97.7%–1 gap	-8.58	116.18
Gerung	Jan 1959–Dec 2007	48yrs @ 72.6%–40 gaps	-8.69	116.12
GunungSari	Jan 1983–Dec 2007	24yrs @ 100%	-8.52	116.11
Janapria	Jan 1950–Dec 2007	57yrs @ 99.9%–1 gap	-8.71	116.39
JurangSate	Jan 1983–Dec 2007	24yrs @ 100%	-8.58	116.28
Kediri	Jan 1962–Dec 2007	45yrs @ 81.3%–17 gaps	-8.64	116.17
Keruak	Jan 1982–Dec 2007	25yrs @ 100%	-8.76	116.49
Kopang	Jan 1926–Dec 2007	81yrs @ 86.3%–13 gaps	-8.63	116.34
Kuripan	Jan 1983–Dec 2007	24yrs @ 99.3%–2 gaps	-8.69	116.16
LingkukLima	Mar 1974–Dec 2007	33yrs @ 86.2%–1 gap	-8.73	116.47
Majeluk	Jan 1951–Dec 2007	56yrs @ 100%	-8.60	116.12
Mantang	Jan 1950–Dec 2007	57yrs @ 100%	-8.60	116.32
Pengadang	Jan 1983–Dec 2007	24yrs @ 100%	-8.69	116.33
Peninjauan Narmada	Jan 1962–Dec 2007	45yrs @ 93.3%–2 gaps	-8.59	116.21
Penujak	Jan 1950–Dec 2007	57yrs @ 100%	-8.76	116.26
Praya	Jan 1973–Dec 2007	34yrs @ 100%	-8.70	116.30
Sambelie	Jan 1974–Dec 2007	33yrs @ 99.8%–1 gap	-8.39	116.71
Sekotong	Jan 1962–Dec 2007	45yrs @ 61.4%–50 gaps	-8.78	116.06

Sengkol	Jan 1950–Dec 2007	57yrs @ 100%	-8.82	116.31
Sesaot	Jan 1974–Dec 2007	33yrs @ 97.8%–5 gaps	-8.51	116.23
Sikur	Jan 1962–Dec 2007	45yrs @ 84.4%–8 gaps	-8.61	116.45
Sumbawa	Jan 1961–Apr 1999	38yrs @ 100%	-8.42	116.42
Tanjung	Jan 1962–Dec 2007	45yrs @ 97.6%–2 gaps	-8.35	116.15
Terara	Jan 1983–Dec 2007	24yrs @ 100%	-8.62	116.42

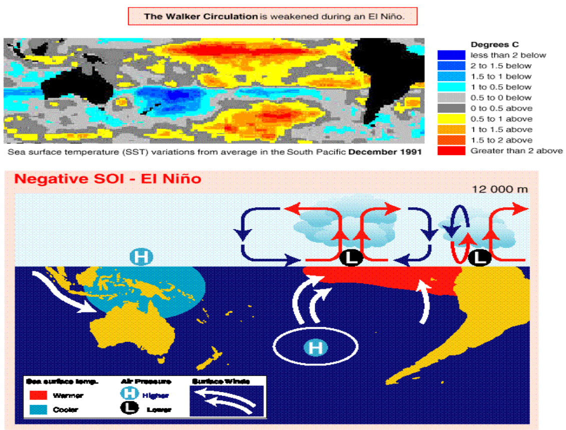
10.2 Appendix 2: Background to seasonal climate forecasting

10.2.1 El Niño Southern Oscillation (ENSO)

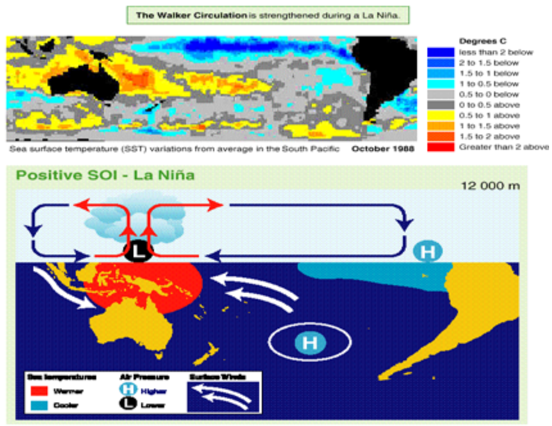
El Niño and La Niña are part of the El Niño Southern Oscillation (ENSO) global climate phenomenon, and can form the basis of seasonal climate forecasting. ENSO has had a major influence on climate variability in many parts of the world (Kuhnel et al. 1990; Hammer et al. 1996; Piechota et al. 1998; Mantua, 2001a).

El Niño refers to the warming of sea surface temperatures (SST) in the eastern equatorial Pacific around the coast of Peru. In early studies, El Niño was seen as an event of local importance, but after the 1957 El Niño and studies of subsequent El Niño events, it was linked to the global atmospheric phenomenon known as the Southern Oscillation. The Southern Oscillation is a seesaw of air pressure between the Pacific and Indian Oceans. At one extreme of the oscillation, when the atmospheric pressure is lower than normal over the central Pacific, it tends to be higher over much of Australia. This pressure anomaly coincides with an increase in sea surface temperatures in the central and eastern equatorial Pacific and a decrease in sea surface temperatures in the western equatorial Pacific. The coupling of the warm SST and the Southern Oscillation (SO) is usually referred to as an ENSO event.

During a warm ENSO event, the trade winds in the western Pacific, which are a major source of moisture to rainfall-producing weather systems in eastern and northern Australia, reduce in strength and this combined with higher than normal atmospheric pressures, reduces rainfall and causes drought conditions (Figure A2.1a). Concurrently, in the central Pacific and along the west coast of South America, convection and rainfall occurrences increase. During an anti-ENSO (La Niña) event, the situation is reversed (Figure A2.1b).



(a) El Niño event



(b) La Niña event

Figure A2.1: Coupling of sea surface temperature and atmospheric pressure along the equator during an (a) El Niño and (b) La Niña event. (source: Australian Rainman version 3.2)

ENSO cycle

El Niño episodes reflect periods of above-average warm sea-surface temperatures across the eastern tropical Pacific. La Niña episodes represent periods of below-average sea-surface temperatures across the eastern tropical Pacific. For both El Niño and La Niña the tropical rainfall, wind, and air pressure patterns over the equatorial Pacific Ocean are most strongly linked to the underlying sea-surface temperatures, and vice versa, during November-February. During this period the El Niño and La Niña conditions are typically strongest.

During a strong El Niño, ocean temperatures for December to February can average 2° C to 3.5° C above normal between the date line and the west coast of South America. These areas of exceptionally warm waters coincide with the regions of above-average tropical rainfall. During a La Niña, ocean temperatures for December to February average 1° C to 3° C below normal between the date line and the west coast of South America. This large region of below-average temperatures coincides with the area of well below average tropical rainfall.

El Niño and La Niña episodes typically last approximately 9–12 months. They often begin to form during late autumn, reach peak strength during November to February, and then decay during mid to late austral autumn of the following year (Figure A2.2). However, some episodes have been prolonged and lasted two years and even as long as three to four years. While their periodicity can be quite irregular, El Niño and La Niña occur every three to five years on average.

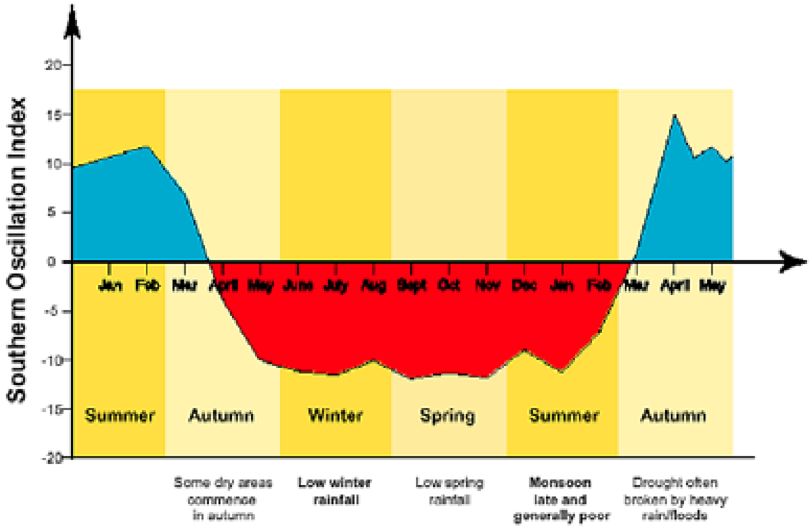


Figure A2.2: A typical ENSO Event.

Southern Oscillation Index

A common measure of ENSO is the Southern Oscillation Index. The index is the difference in surface atmospheric pressure between Tahiti (17° S, 150° W) and Darwin (12° S, 131° E), standardised to a mean of zero and a standard deviation of 10. For example, a monthly average SOI value of −10 means the SOI is one standard deviation on the negative side of the long-term mean for that month.

A negative value of the SOI suggests higher atmospheric pressure at Darwin compared to Tahiti and often suggests lower than average rainfall over most of eastern Australia. Conversely, a positive value of SOI suggests a low-pressure system over Darwin and higher than average rainfall in eastern Australia. Generally, high negative values of monthly SOI accompany drought conditions while high positive values tend to accompany high rainfall in forthcoming months in eastern Australia.

Sea surface temperature anomalies

Sea surface temperatures in the Central Eastern Pacific area highly correlated with ENSO. Indices based upon sea surface temperature (or, more often, its departure from the long-term average) can be used for seasonal climate forecast and can be obtained by taking the average value over some specified region of the ocean. Research from the Australian Bureau of Meteorology Research Group (Drosdowsky and Chambers, 1998) identified 12 principal components of sea-surface temperature anomalies in the Pacific and Indian Oceans (Figure A2.3). This represents the 12 most dominant signals of sea-surface temperature in the Indian and Pacific Oceans, explaining about 46% of the variability. The first two of these components representing temperature anomalies in the Central Eastern Pacific Ocean (SSTaEOF1) and Western Indian Ocean (SSTaEOF2) have been used as predictors in generating the outlooks for Australian rainfall and temperature forecasts. Given the close geographic location of Indonesia to Australia, it is likely that these predictors will be useful in generating forecasts in this region as well.

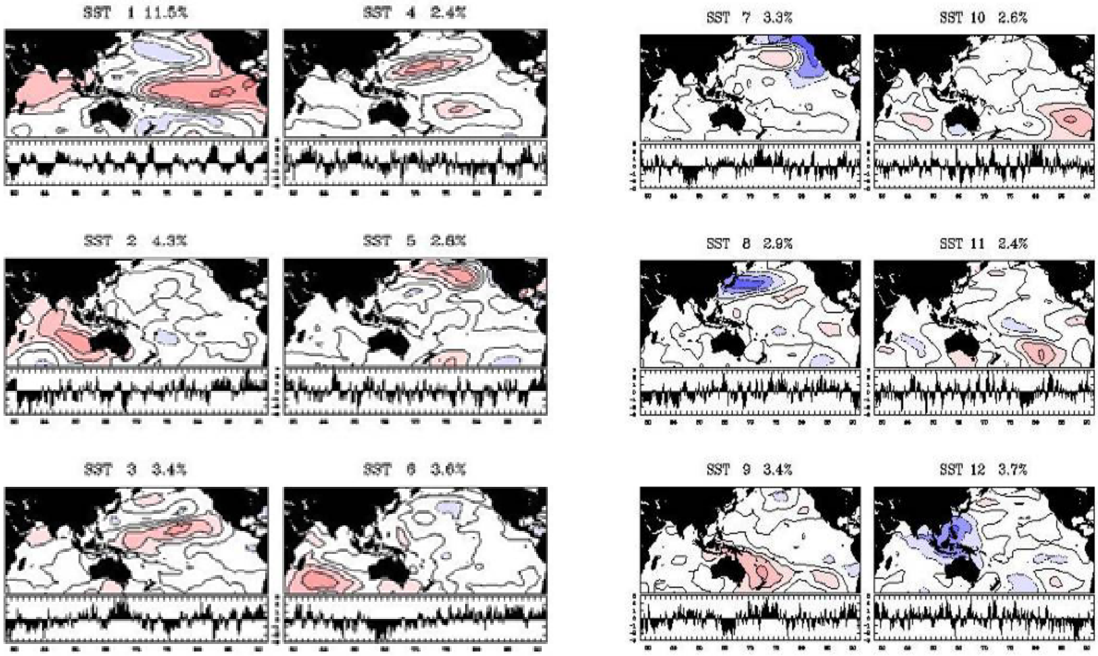


Figure A2.3 First twelve principal components of sea surface temperature anomalies in the Pacific and Indian Oceans. (http://www.bom.gov.au/bmrc/clfor/cfstaff/wld/RESREP65/rr65.htm#PCA_SST)

The time series represented by the first principal component (SSTaEOF1) is significantly correlated with SOI, and the spatial patterns shown in Figure A2.3 (SSTaEOF1) represent the mature state of an El Niño event. The second principal component (SST EOF2) is significantly correlated with the Indian Ocean index devised by Drosdowsky (1993) and is strongly related to Australian early winter rainfall.

10.2.2 Seasonal climate forecasting

Methodologies

Methodologies for generating seasonal climate forecasts can be classed as being either dynamically or empirically derived. Dynamical methods (which we will not consider in this study) use complex physically based models to simulate the ocean/atmosphere interactions requiring high computing power. Empirical methods are much simpler using statistical and historical predictor/predictand relationships to identify patterns in the distribution of events to generate forecasts. The most common empirical methodologies used in practice include stratified climatological forecasting methodology (sometimes known as ‘analogue years’ methodology), and discriminant analysis methodology, both of which generate probabilistic forecasts[9].

[9] *The FlowCast software developed in this project employs both of the methodologies.*

Stratified climatological forecasts are generated by 'sampling' a subset of analogue years (a summary of the period of interest for each year) from the historical record according to some relevant criterion, and calculating relevant probabilities from the subset (Stone et al. 2003). The number of possible stratifications or 'phases' is predetermined for each predictive system, and impacts on the 'quality' of the results. Typically this ranges from three to five phases with greater numbers leading to small sample sizes. It is recommended that each stratification or subset contain at least 15–20 years of data in order for the methodology to be statistically viable. Also, stratifications must be statistically different from one another (which can be tested using non-parametric hypothesis testing) for there to be any skill in the forecasts.

The discriminant analysis methodology employed in FlowCast is the same as that used by the Australian Bureau of Meteorology in their operational forecast system (Drowdowsky and Chambers 1998, 2001; Jones 1998). It aims to calculate the probability that rainfall at individual locations will be in a particular category (tercile, or above or below median) for the current state of predictor conditions. This method uses Bayes Theorem to 'invert conditional probabilities' (Huberty 1994; Wilks 1995) in a procedure similar to that used by Ward and Folland (1991) and He and Barnston (1996). It assesses the historical record to analyse how the predictand category varies with different predictor observations (such as SOI or SSTa principal components) and calculates conditional probabilities for the occurrence of new observations of predictor value for each category of predictand. This is not to be confused with 'linear' discriminant analysis (for example, see Wilks, 1995, pages 409-415) which effectively stratifies rainfall data dynamically based on the discriminant groupings, resulting in only a subset of the training data being used to calculate probabilities. In comparison, the method described above uses all training data in calculating probabilities.

Each methodology has its advantages and disadvantages. For example, the stratification method is simple to understand and calculate, while the discriminant analysis method employs complex statistical equations and is difficult to conceptualise, especially when multiple predictors are combined (which is a powerful mechanism to better capture the effects of climate variability, but is subject to orthogonality rules leaving it open to misuse). A distinct advantage of the stratification method is that it provides detailed probability outputs across the complete range of likely predictand values (a complete probability distribution). In comparison, discriminant analysis only provides probabilities for medianal or tercile boundary conditions10. Also, the stratification methodology produces a discrete number of probability distributions (one for each stratification or climate type) allowing visual interpretation of the forecast system's ability to discriminate between different climate types. This makes it amenable to non-parametric hypothesis testing to assess whether these distributions are statistically different. This categorisation of years is also highly applicable in a systems-modelling situation when distinct climate types are required to define scenarios (such as in CropOptimiser which produces outputs for the predefined climate types of El Niño, La Niña and Neutral conditions). However, the main disadvantage of the stratification methodology is that it requires much more data than discriminant analysis. Stratification forecasts are based on a subset of the entire data record, which must be sufficiently long to ensure that the subset of stratification data is of adequate length to generate a forecast. In comparision, discriminant analysis uses all available data when generating a forecast, so it better accommodate shorter lengths of data record. The data requirements of the stratification methology increase with the number of required stratifications. Also the discrete nature of the categorisations means that some conditions could be handled poorly, lying at the boundary of two stratifications.

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[10] *Complete probability distributions can be generated using discriminant analysis methodology by undertaking multiple two-category analysis with differing thresholds (not only the median).*

Assessing the forecast skill

The "forecasting skill" associated seasonal climate outlooks can vary from location to location, predictors used, season starting-periods and lengths, and forecast lead-times. An understanding of the nature of the skill is necessary to maximize the effectiveness of the forecasts for use in decision-making.

The aim of this study is to assess the potential of rainfall-based seasonal climate outlooks in Indonesia using the FlowCast software. This involves examining the nature of forecasting skill through analysing different predictors, locations, periods of the year, lead-times and season lengths. Specifically, the objectives of the study are:

- to identify which predictors are most suitable for developing seasonal climate outlooks in the study area
- to determine the periods of the year were forecasting skill exists, and those which aren't associated with skill
- to determine the range of season lengths that can be forecast with adequate skill
- to study how geographical location affects forecasting skill over the study area.

The principal measure of forecast repeatability or skill used in this study is the hindcast-based LEPS (Linear Error in Probability Space) skill score tests. These tests can identify forecast "signals" highlighting the times of the year when a forecast will be most reliable, and the corresponding envelope of lead times that will maintain forecast reliability.

A LEPS skill score is a measure of forecast skill providing an indication of how well the forecasting system has performed in the past. LEPS is analogous to a scoring system that rates the performance of a forecast by rewarding good predictions and penalising bad ones while assigning some weighting proportional to the degree of difficulty of a forecast. This is achieved through measurement of the forecast error in probability space as opposed to measurement space. LEPS skill scores are calculated by accumulating these scores over several years of "hindcast" analysis to assess the performance of the forecast system using past data.

FlowCast is able to generate a "Skill Map" of LEPS skills scores for a range of inter-annual forecast periods and lead-times (Figure A2.4). The map represents the LEPS results (expressed as a percentage) of 108 separate "hindcast" analyses (12 periods by 9 lead times). These results are "cross-validated" meaning that the model is trained with all the data except for the period that we produce the forecast, so as not to bias the results. The forecast period is represented on the x-axis, with the lead-time on the y-axis. The skill score results are assigned colours relative to the magnitude of each score: a blue square denotes forecasting skill greater than climatology (chance); a red square denotes forecasting skill worse than climatology; while a white square denotes skill the same as climatology.

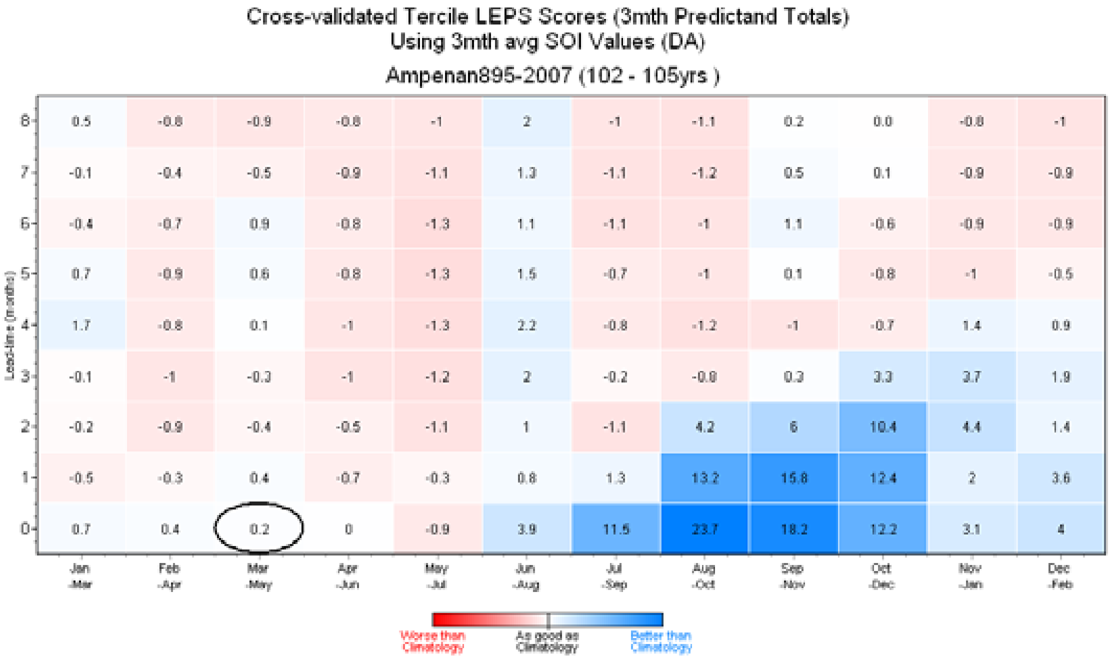


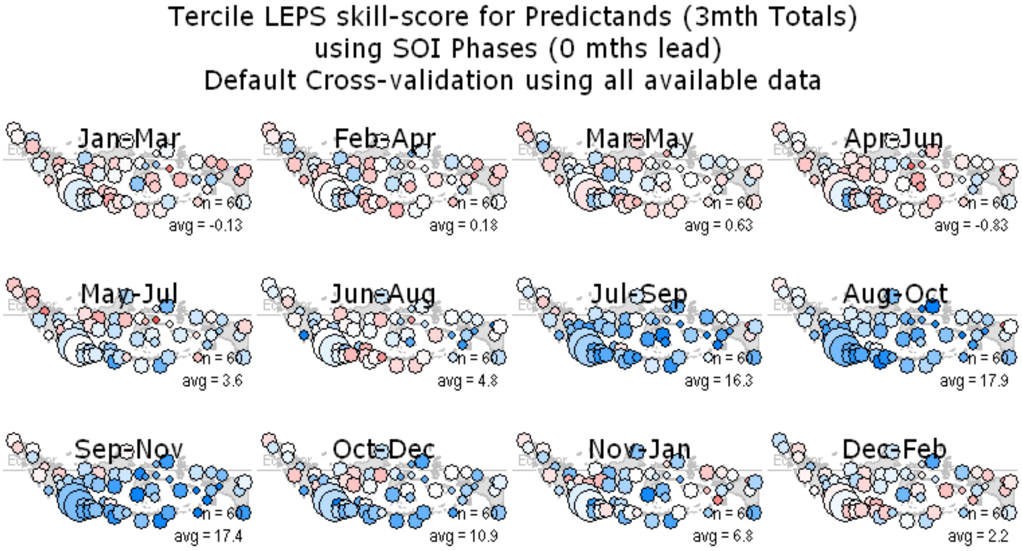
Figure A2.4: Skill Map of cross-validated LEPS skill scores.

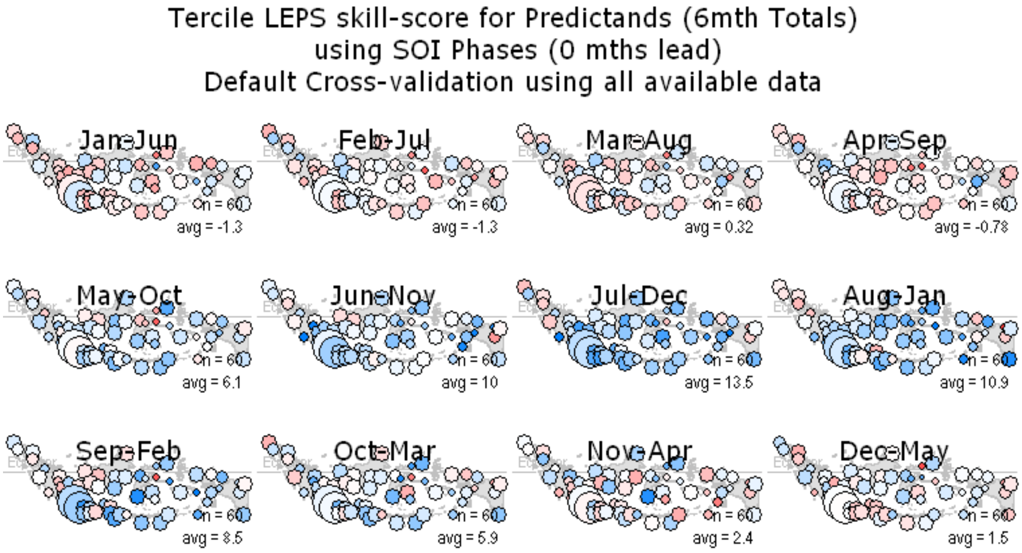
The range of possible LEPS skill scores is from −100% to 100%. In practice, a score of 100% would never be achieved. For this to occur, the “hindcast” analysis would have to be correct every year in the first or third category (tercile forecast) to achieve the maximum reward weighting. Typically LEPS skill score values range non-linearly from −30% to 40%, but this can be influenced by the length of record (LEPS skill score for a 100 year analysis can be about half that of a 50 years analysis), the forecast methodology used (stratification or discriminant analysis), and characteristics of the methodology such as phase count or number of predictors. For this reason, it can be difficult to directly compare LEPS scores across different forecast systems, and this was experienced during this study.

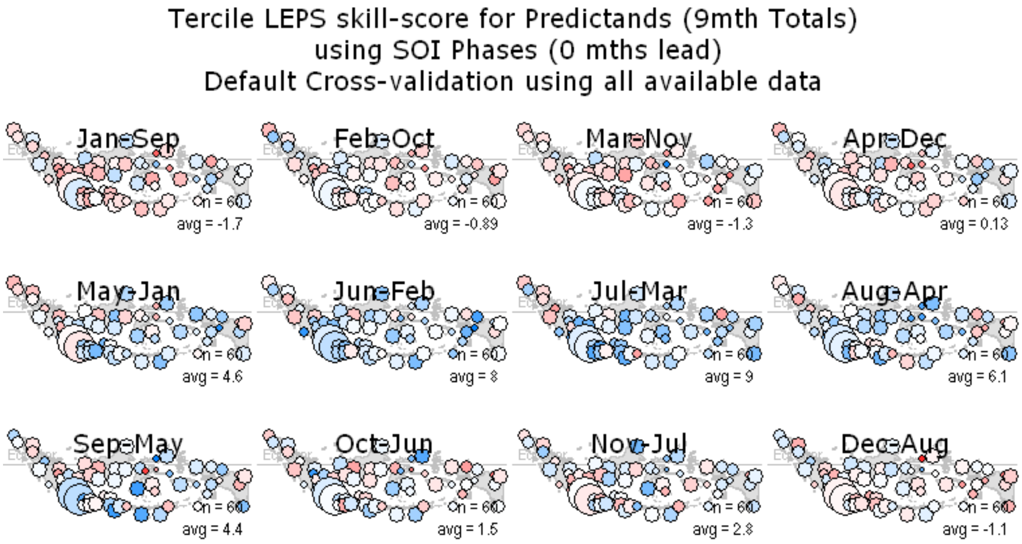
However, individual LEPS skill scores across the map (Figure A2.4) can be compared directly with each other and several conclusions can be drawn from the resulting patterns:

1. LEPS skill scores generally decrease with increasing lead-time. Sometimes, there may be an initial one- or two-month lag before this takes effect. Note that this may not be observed with predictors with an inherently long wavelength (such as tidal predictors), whose values do not change significantly from month to month.
2. Blocks of “skill” and “no-skill” tend to group together around particular periods of the year. From this, we can determine periods when forecasting is more reliable.

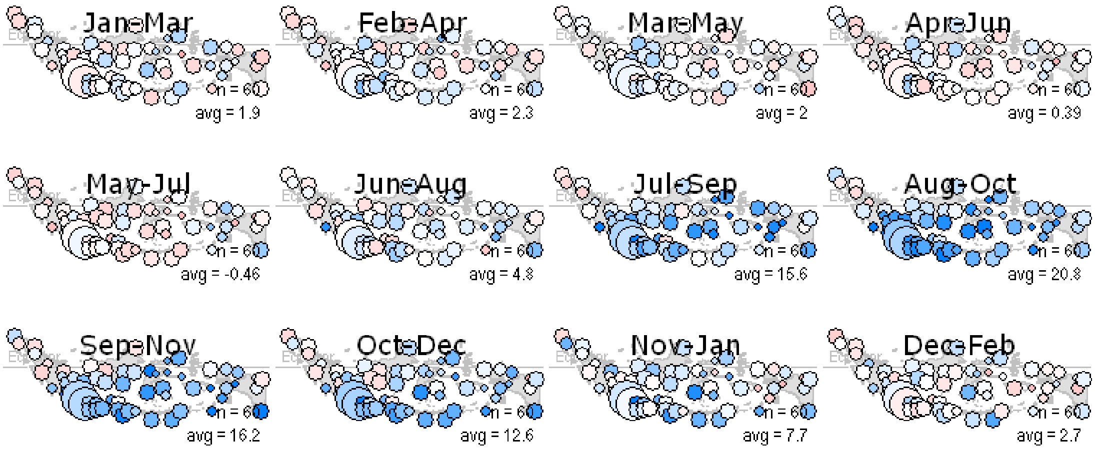
10.3 Appendix 3: Skill score assessment for Indonesian rainfall



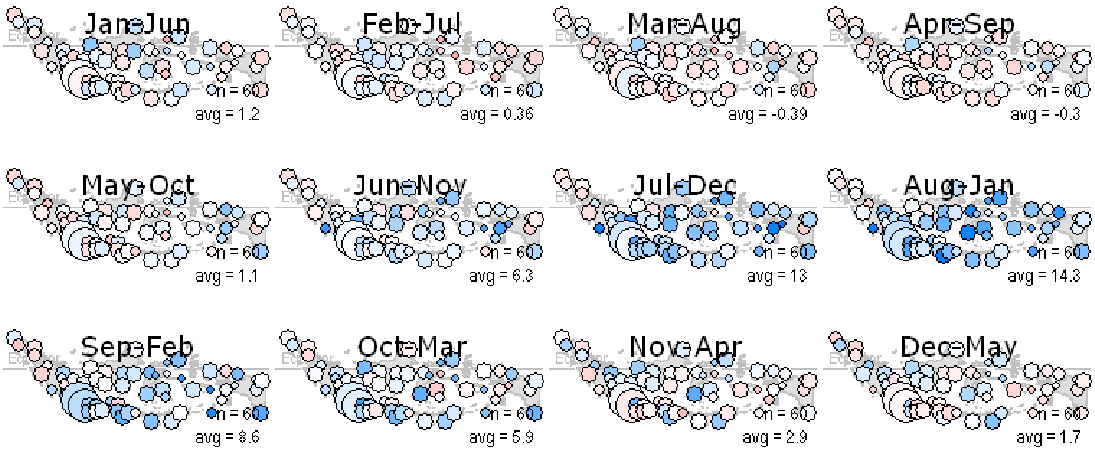




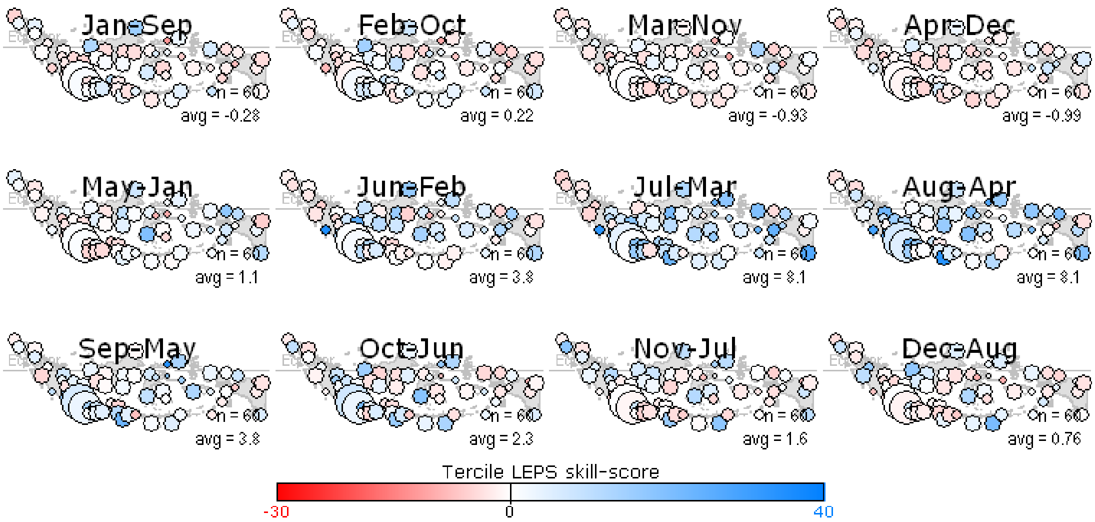
Tercile LEPS skill-score for Predictands (3mth Totals)
using 3-Cat SOI Values (0 mths lead)
Default Cross-validation using all available data

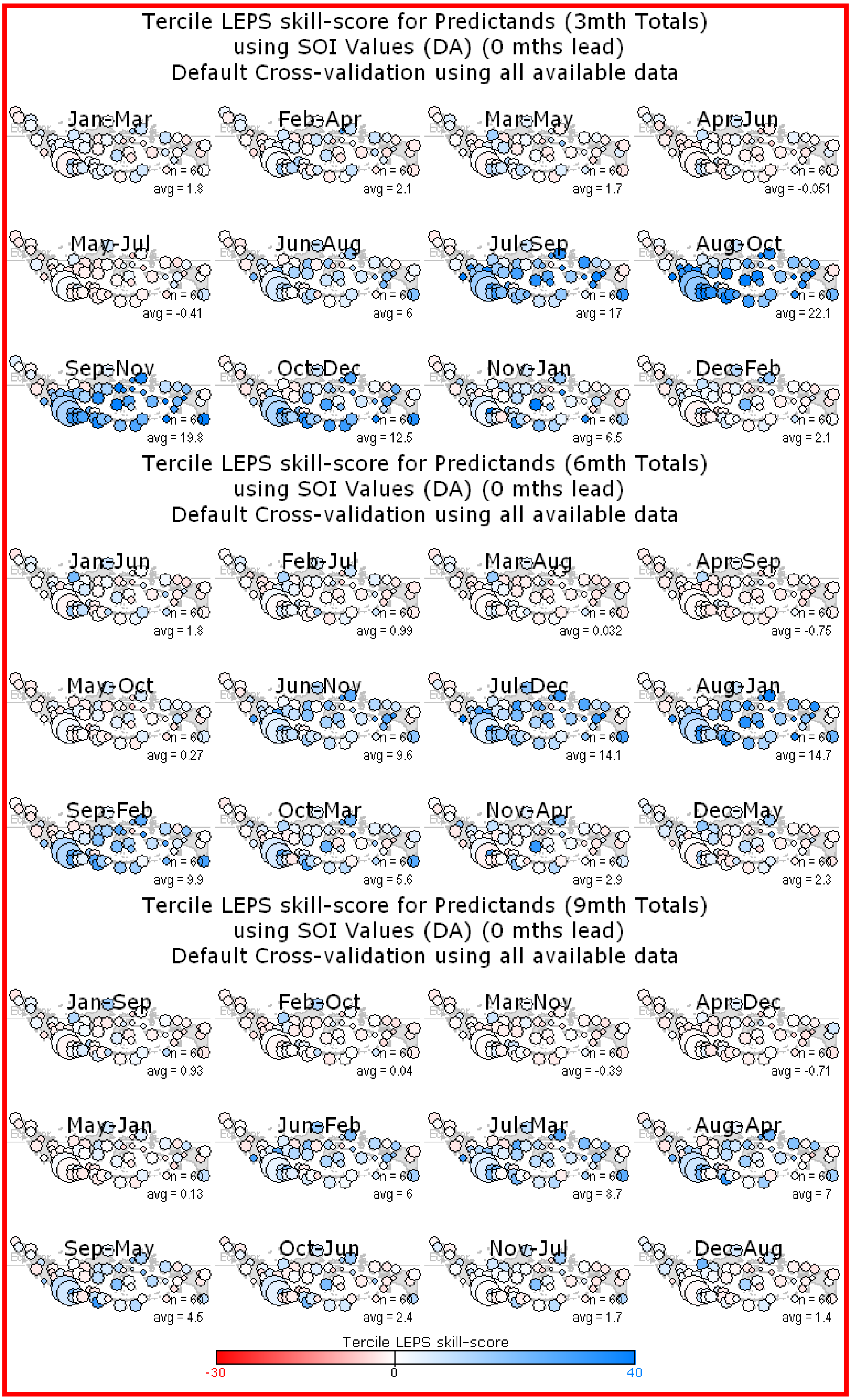


Tercile LEPS skill-score for Predictands (6mth Totals)
using 3-Cat SOI Values (0 mths lead)
Default Cross-validation using all available data

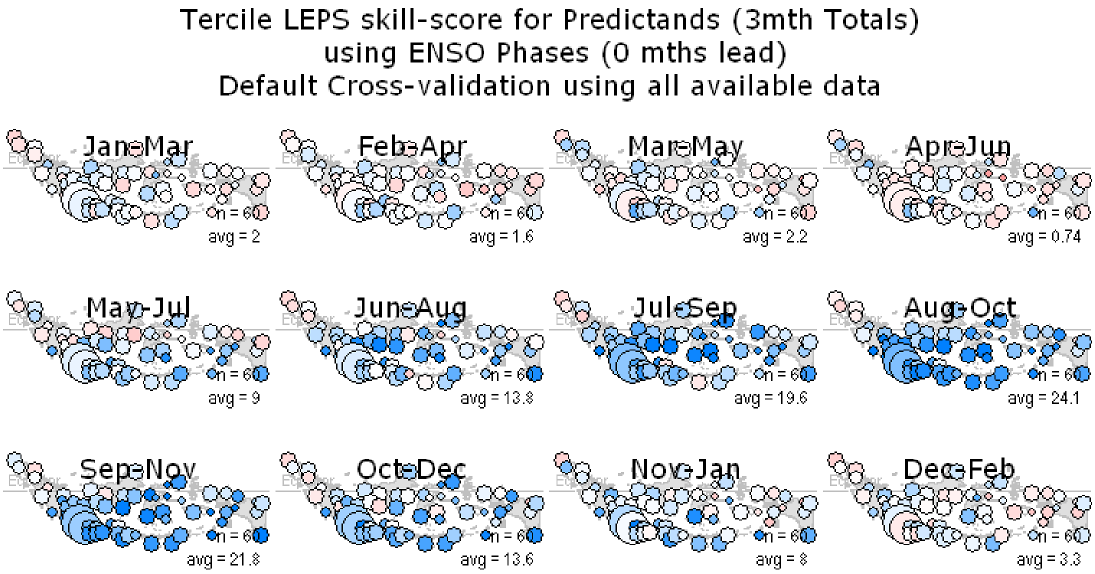


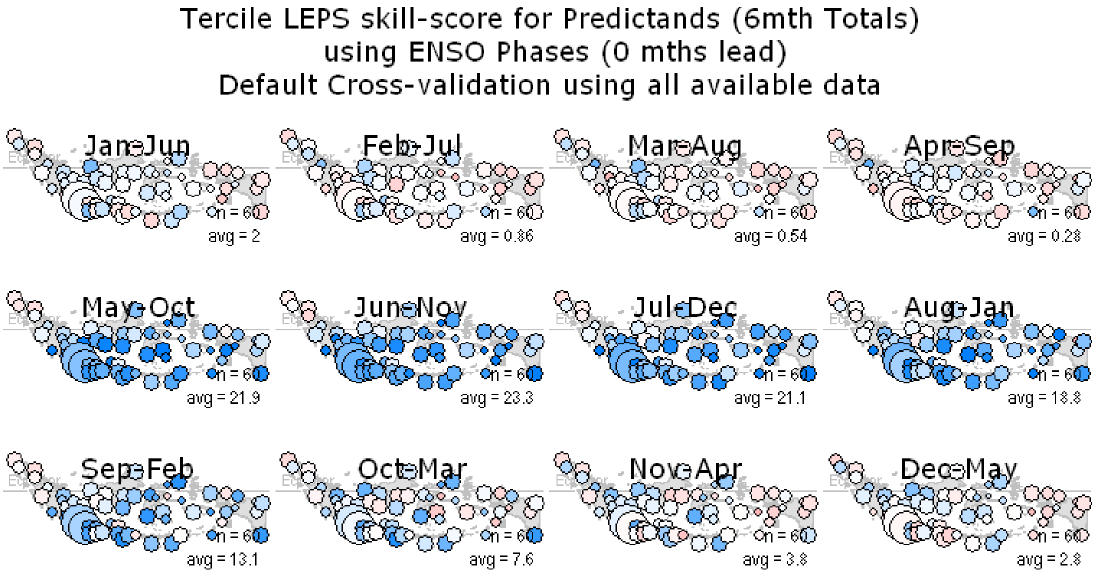
Tercile LEPS skill-score for Predictands (9mth Totals)
using 3-Cat SOI Values (0 mths lead)
Default Cross-validation using all available data

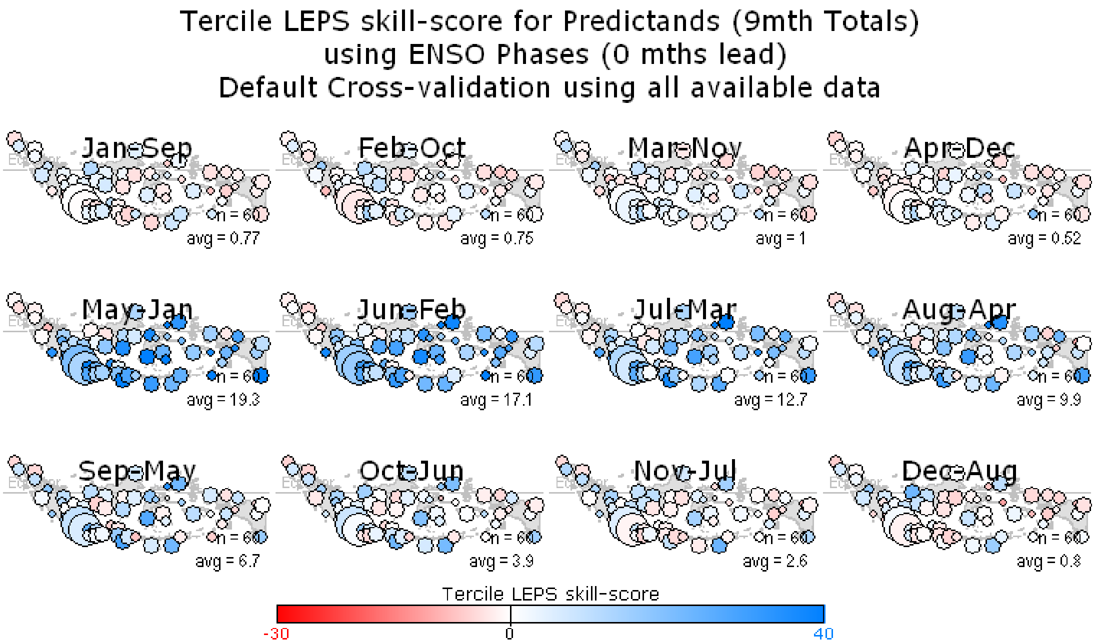


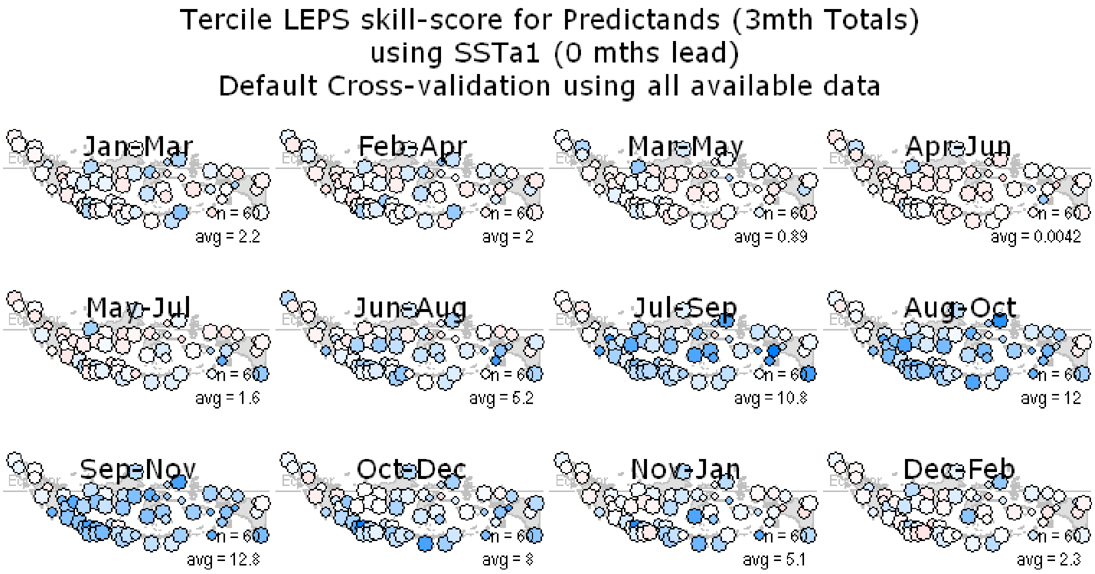


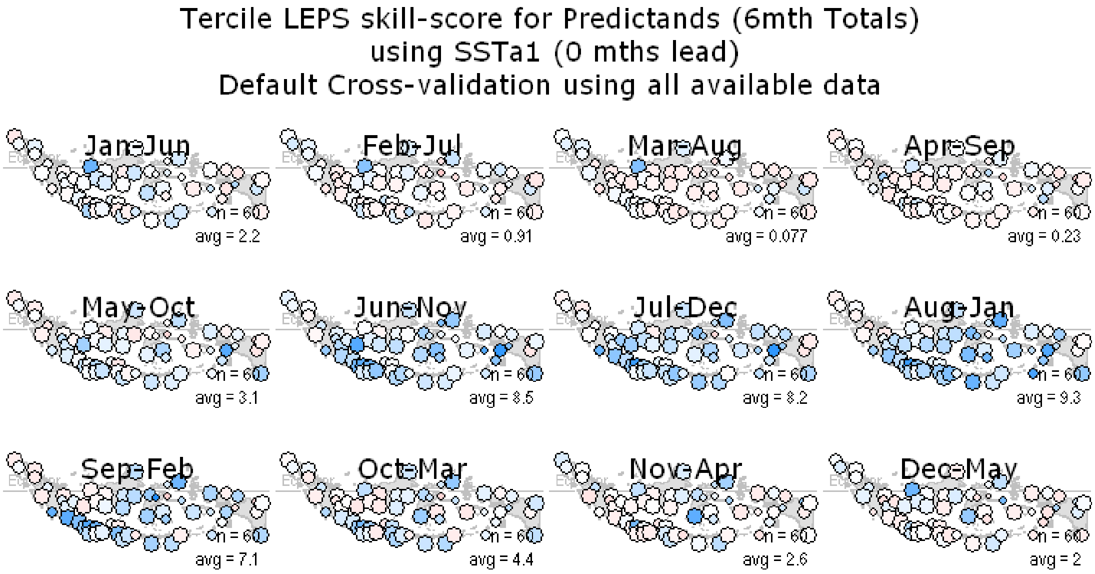
This is the preferred predictive system for an operational empirical forecast system.

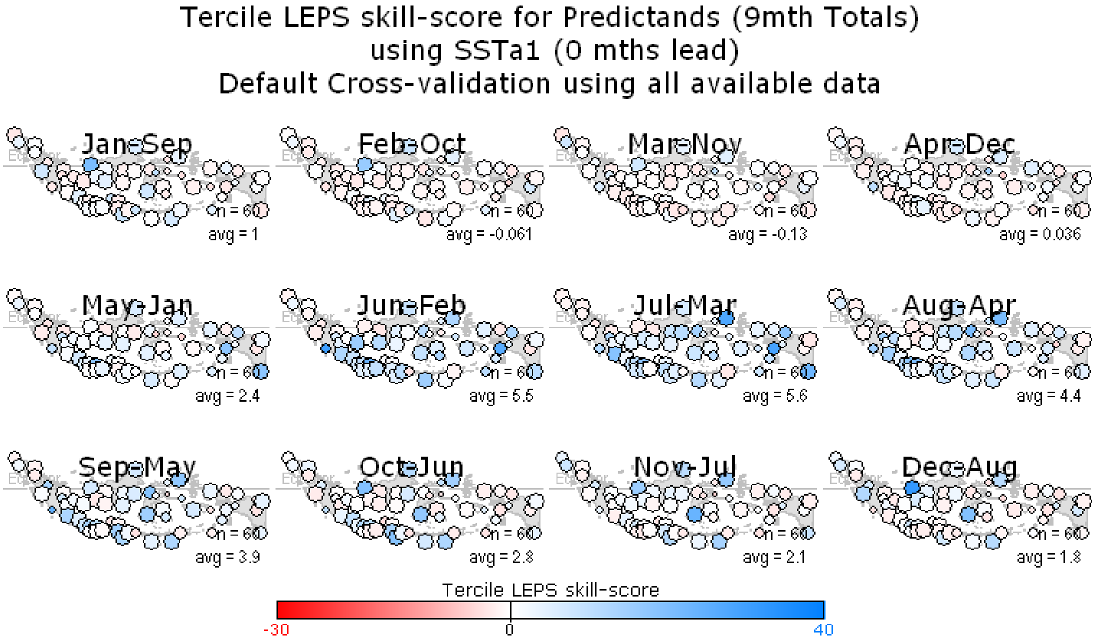

Tercile LEPS skill-score for Predictands (3mth Totals)
using ENSO Phases (0 mths lead)
Default Cross-validation using all available data
Jan-Mar
avg = 2
Feb-Apr
avg = 1.6
Mar-May
avg = 2.2
Apr-Jun
avg = 0.74
May-Jul
avg = 9
Jun-Aug
avg = 13.8
Jul-Sep
avg = 19.6
Aug-Oct
avg = 24.1
Sep-Nov
avg = 21.8
Oct-Dec
avg = 13.6
Nov-Jan
avg = 8
Dec-Feb
avg = 3.3


Tercile LEPS skill-score for Predictands (6mth Totals)
using ENSO Phases (0 mths lead)
Default Cross-validation using all available data
Jan-Jun
avg = 2
Feb-Jul
avg = 0.86
Mar-Aug
avg = 0.54
Apr-Sep
avg = 0.28
May-Oct
avg = 21.9
Jun-Nov
avg = 23.3
Jul-Dec
avg = 21.1
Aug-Jan
avg = 18.8
Sep-Feb
avg = 13.1
Oct-Mar
avg = 7.6
Nov-Apr
avg = 3.8
Dec-May
avg = 2.8

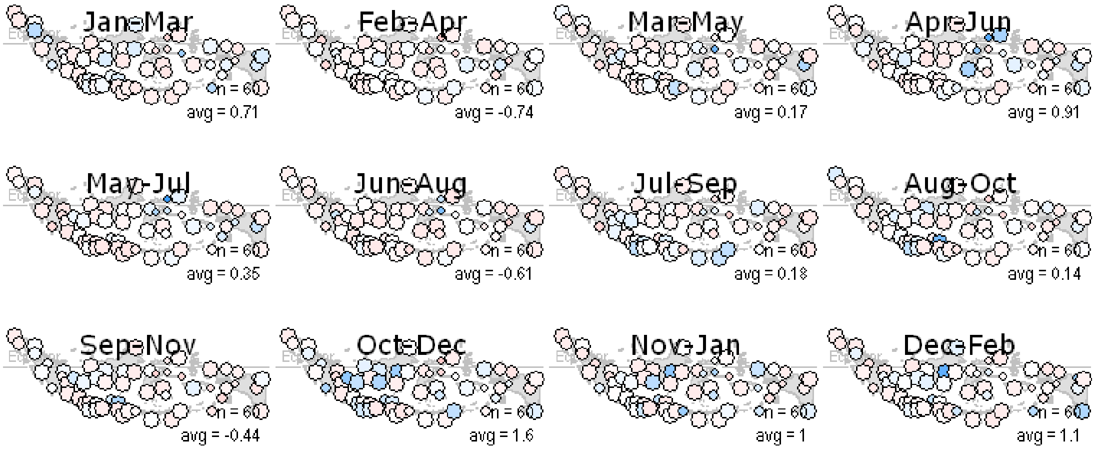

Tercile LEPS skill-score for Predictands (9mth Totals)
using ENSO Phases (0 mths lead)
Default Cross-validation using all available data
Jan-Sep
avg = 0.77
Feb-Oct
avg = 0.75
Mar-Nov
avg = 1
Apr-Dec
avg = 0.52
May-Jan
avg = 19.3
Jun-Feb
avg = 17.1
Jul-Mar
avg = 12.7
Aug-Apr
avg = 9.9
Sep-May
avg = 6.7
Oct-Jun
avg = 3.9
Nov-Jul
avg = 2.6
Dec-Aug
avg = 0.8
Tercile LEPS skill-score
-30
0
40


Tercile LEPS skill-score for Predictands (3mth Totals)
using SSTa1 (0 mths lead)
Default Cross-validation using all available data
Jan-Mar
n = 60
avg = 2.2
Feb-Apr
n = 60
avg = 2
Mar-May
n = 60
avg = 0.89
Apr-Jun
n = 60
avg = 0.0042
May-Jul
n = 60
avg = 1.6
Jun-Aug
n = 60
avg = 5.2
Jul-Sep
n = 60
avg = 10.8
Aug-Oct
n = 60
avg = 12
Sep-Nov
n = 60
avg = 12.8
Oct-Dec
n = 60
avg = 8
Nov-Jan
n = 60
avg = 5.1
Dec-Feb
n = 60
avg = 2.3

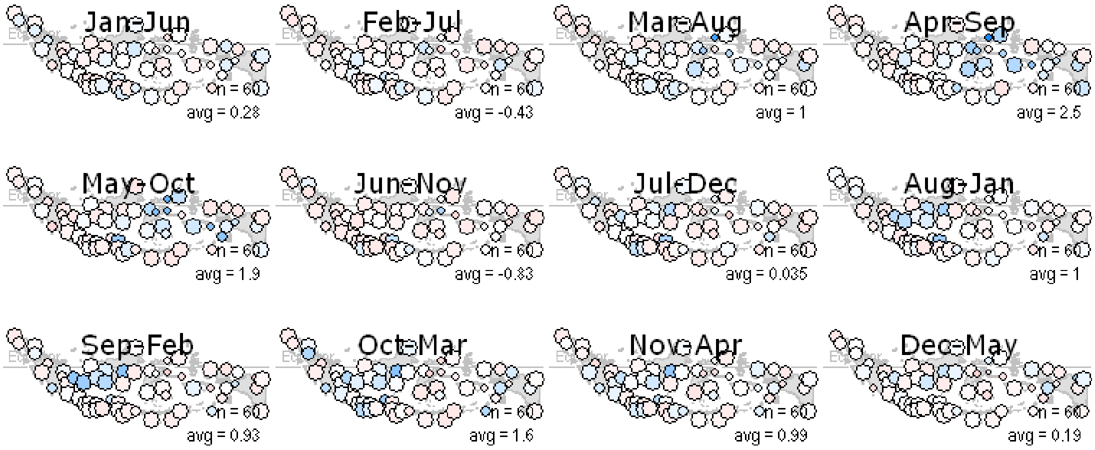

Tercile LEPS skill-score for Predictands (6mth Totals)
using SSTa1 (0 mths lead)
Default Cross-validation using all available data
Jan-Jun
n = 60
avg = 2.2
Feb-Jul
n = 60
avg = 0.91
Mar-Aug
n = 60
avg = 0.077
Apr-Sep
n = 60
avg = 0.23
May-Oct
n = 60
avg = 3.1
Jun-Nov
n = 60
avg = 8.5
Jul-Dec
n = 60
avg = 8.2
Aug-Jan
n = 60
avg = 9.3
Sep-Feb
n = 60
avg = 7.1
Oct-Mar
n = 60
avg = 4.4
Nov-Apr
n = 60
avg = 2.6
Dec-May
n = 60
avg = 2


Tercile LEPS skill-score for Predictands (9mth Totals)
using SSTa1 (0 mths lead)
Default Cross-validation using all available data
Jan-Sep
n = 60
avg = 1
Feb-Oct
n = 60
avg = -0.061
Mar-Nov
n = 60
avg = -0.13
Apr-Dec
n = 60
avg = 0.036
May-Jan
n = 60
avg = 2.4
Jun-Feb
n = 60
avg = 5.5
Jul-Mar
n = 60
avg = 5.6
Aug-Apr
n = 60
avg = 4.4
Sep-May
n = 60
avg = 3.9
Oct-Jun
n = 60
avg = 2.8
Nov-Jul
n = 60
avg = 2.1
Dec-Aug
n = 60
avg = 1.8
Tercile LEPS skill-score
-30
0
40

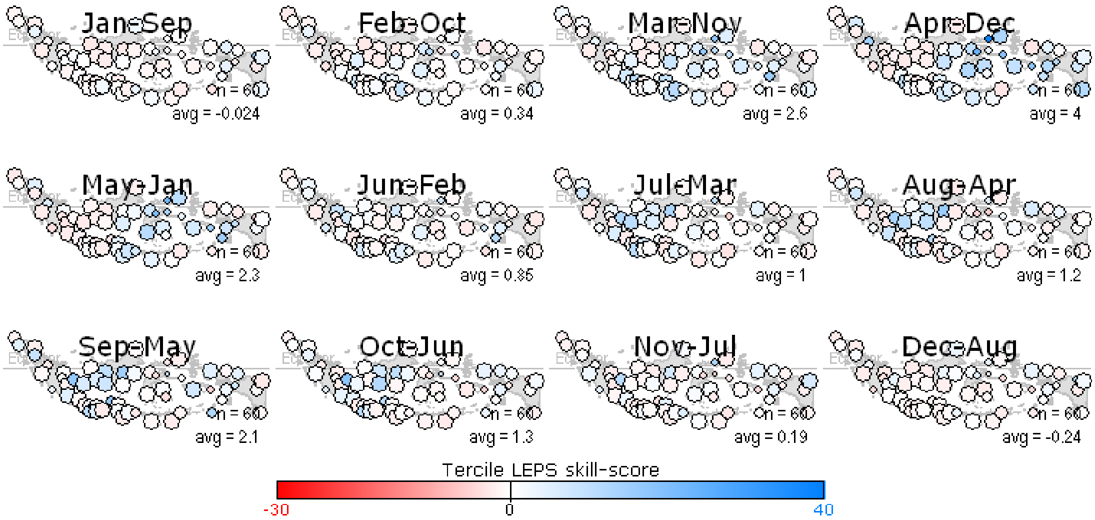
Tercile LEPS skill-score for Predictands (3mth Totals)
using SSTa2 (0 mths lead)
Default Cross-validation using all available data

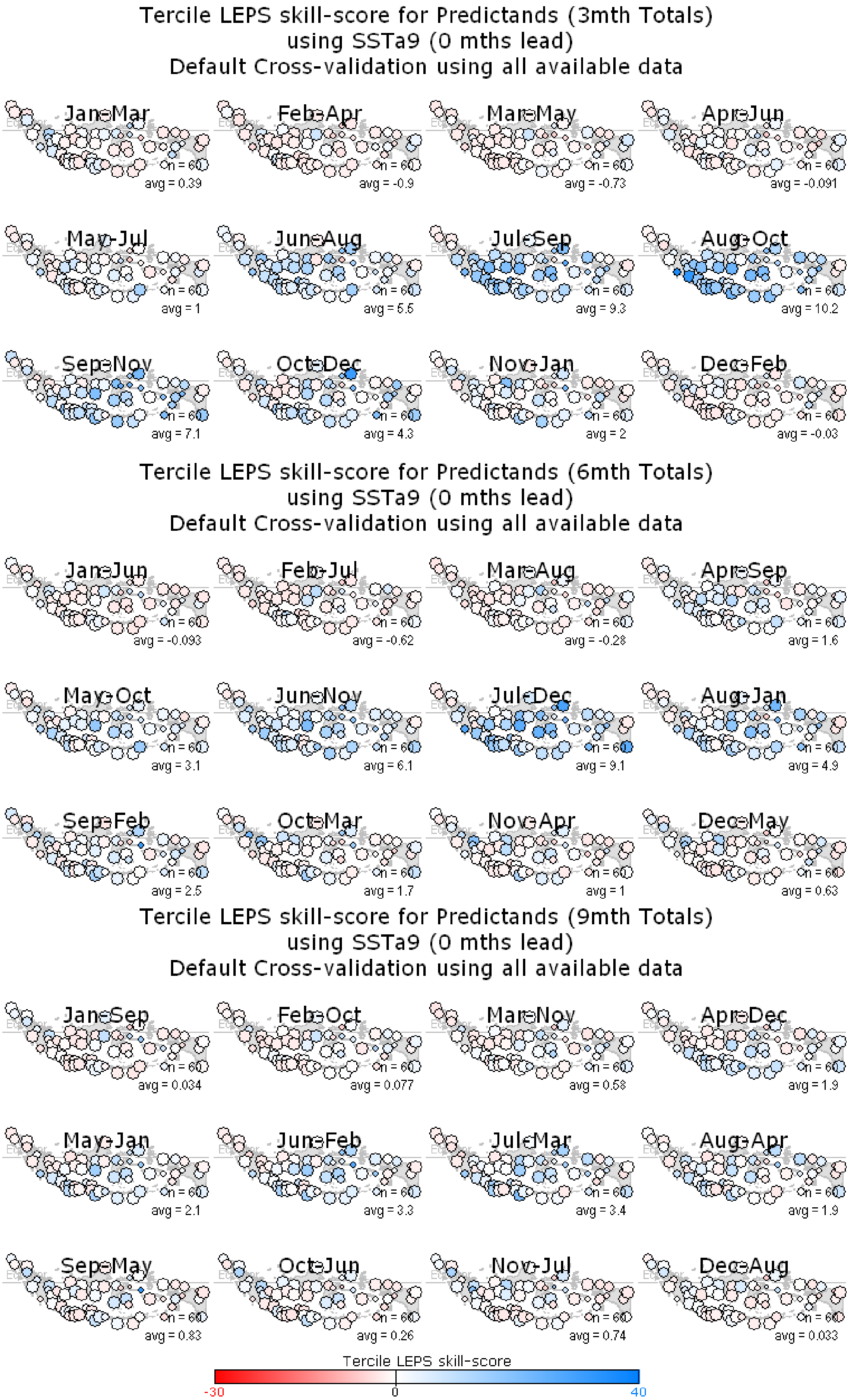


Tercile LEPS skill-score for Predictands (6mth Totals)
using SSTa2 (0 mths lead)
Default Cross-validation using all available data

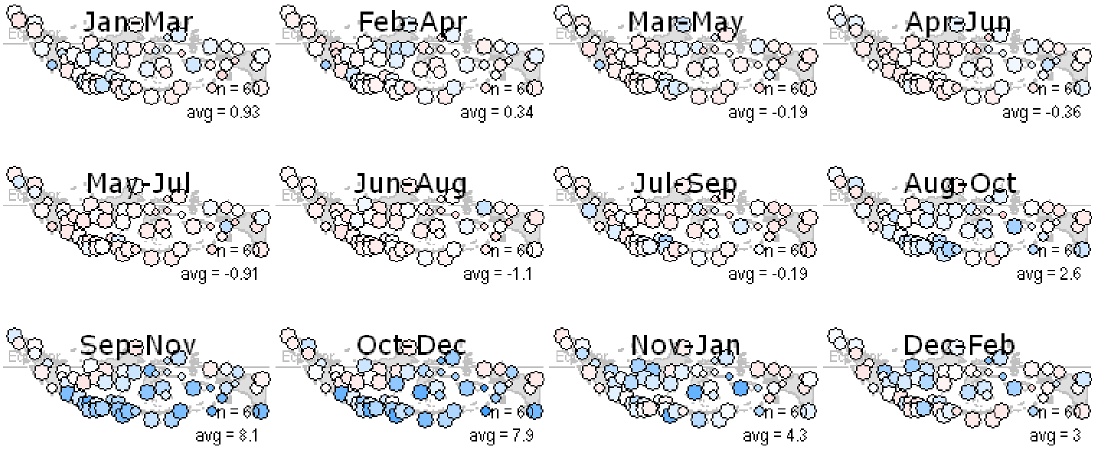


Tercile LEPS skill-score for Predictands (9mth Totals)
using SSTa2 (0 mths lead)
Default Cross-validation using all available data

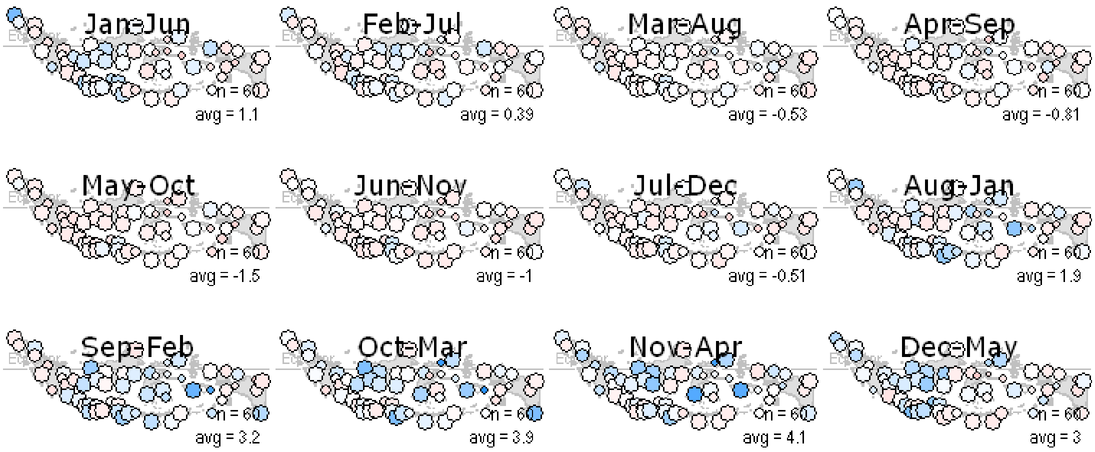



Tercile LEPS skill-score for Predictands (3mth Totals)
using SSTa9 (0 mths lead)
Default Cross-validation using all available data
Jan-Mar n = 60 avg = 0.39
Feb-Apr n = 60 avg = -0.9
Mar-May n = 60 avg = -0.73
Apr-Jun n = 60 avg = -0.091
May-Jul n = 60 avg = 1
Jun-Aug n = 60 avg = 5.5
Jul-Sep n = 60 avg = 9.3
Aug-Oct n = 60 avg = 10.2
Sep-Nov n = 60 avg = 7.1
Oct-Dec n = 60 avg = 4.3
Nov-Jan n = 60 avg = 2
Dec-Feb n = 60 avg = -0.03
Tercile LEPS skill-score for Predictands (6mth Totals)
using SSTa9 (0 mths lead)
Default Cross-validation using all available data
Jan-Jun n = 60 avg = -0.093
Feb-Jul n = 60 avg = -0.62
Mar-Aug n = 60 avg = -0.28
Apr-Sep n = 60 avg = 1.6
May-Oct n = 60 avg = 3.1
Jun-Nov n = 60 avg = 6.1
Jul-Dec n = 60 avg = 9.1
Aug-Jan n = 60 avg = 4.9
Sep-Feb n = 60 avg = 2.5
Oct-Mar n = 60 avg = 1.7
Nov-Apr n = 60 avg = 1
Dec-May n = 60 avg = 0.63
Tercile LEPS skill-score for Predictands (9mth Totals)
using SSTa9 (0 mths lead)
Default Cross-validation using all available data
Jan-Sep n = 60 avg = 0.034
Feb-Oct n = 60 avg = 0.077
Mar-Nov n = 60 avg = 0.58
Apr-Dec n = 60 avg = 1.9
May-Jan n = 60 avg = 2.1
Jun-Feb n = 60 avg = 3.3
Jul-Mar n = 60 avg = 3.4
Aug-Apr n = 60 avg = 1.9
Sep-May n = 60 avg = 0.83
Oct-Jun n = 60 avg = 0.26
Nov-Jul n = 60 avg = 0.74
Dec-Aug n = 60 avg = 0.033
Tercile LEPS skill-score
-30
0
40

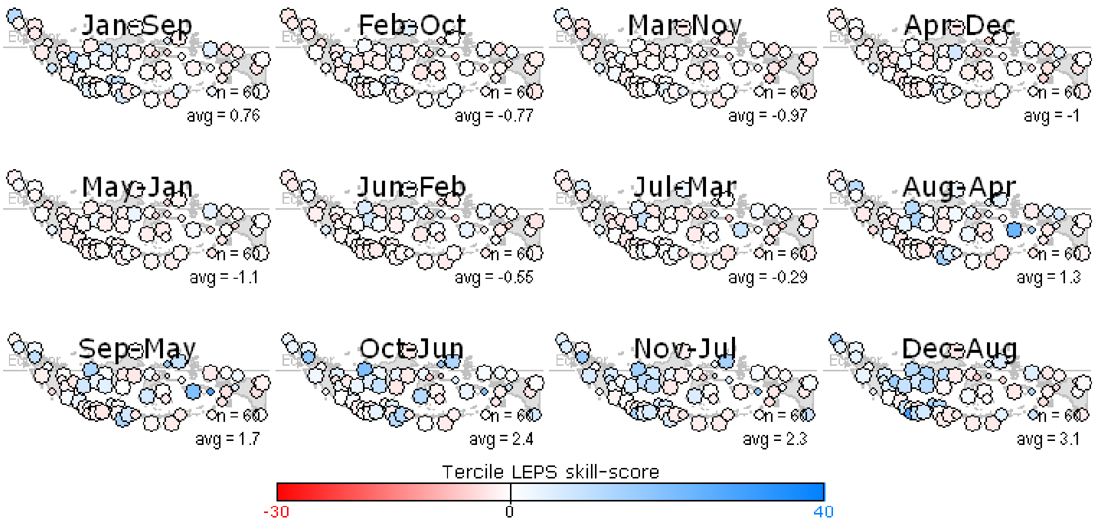
Tercile LEPS skill-score for Predictands (3mth Totals)
using SSTa12 (0 mths lead)
Default Cross-validation using all available data

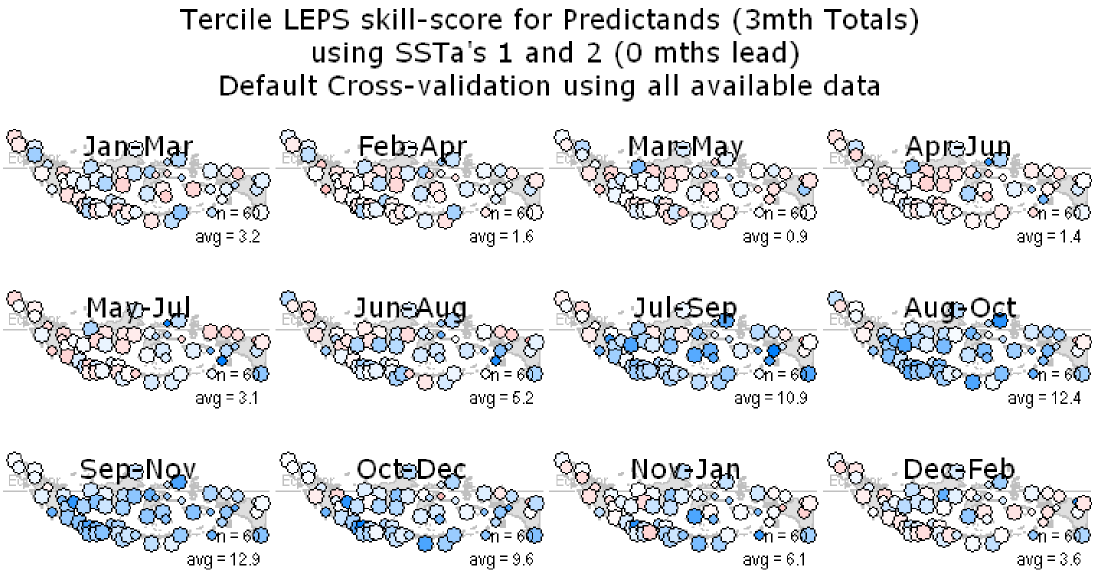


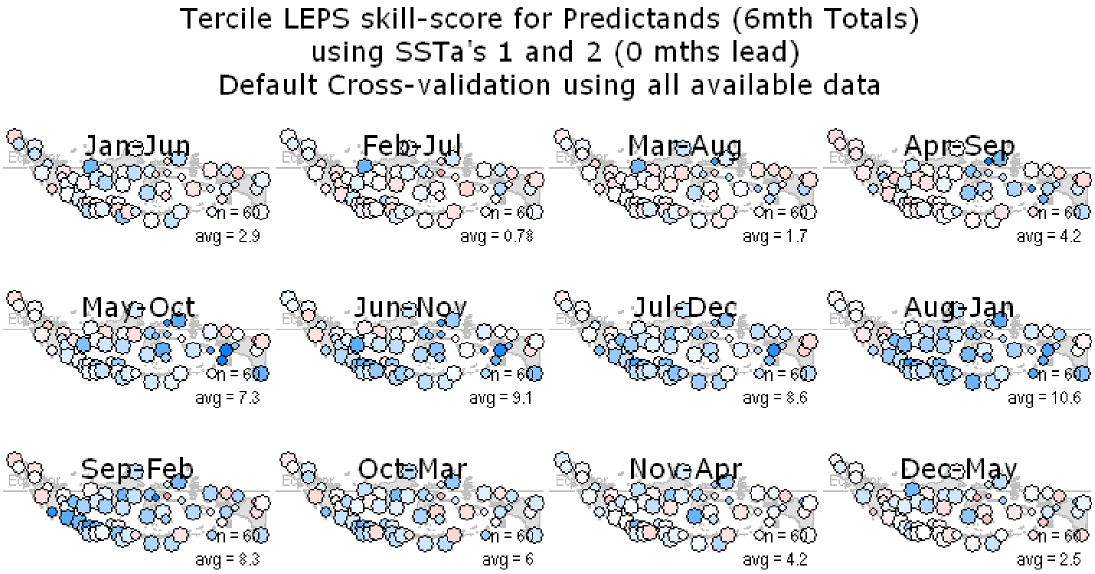
Tercile LEPS skill-score for Predictands (6mth Totals)
using SSTa12 (0 mths lead)
Default Cross-validation using all available data

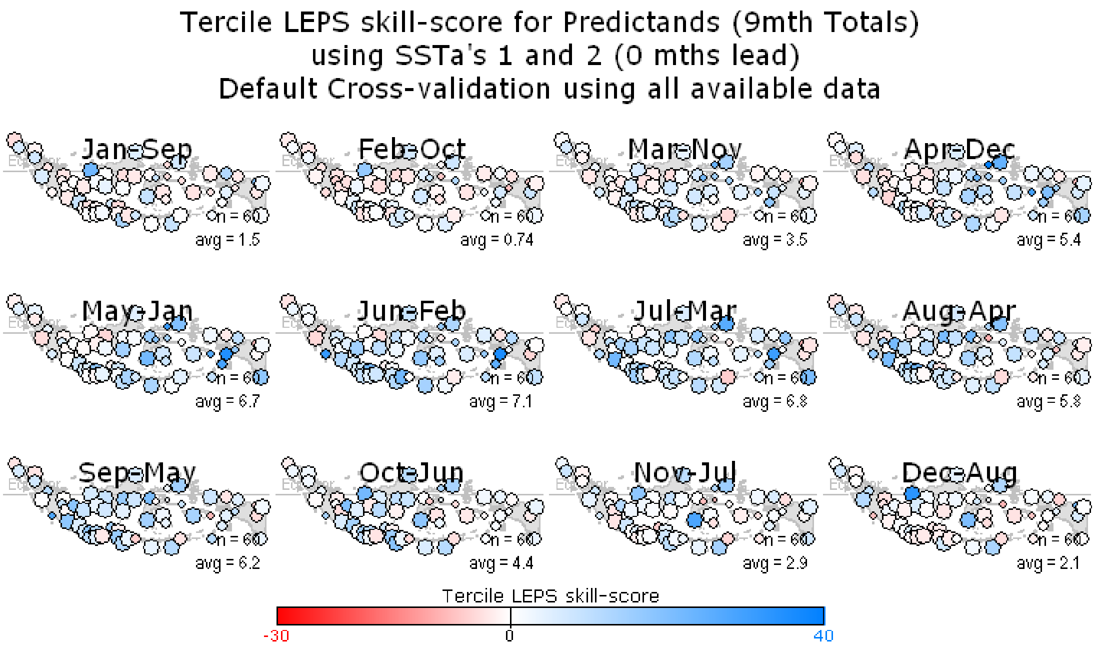


Tercile LEPS skill-score for Predictands (9mth Totals)
using SSTa12 (0 mths lead)
Default Cross-validation using all available data

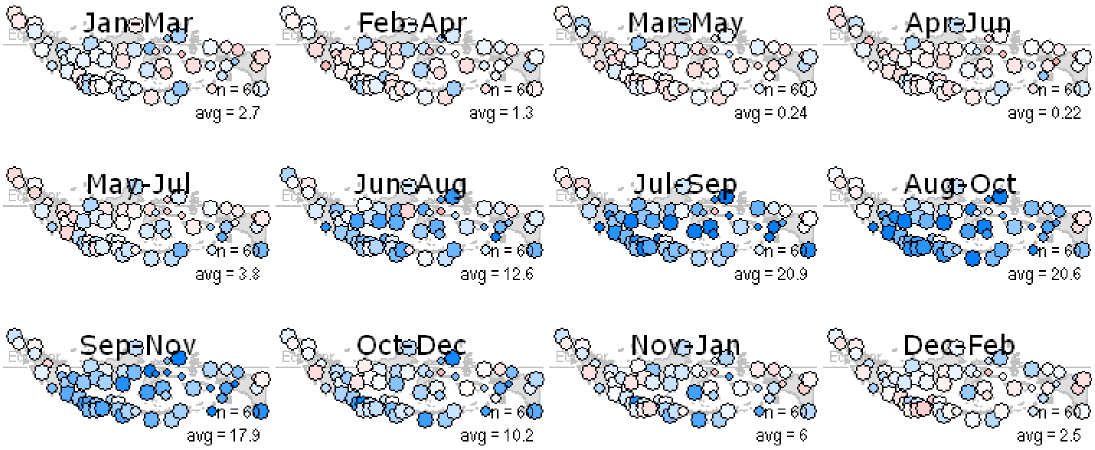



Tercile LEPS skill-score for Predictands (3mth Totals)
using SSTa's 1 and 2 (0 mths lead)
Default Cross-validation using all available data
Jan-Mar n = 60 avg = 3.2
Feb-Apr n = 60 avg = 1.6
Mar-May n = 60 avg = 0.9
Apr-Jun n = 60 avg = 1.4
May-Jul n = 60 avg = 3.1
Jun-Aug n = 60 avg = 5.2
Jul-Sep n = 60 avg = 10.9
Aug-Oct n = 60 avg = 12.4
Sep-Nov n = 60 avg = 12.9
Oct-Dec n = 60 avg = 9.6
Nov-Jan n = 60 avg = 6.1
Dec-Feb n = 60 avg = 3.6

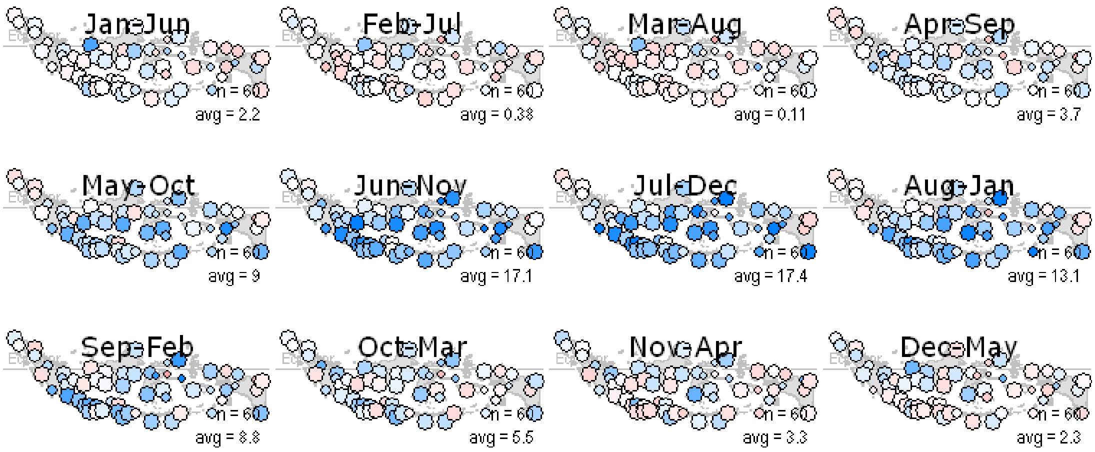

Tercile LEPS skill-score for Predictands (6mth Totals)
using SSTa's 1 and 2 (0 mths lead)
Default Cross-validation using all available data
Jan-Jun n = 60 avg = 2.9
Feb-Jul n = 60 avg = 0.78
Mar-Aug n = 60 avg = 1.7
Apr-Sep n = 60 avg = 4.2
May-Oct n = 60 avg = 7.3
Jun-Nov n = 60 avg = 9.1
Jul-Dec n = 60 avg = 8.6
Aug-Jan n = 60 avg = 10.6
Sep-Feb n = 60 avg = 8.3
Oct-Mar n = 60 avg = 6
Nov-Apr n = 60 avg = 4.2
Dec-May n = 60 avg = 2.5


Tercile LEPS skill-score for Predictands (9mth Totals)
using SSTa's 1 and 2 (0 mths lead)
Default Cross-validation using all available data
Jan-Sep n = 60 avg = 1.5
Feb-Oct n = 60 avg = 0.74
Mar-Nov n = 60 avg = 3.5
Apr-Dec n = 60 avg = 5.4
May-Jan n = 60 avg = 6.7
Jun-Feb n = 60 avg = 7.1
Jul-Mar n = 60 avg = 6.8
Aug-Apr n = 60 avg = 5.8
Sep-May n = 60 avg = 6.2
Oct-Jun n = 60 avg = 4.4
Nov-Jul n = 60 avg = 2.9
Dec-Aug n = 60 avg = 2.1
Tercile LEPS skill-score
-30
0
40

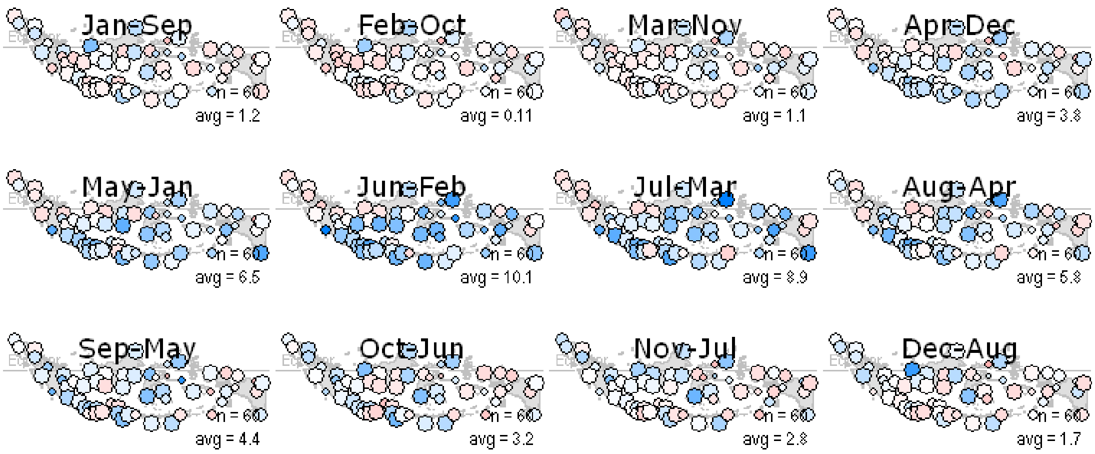
Tercile LEPS skill-score for Predictands (3mth Totals)
using SSTa's 1 and 9 (0 mths lead)
Default Cross-validation using all available data

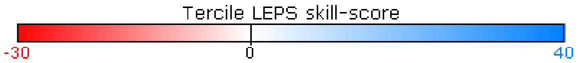


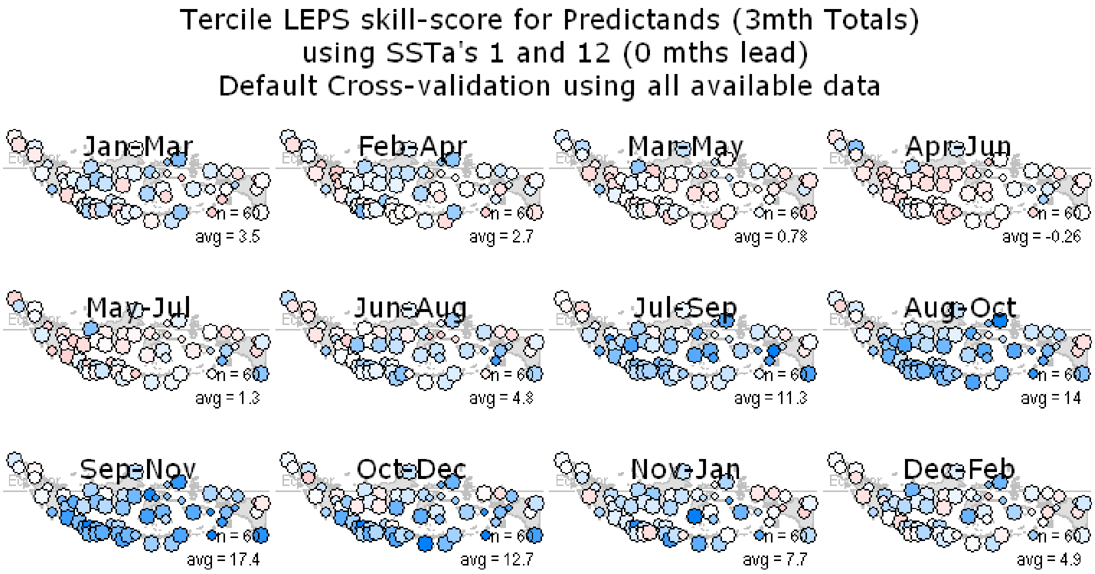
Tercile LEPS skill-score for Predictands (6mth Totals)
using SSTa's 1 and 9 (0 mths lead)
Default Cross-validation using all available data

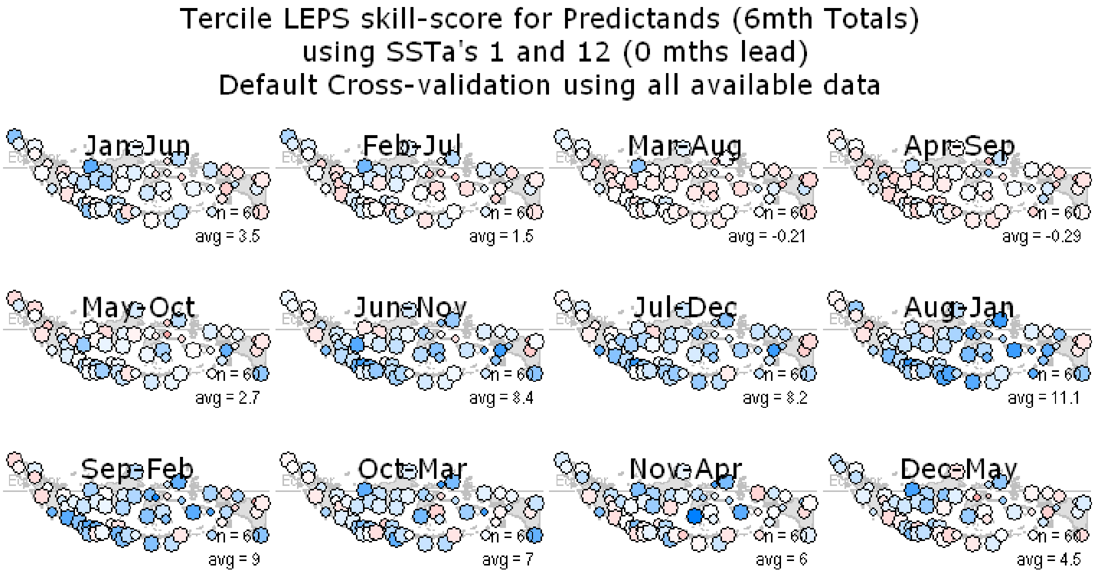


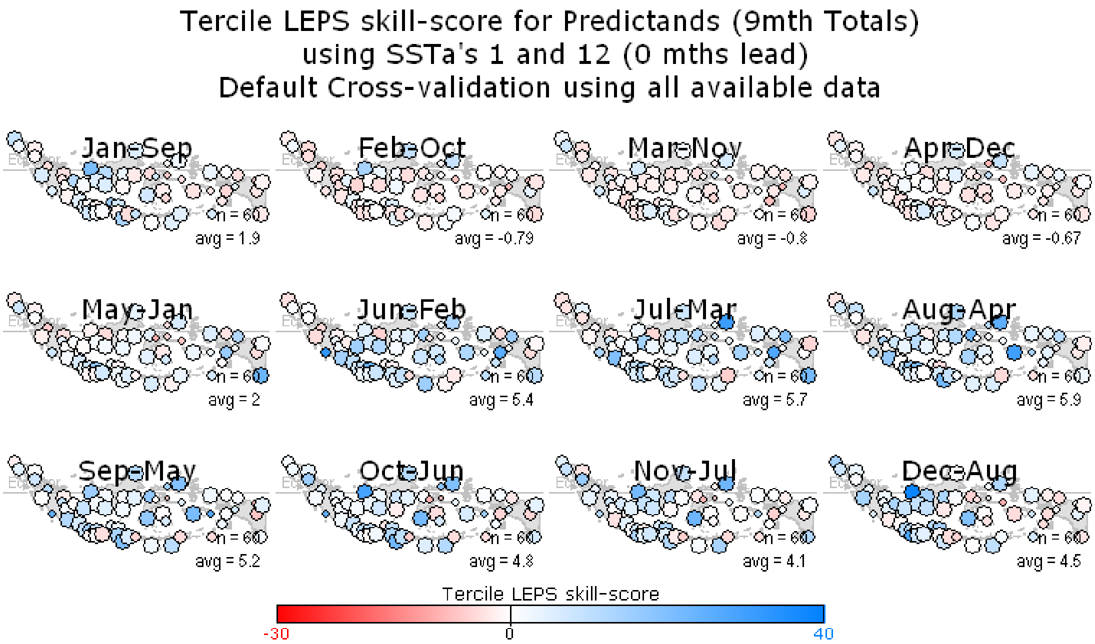
Tercile LEPS skill-score for Predictands (9mth Totals)
using SSTa's 1 and 9 (0 mths lead)
Default Cross-validation using all available data

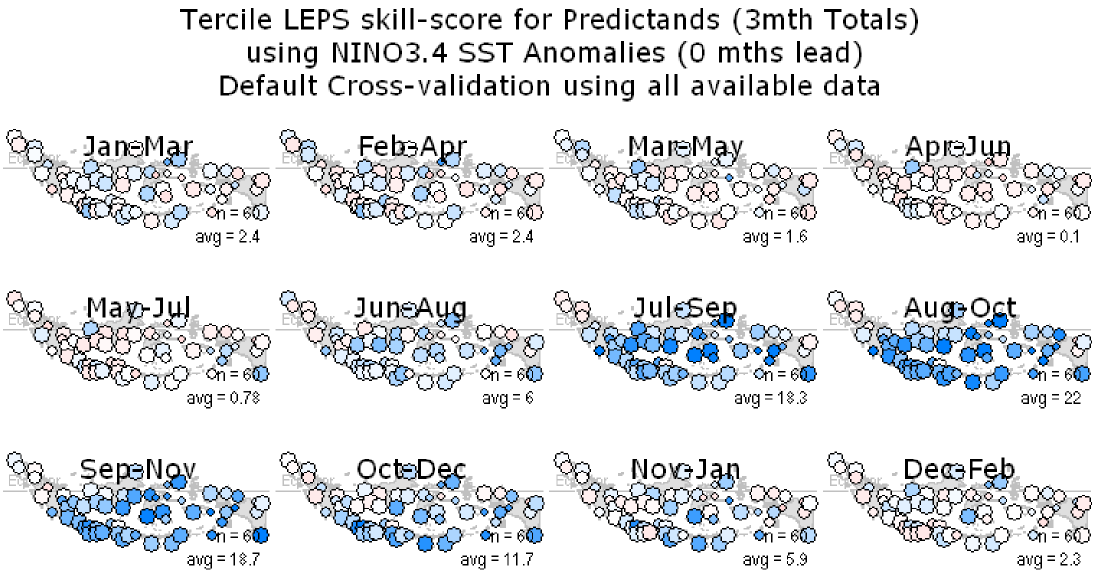


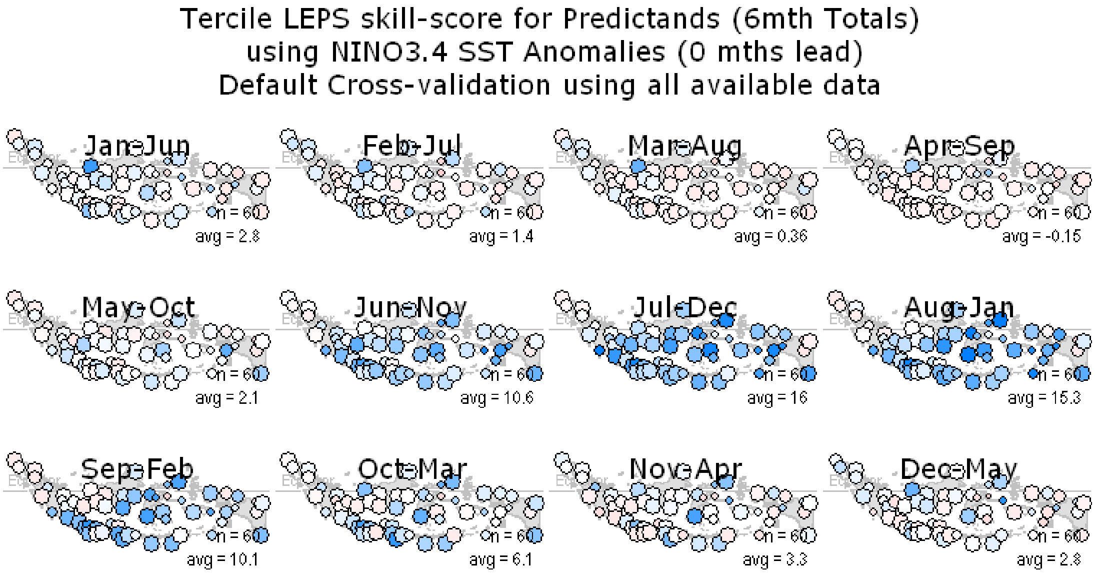


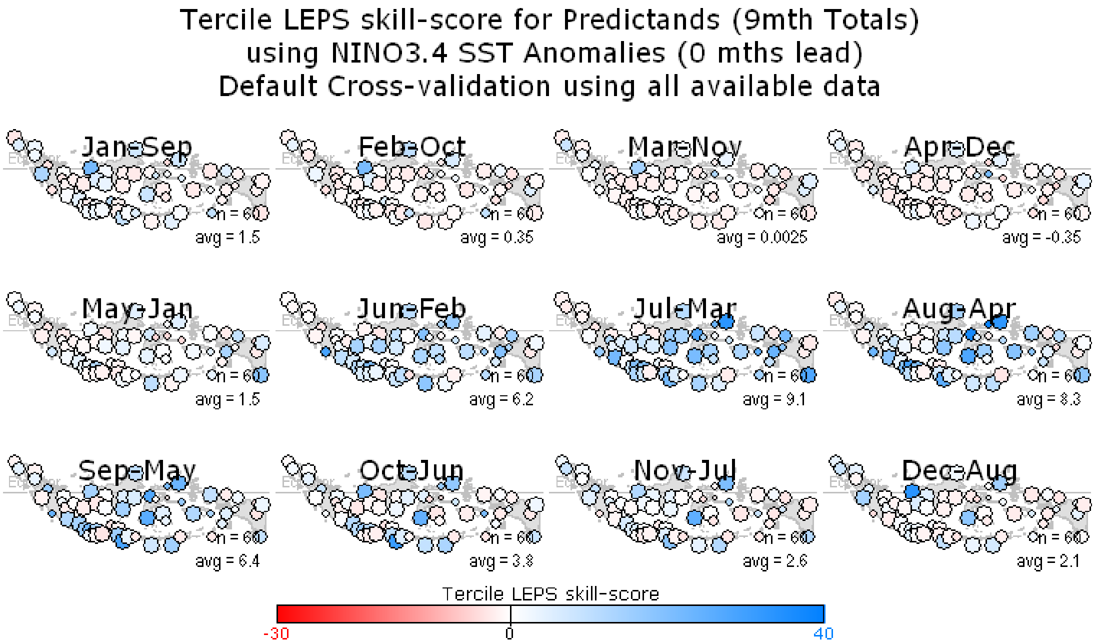

Tercile LEPS skill-score for Predictands (3mth Totals)
using SSTa's 1 and 12 (0 mths lead)
Default Cross-validation using all available data
Jan-Mar n = 60 avg = 3.5
Feb-Apr n = 60 avg = 2.7
Mar-May n = 60 avg = 0.78
Apr-Jun n = 60 avg = -0.26
May-Jul n = 60 avg = 1.3
Jun-Aug n = 60 avg = 4.8
Jul-Sep n = 60 avg = 11.3
Aug-Oct n = 60 avg = 14
Sep-Nov n = 60 avg = 17.4
Oct-Dec n = 60 avg = 12.7
Nov-Jan n = 60 avg = 7.7
Dec-Feb n = 60 avg = 4.9


Tercile LEPS skill-score for Predictands (6mth Totals)
using SSTa's 1 and 12 (0 mths lead)
Default Cross-validation using all available data
Jan-Jun n = 60 avg = 3.5
Feb-Jul n = 60 avg = 1.5
Mar-Aug n = 60 avg = -0.21
Apr-Sep n = 60 avg = -0.29
May-Oct n = 60 avg = 2.7
Jun-Nov n = 60 avg = 8.4
Jul-Dec n = 60 avg = 8.2
Aug-Jan n = 60 avg = 11.1
Sep-Feb n = 60 avg = 9
Oct-Mar n = 60 avg = 7
Nov-Apr n = 60 avg = 6
Dec-May n = 60 avg = 4.5

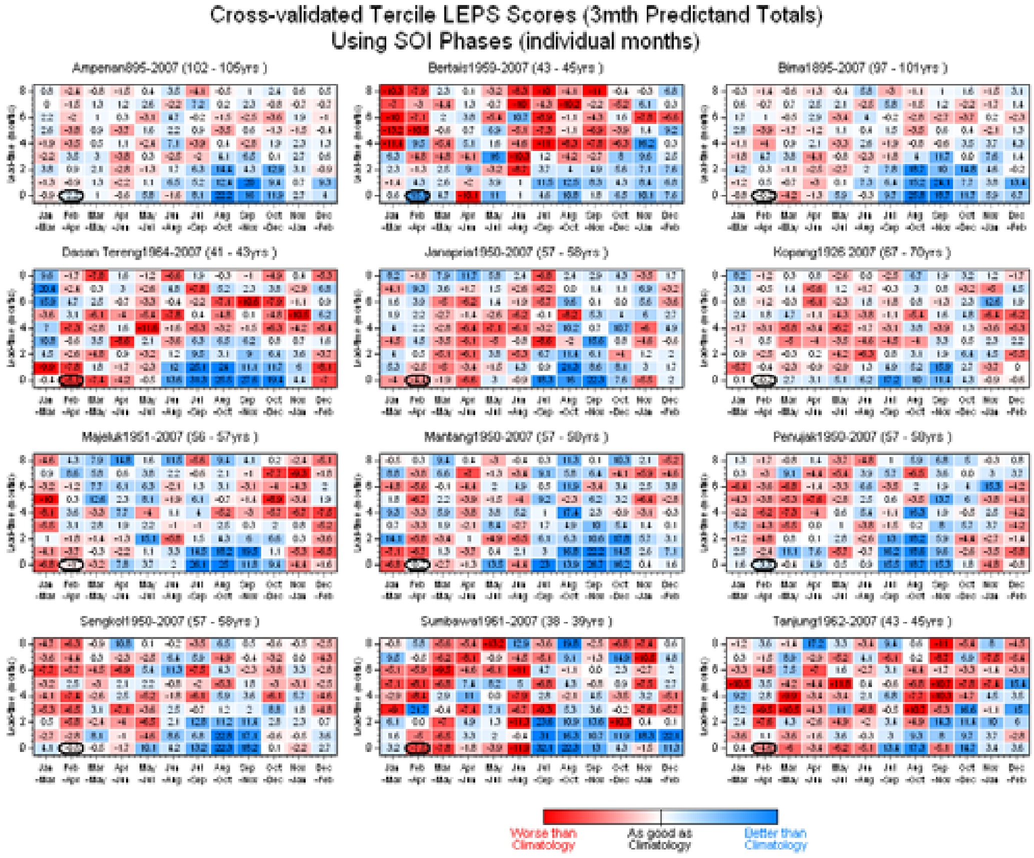

Tercile LEPS skill-score for Predictands (9mth Totals)
using SSTa's 1 and 12 (0 mths lead)
Default Cross-validation using all available data
Jan-Sep n = 60 avg = 1.9
Feb-Oct n = 60 avg = -0.79
Mar-Nov n = 60 avg = -0.8
Apr-Dec n = 60 avg = -0.67
May-Jan n = 60 avg = 2
Jun-Feb n = 60 avg = 5.4
Jul-Mar n = 60 avg = 5.7
Aug-Apr n = 60 avg = 5.9
Sep-May n = 60 avg = 5.2
Oct-Jun n = 60 avg = 4.8
Nov-Jul n = 60 avg = 4.1
Dec-Aug n = 60 avg = 4.5
Tercile LEPS skill-score
-30
0
40

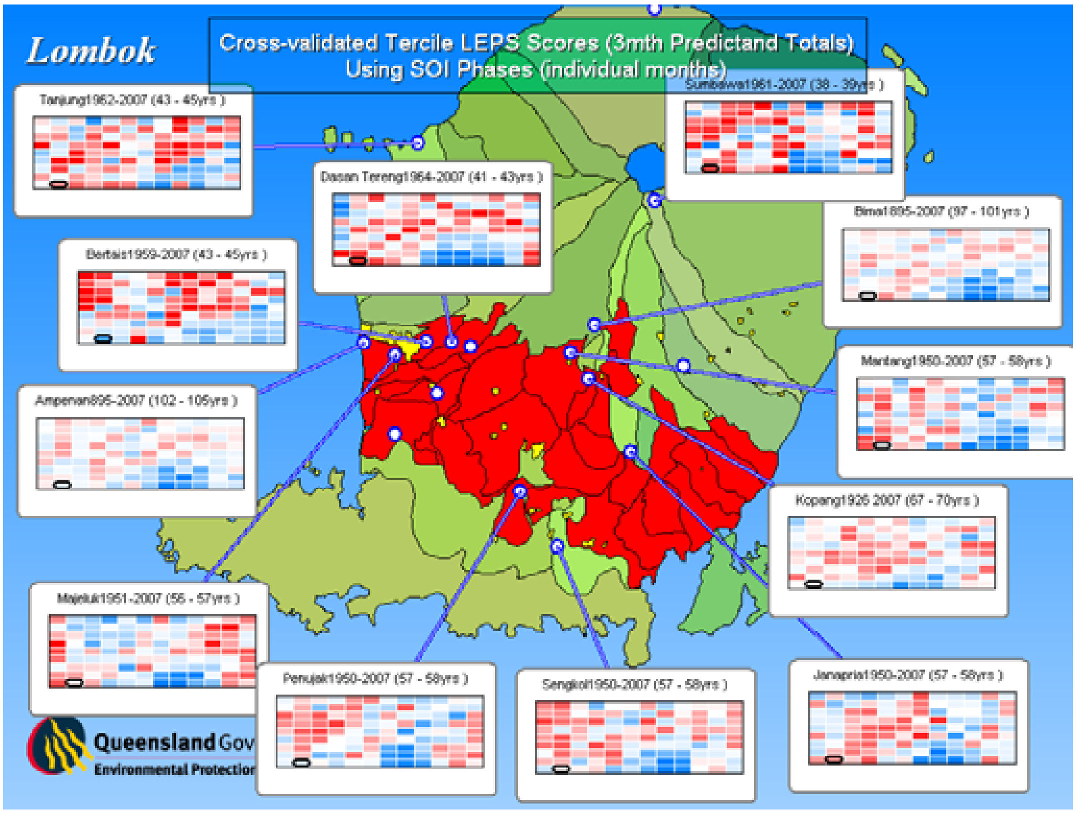

Tercile LEPS skill-score for Predictands (3mth Totals)
using NINO3.4 SST Anomalies (0 mths lead)
Default Cross-validation using all available data
Jan-Mar n = 60 avg = 2.4
Feb-Apr n = 60 avg = 2.4
Mar-May n = 60 avg = 1.6
Apr-Jun n = 60 avg = 0.1
May-Jul n = 60 avg = 0.78
Jun-Aug n = 60 avg = 6
Jul-Sep n = 60 avg = 18.3
Aug-Oct n = 60 avg = 22
Sep-Nov n = 60 avg = 18.7
Oct-Dec n = 60 avg = 11.7
Nov-Jan n = 60 avg = 5.9
Dec-Feb n = 60 avg = 2.3

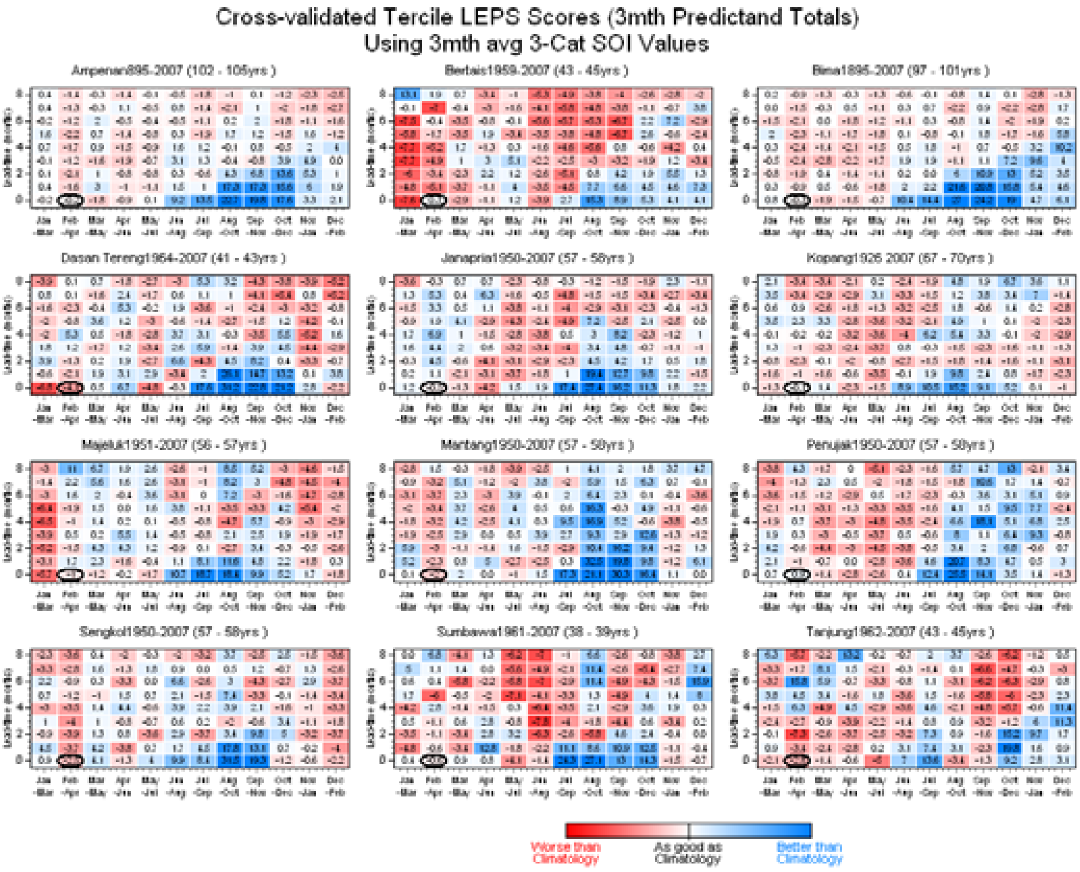

Tercile LEPS skill-score for Predictands (6mth Totals)
using NINO3.4 SST Anomalies (0 mths lead)
Default Cross-validation using all available data
Jan-Jun n = 60 avg = 2.8
Feb-Jul n = 60 avg = 1.4
Mar-Aug n = 60 avg = 0.36
Apr-Sep n = 60 avg = -0.15
May-Oct n = 60 avg = 2.1
Jun-Nov n = 60 avg = 10.6
Jul-Dec n = 60 avg = 16
Aug-Jan n = 60 avg = 15.3
Sep-Feb n = 60 avg = 10.1
Oct-Mar n = 60 avg = 6.1
Nov-Apr n = 60 avg = 3.3
Dec-May n = 60 avg = 2.8

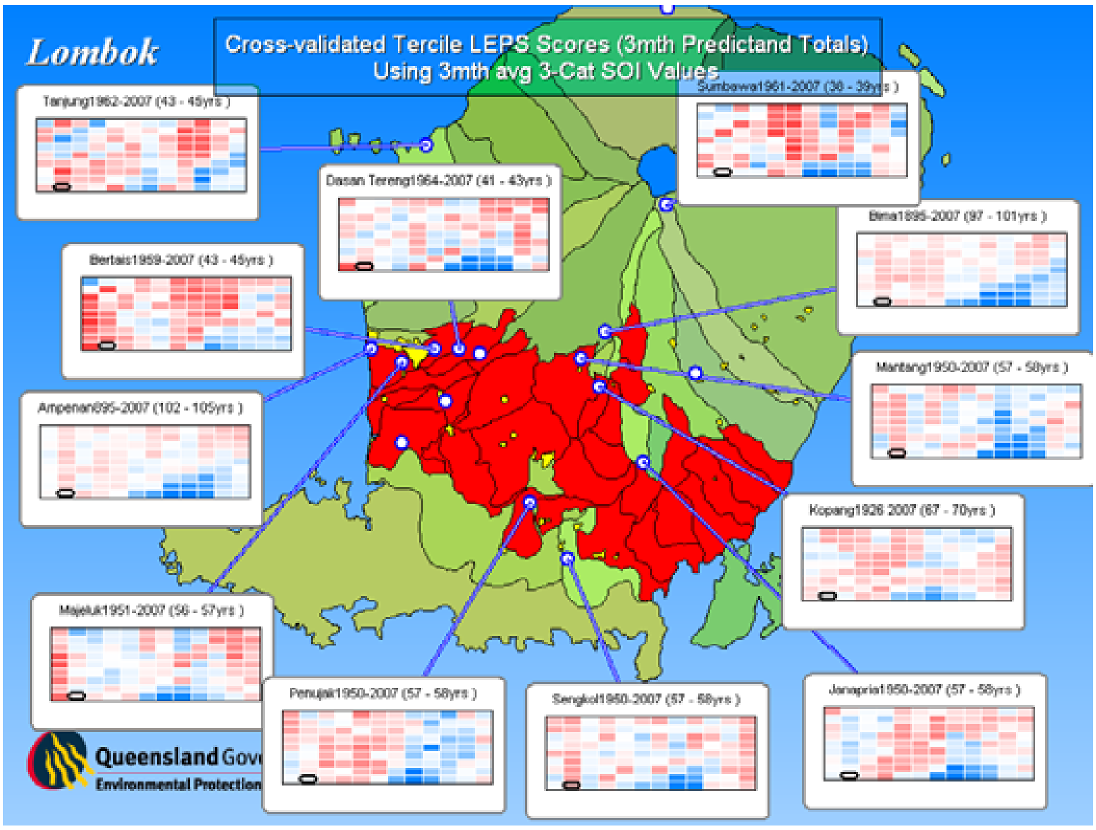

Tercile LEPS skill-score for Predictands (9mth Totals)
using NINO3.4 SST Anomalies (0 mths lead)
Default Cross-validation using all available data
Jan-Sep n = 60 avg = 1.5
Feb-Oct n = 60 avg = 0.35
Mar-Nov n = 60 avg = 0.0025
Apr-Dec n = 60 avg = -0.35
May-Jan n = 60 avg = 1.5
Jun-Feb n = 60 avg = 6.2
Jul-Mar n = 60 avg = 9.1
Aug-Apr n = 60 avg = 8.3
Sep-May n = 60 avg = 6.4
Oct-Jun n = 60 avg = 3.8
Nov-Jul n = 60 avg = 2.6
Dec-Aug n = 60 avg = 2.1
Tercile LEPS skill-score
-30
0
40

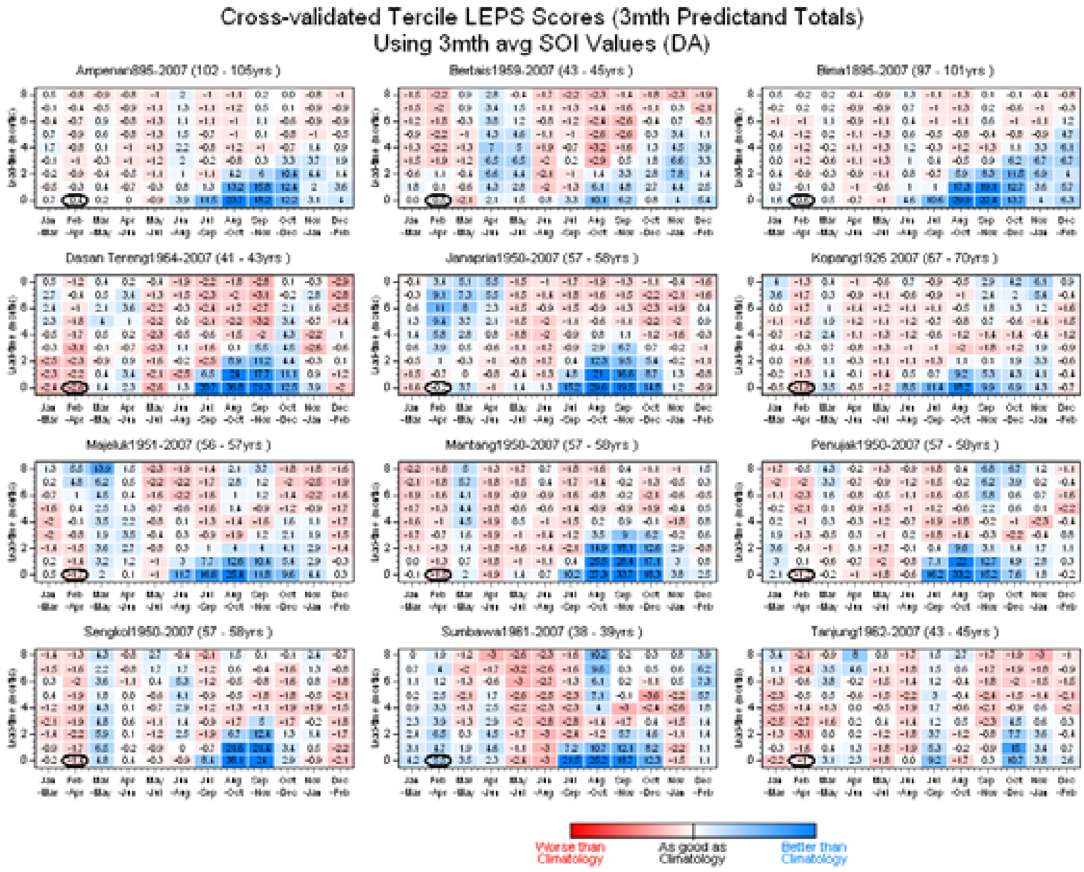
10.4 Appendix 4: Skill score assessment for Lombok rainfall

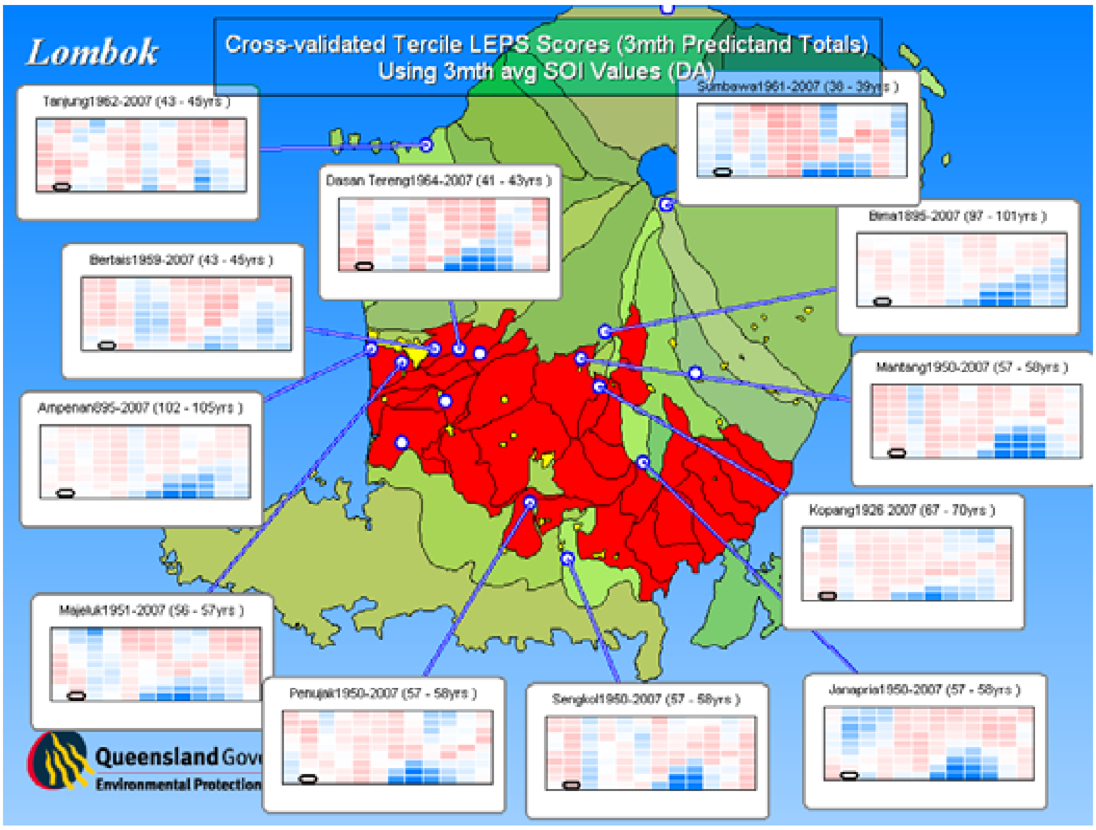


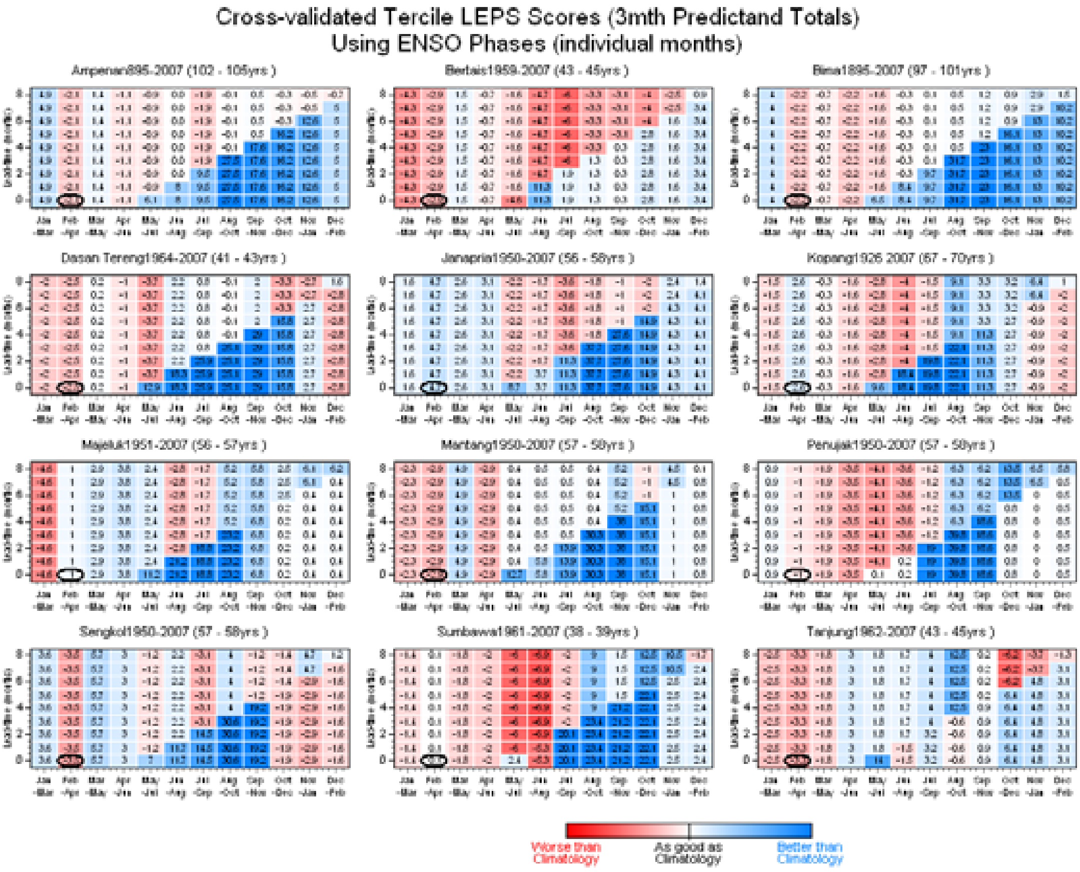


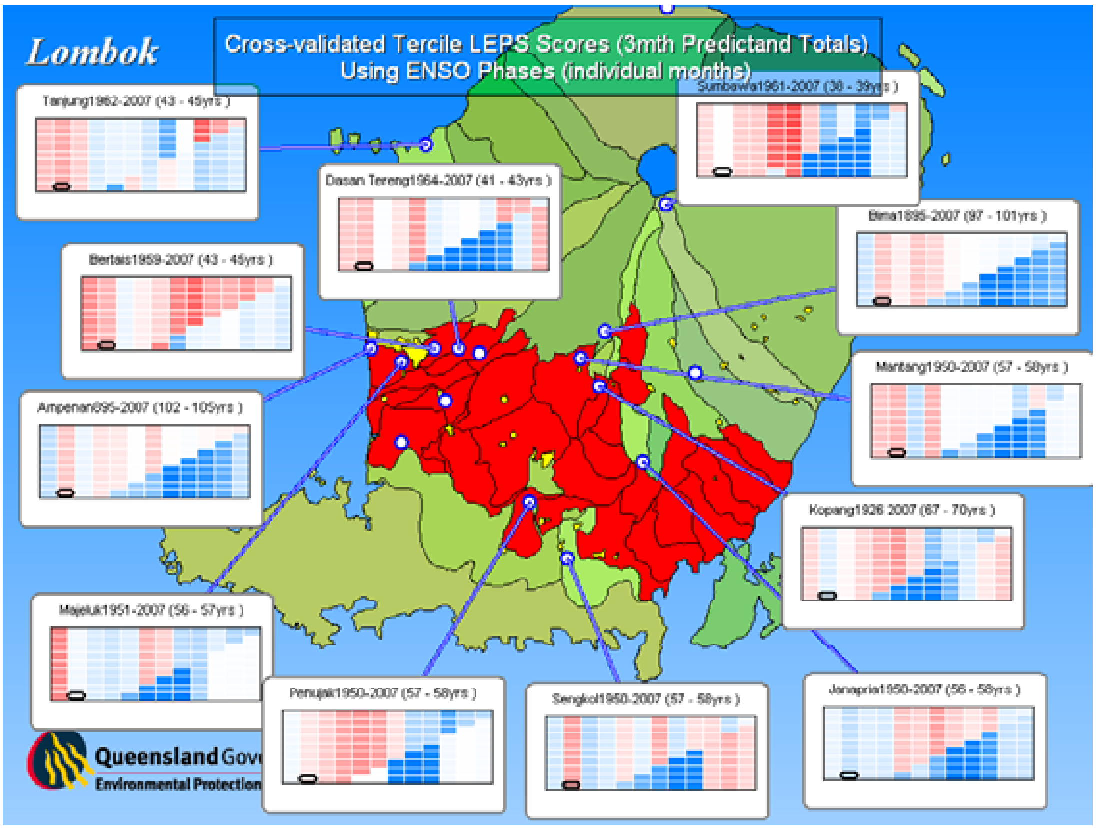

Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 3mth avg 3-Cat SOI Values
Ampenan895-2007 (102 - 105yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (97 - 101yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Janapria1950-2007 (57 - 58yrs)
Kopang1926 2007 (67 - 70yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology

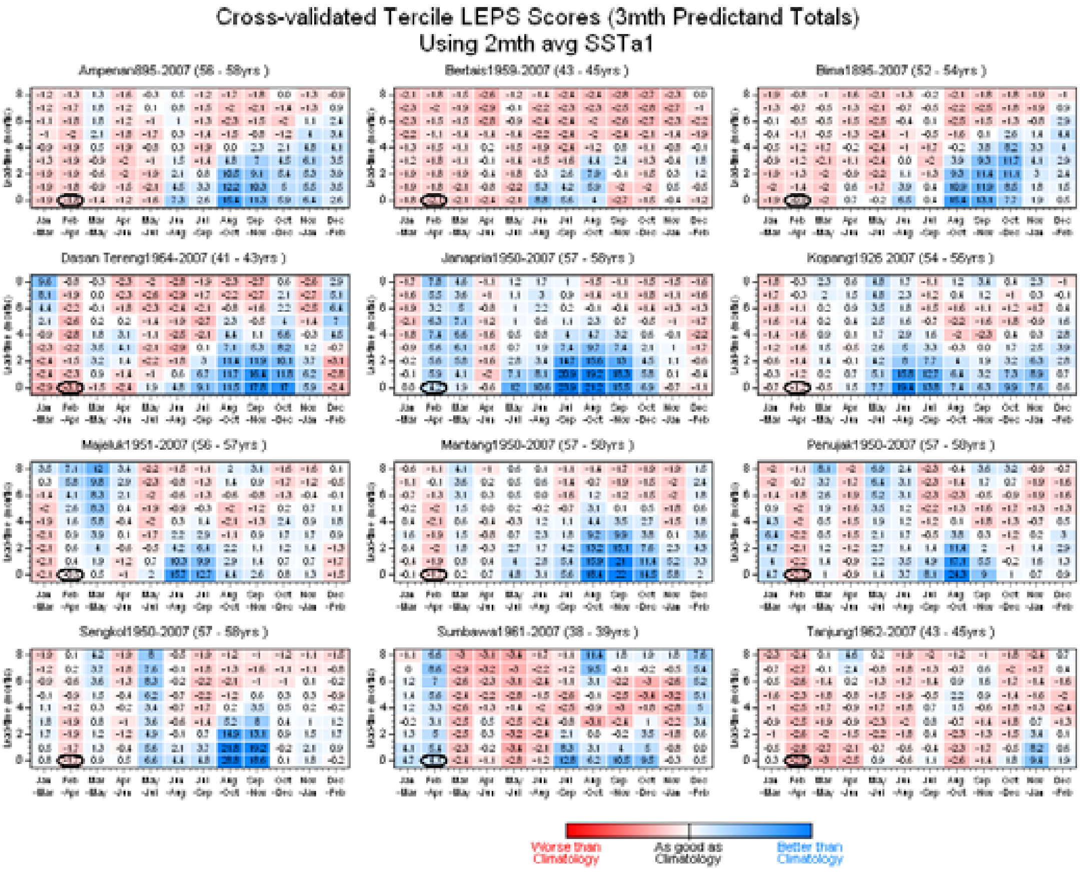

Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 3mth avg 3-Cat SOI Values
Tanjung1962-2007 (43 - 45yrs)
Sumbawa1961-2007 (38 - 39yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Bima1895-2007 (97 - 101yrs)
Bertais1959-2007 (43 - 45yrs)
Mantang1950-2007 (57 - 58yrs)
Ampenan895-2007 (102 - 105yrs)
Kopang1926 2007 (67 - 70yrs)
Majeluk1951-2007 (56 - 57yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (57 - 58yrs)
Queensland Gov
Environmental Protection

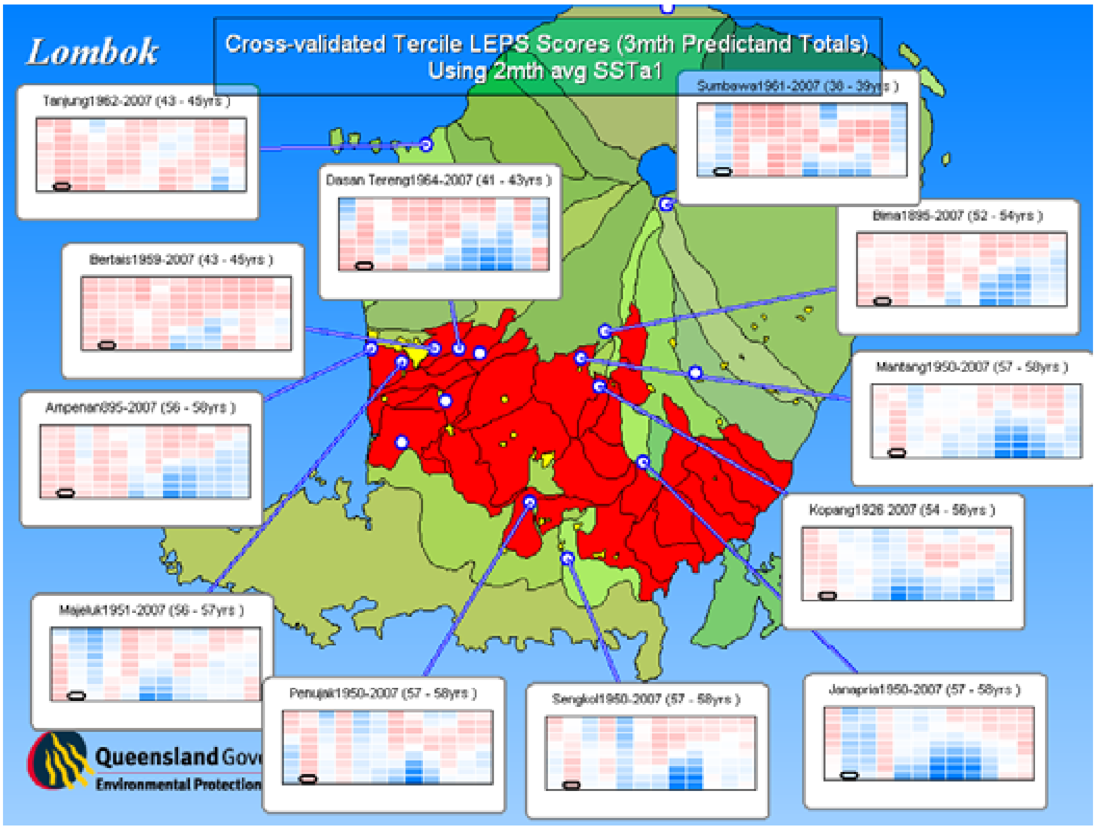

Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 3mth avg SOI Values (DA)
Ampenan895-2007 (102 - 105yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (97 - 101yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Janapria1950-2007 (57 - 58yrs)
Kopang1926 2007 (67 - 70yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology

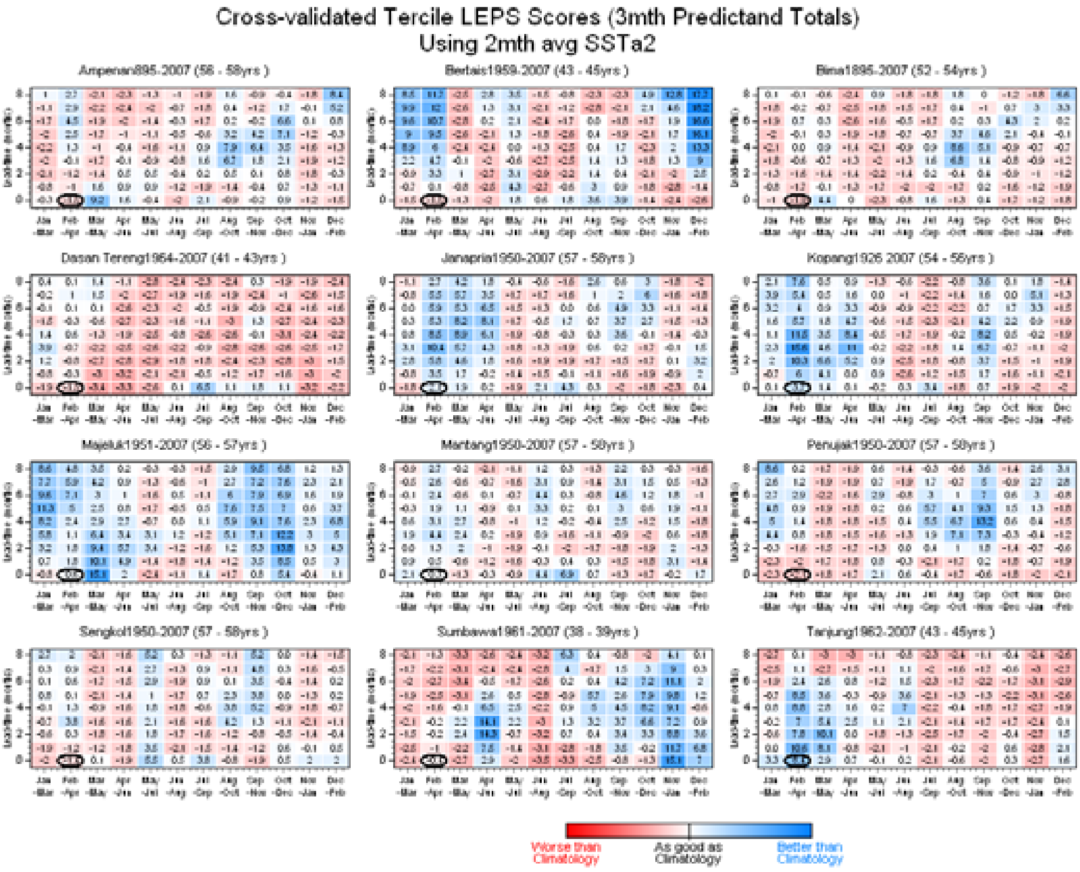

Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 3mth avg SOI Values (DA)
Tanjung1962-2007 (43 - 45yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Sumbawa1961-2007 (38 - 39yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (97 - 101yrs)
Ampenan895-2007 (102 - 105yrs)
Mantang1950-2007 (57 - 58yrs)
Kopang1926 2007 (67 - 70yrs)
Majeluk1951-2007 (56 - 57yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (57 - 58yrs)
Queensland Gov
Environmental Protection

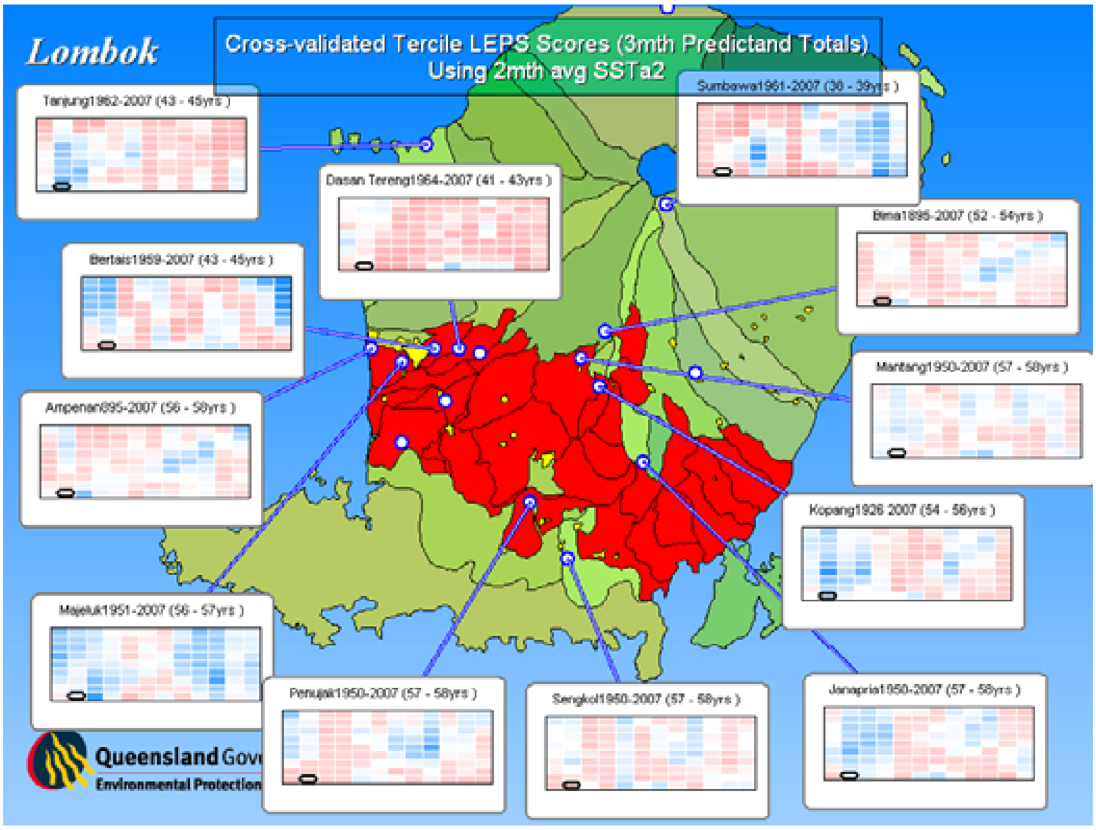

Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using ENSO Phases (individual months)
Ampenan895-2007 (102 - 105yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (97 - 101yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Janapria1950-2007 (56 - 58yrs)
Kopang1926 2007 (67 - 70yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology


Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using ENSO Phases (individual months)
Tanjung1962-2007 (43 - 45yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Sumbawa1961-2007 (38 - 39yrs)
Bima1895-2007 (97 - 101yrs)
Bertais1959-2007 (43 - 45yrs)
Ampenan895-2007 (102 - 105yrs)
Mantang1950-2007 (57 - 58yrs)
Kopang1926 2007 (67 - 70yrs)
Majeluk1951-2007 (56 - 57yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (56 - 58yrs)
Queensland Gov
Environmental Protection


Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa1
Ampenan895-2007 (56 - 58yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (52 - 54yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Janapria1950-2007 (57 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology


Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa1
Tanjung1962-2007 (43 - 45yrs)
Sumbawa1961-2007 (38 - 39yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Bima1895-2007 (52 - 54yrs)
Bertais1959-2007 (43 - 45yrs)
Ampenan895-2007 (56 - 58yrs)
Mantang1950-2007 (57 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (57 - 58yrs)


Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa2
Ampenan895-2007 (56 - 58yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (52 - 54yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Janapria1950-2007 (57 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology


Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa2
Tanjung1962-2007 (43 - 45yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Sumbawa1961-2007 (38 - 39yrs)
Bima1895-2007 (52 - 54yrs)
Bertais1959-2007 (43 - 45yrs)
Mantang1950-2007 (57 - 58yrs)
Ampenan895-2007 (56 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
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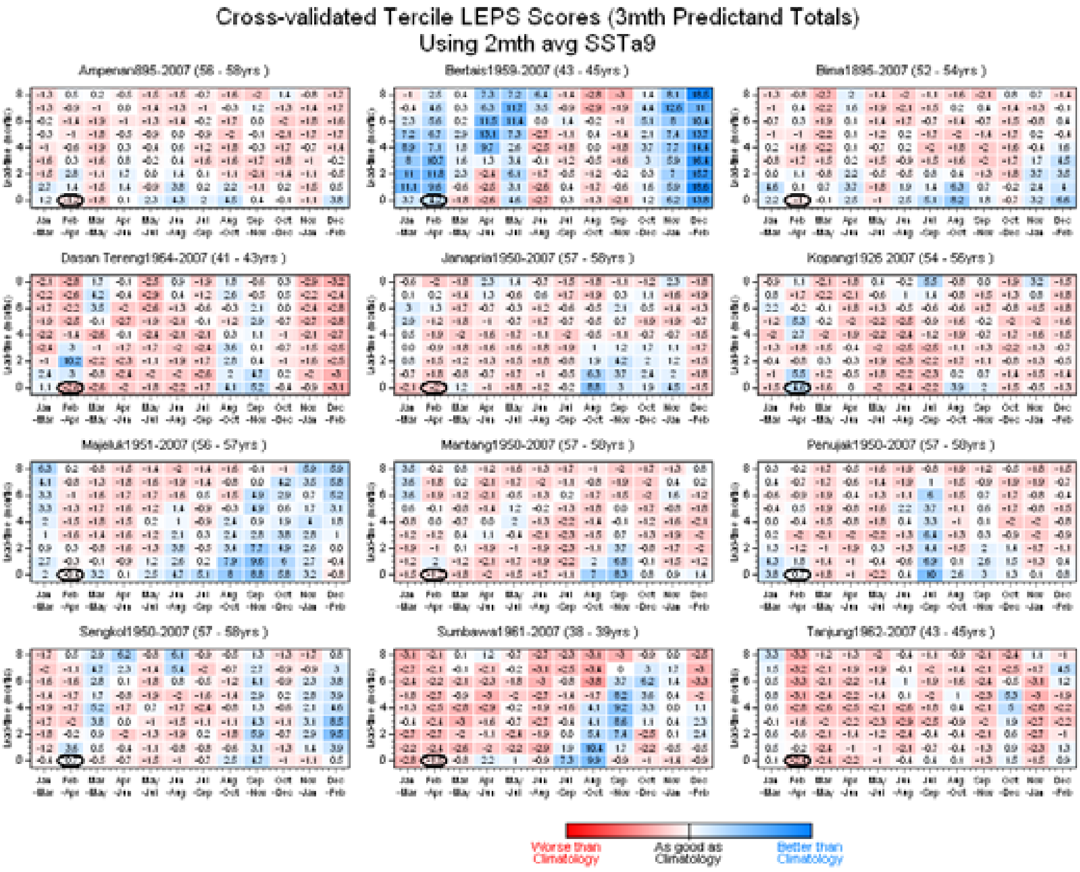
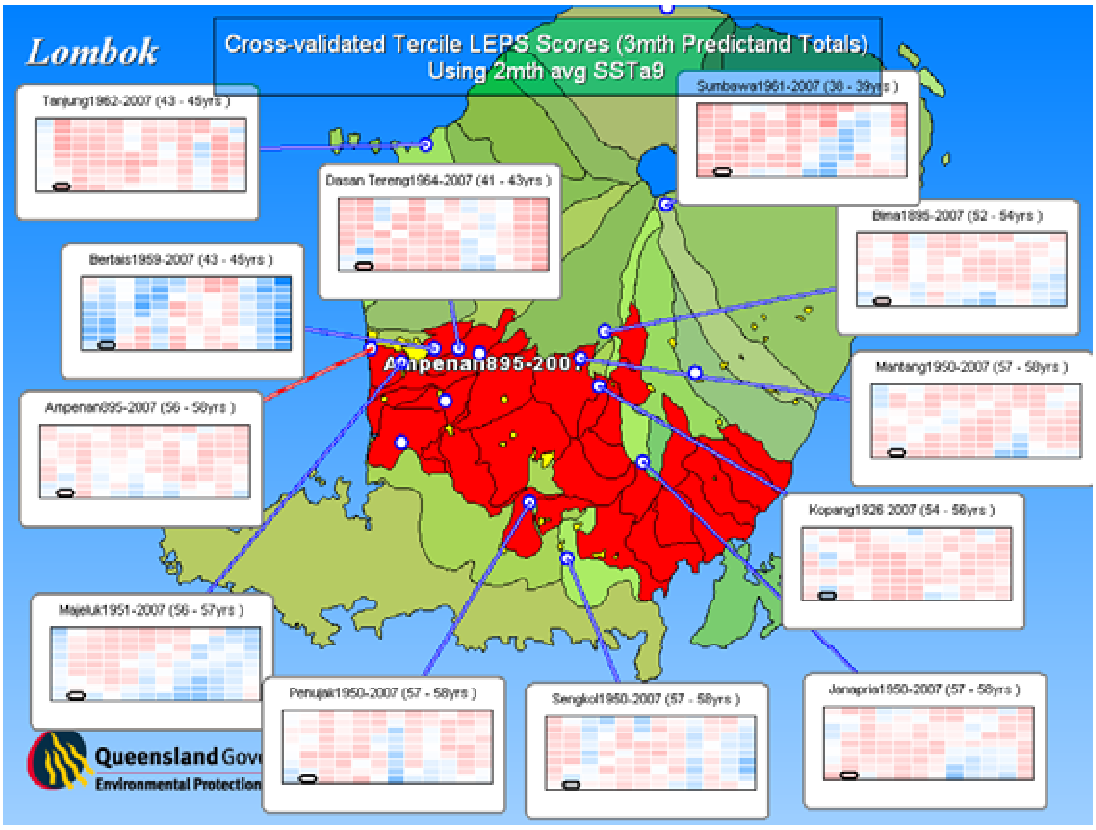
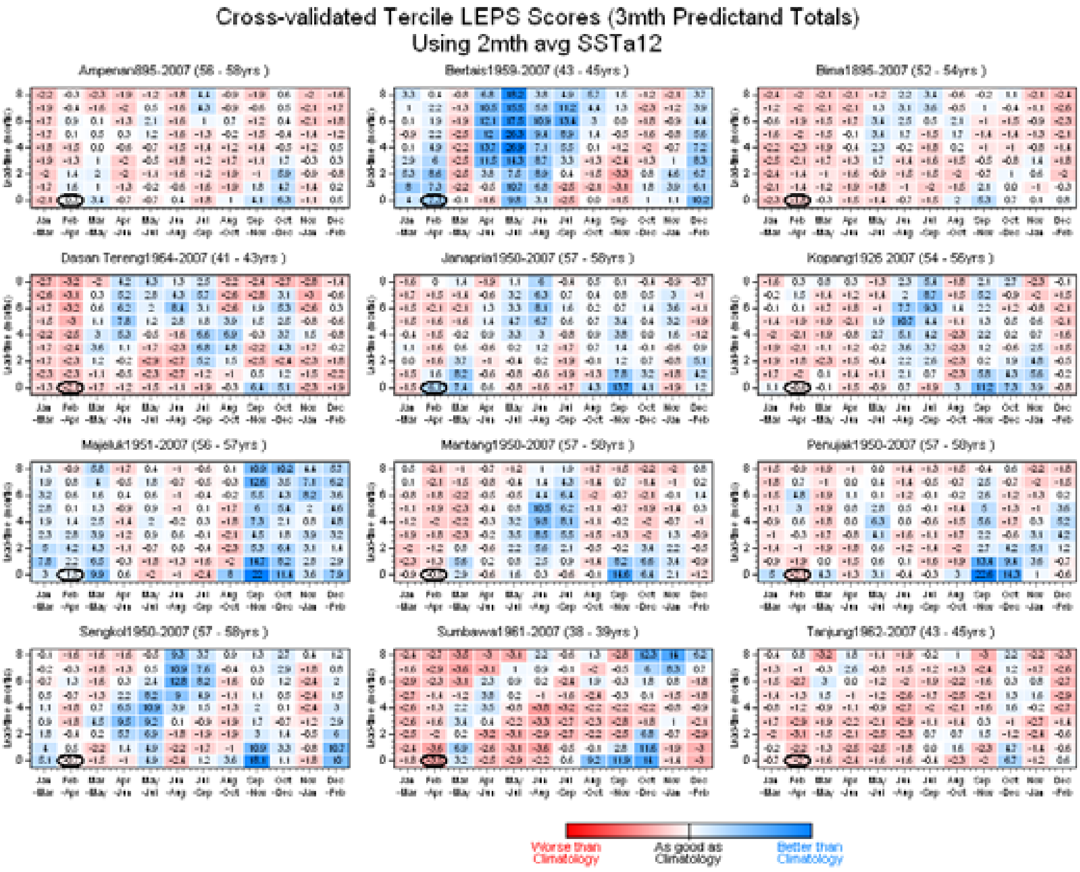
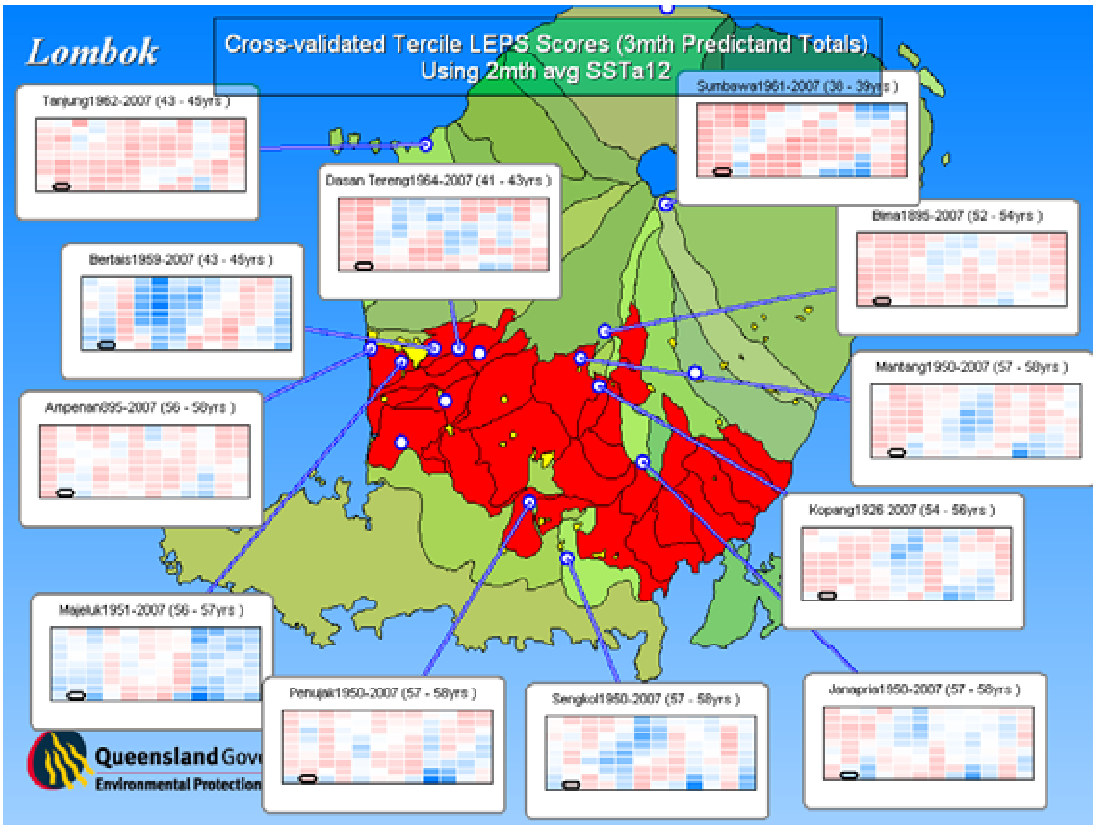
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (57 - 58yrs)
Queensland Gov
Environmental Protection


Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa9
Ampenan895-2007 (56 - 58yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (52 - 54yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Janapria1950-2007 (57 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology

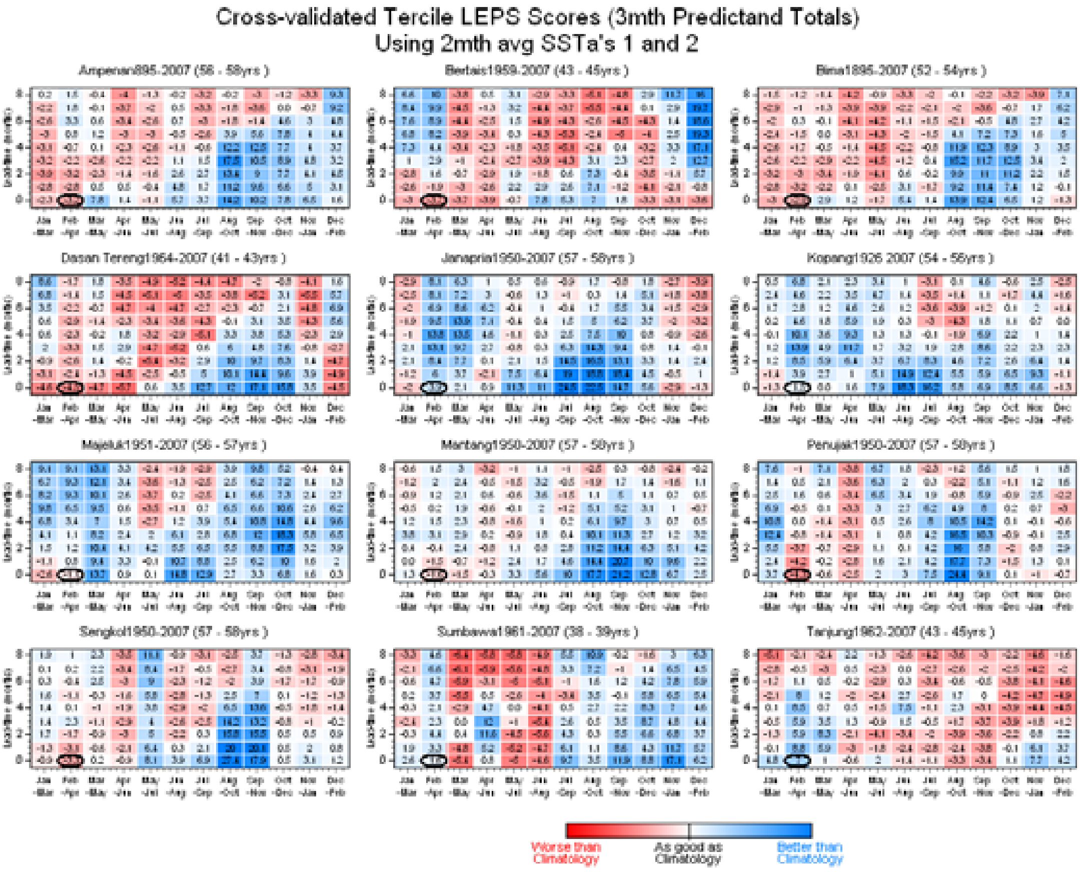

Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa9
Tanjung1962-2007 (43 - 45yrs)
Sumbawa1961-2007 (38 - 39yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Bima1895-2007 (52 - 54yrs)
Bertais1959-2007 (43 - 45yrs)
Ampenan895-200
Mantang1950-2007 (57 - 58yrs)
Ampenan895-2007 (56 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (57 - 58yrs)

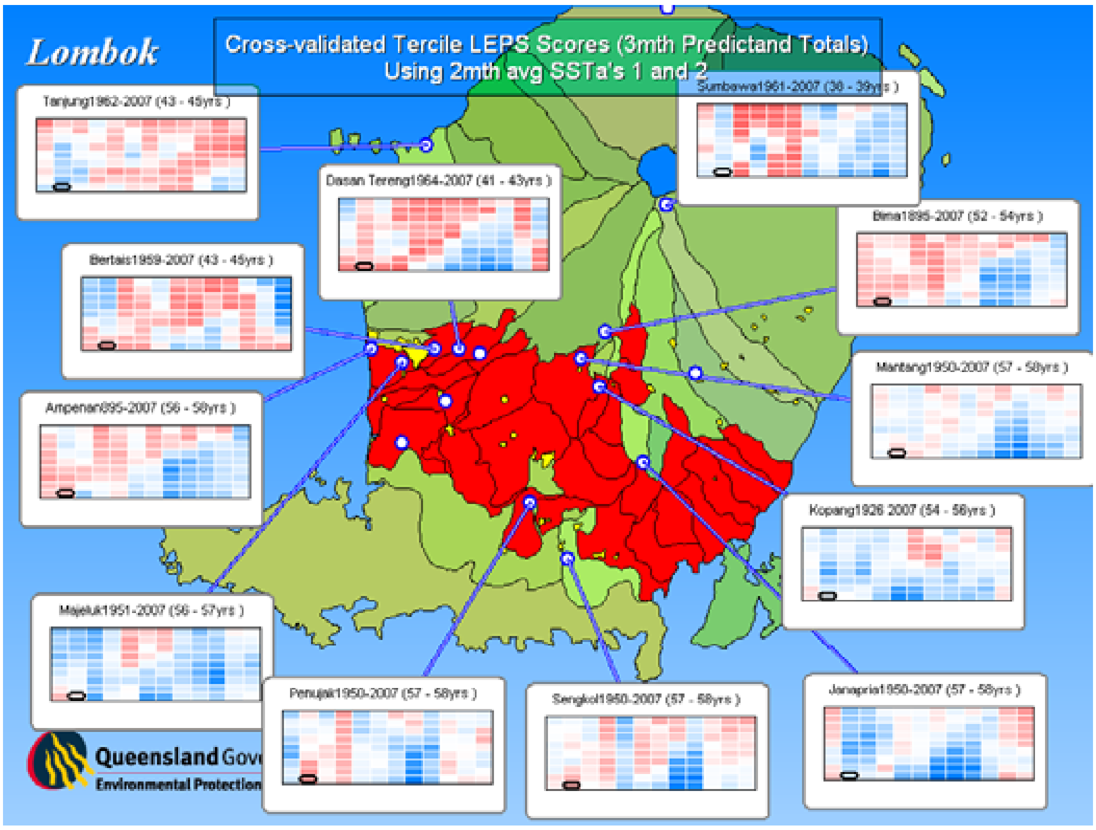


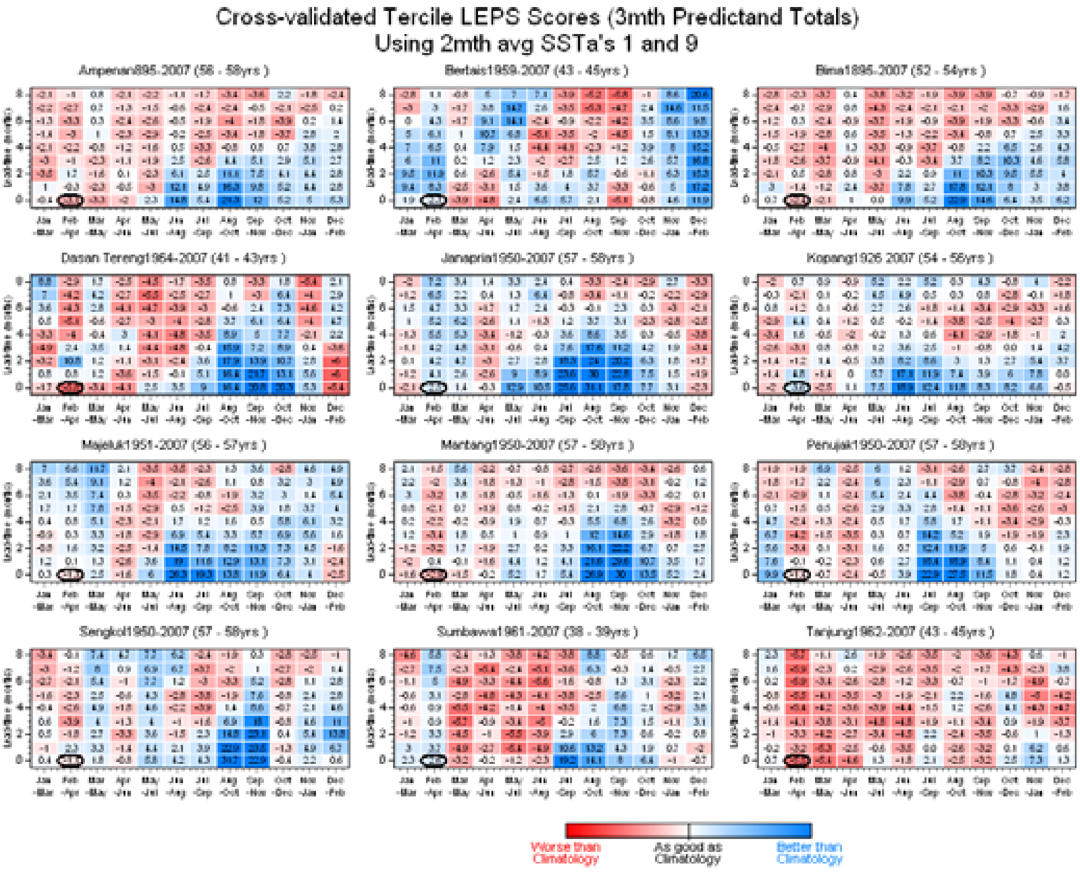
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa12
Ampenan895-2007 (56 - 58yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (52 - 54yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Janapria1950-2007 (57 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology

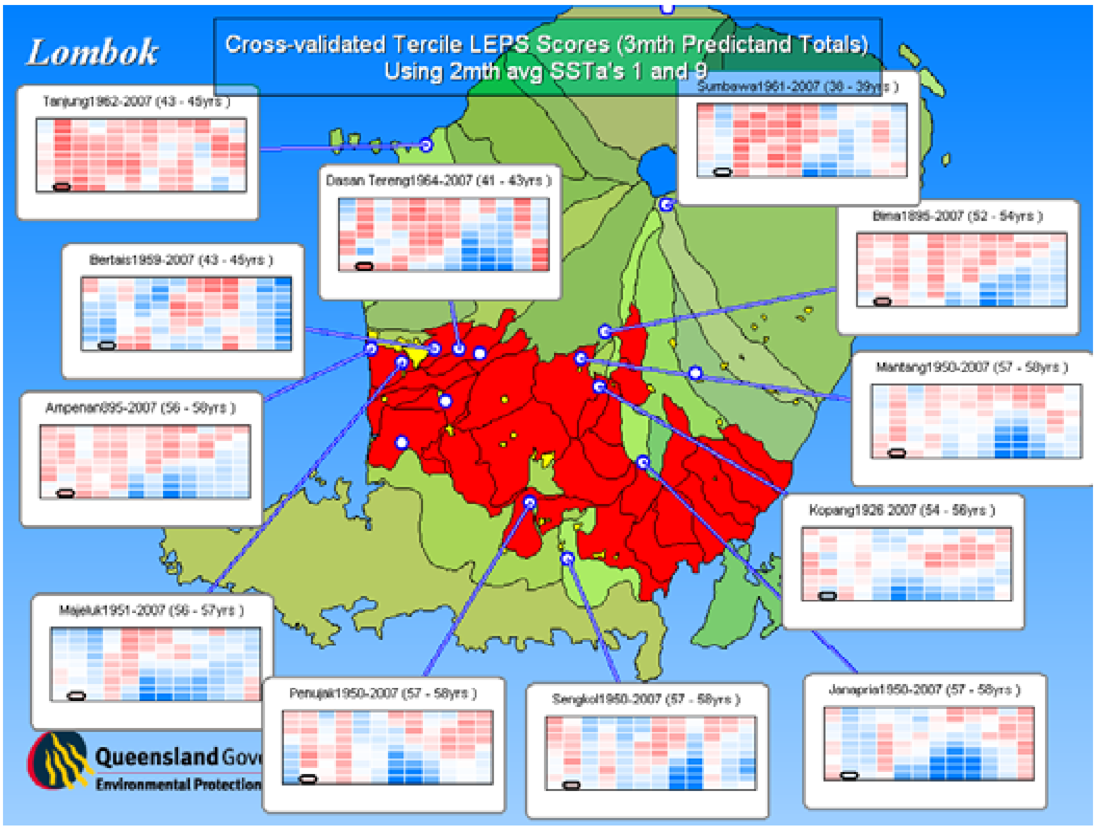


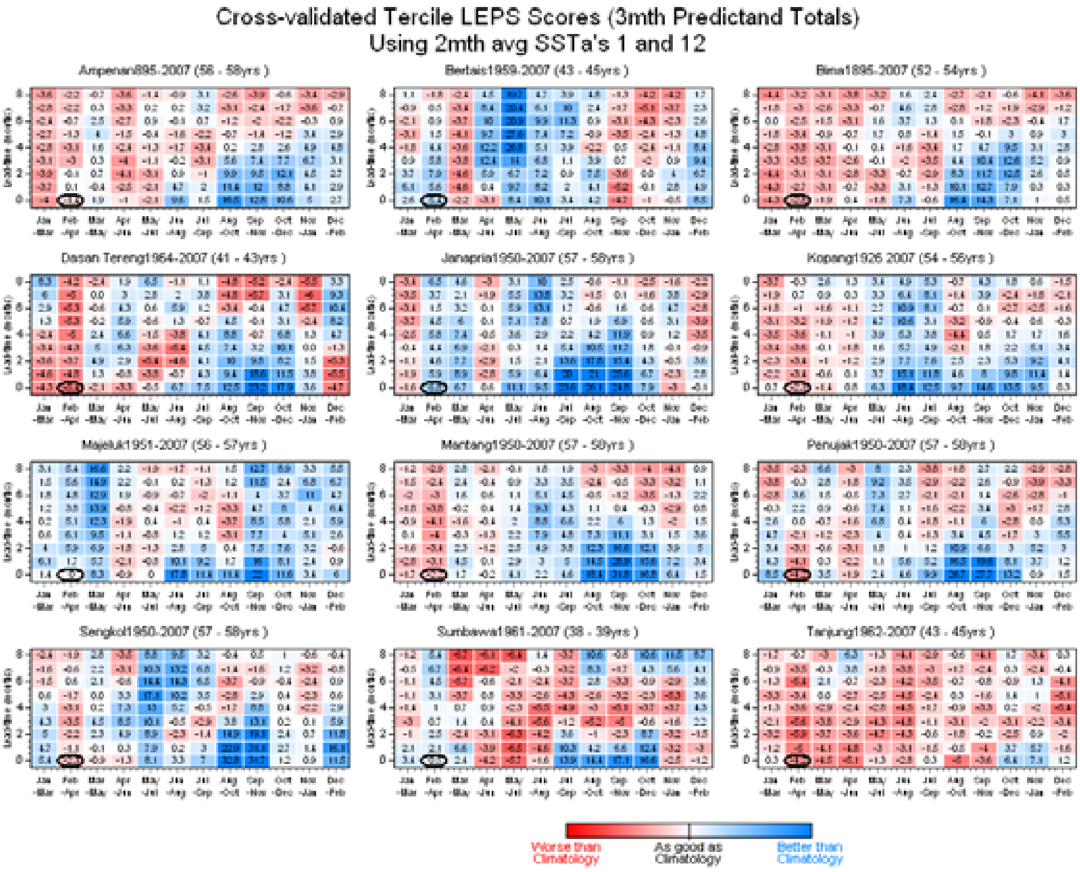
Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa12
Tanjung1962-2007 (43 - 45yrs)
Sumbawa1961-2007 (38 - 39yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Bima1895-2007 (52 - 54yrs)
Bertais1959-2007 (43 - 45yrs)
Mantang1950-2007 (57 - 58yrs)
Ampenan895-2007 (56 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (57 - 58yrs)

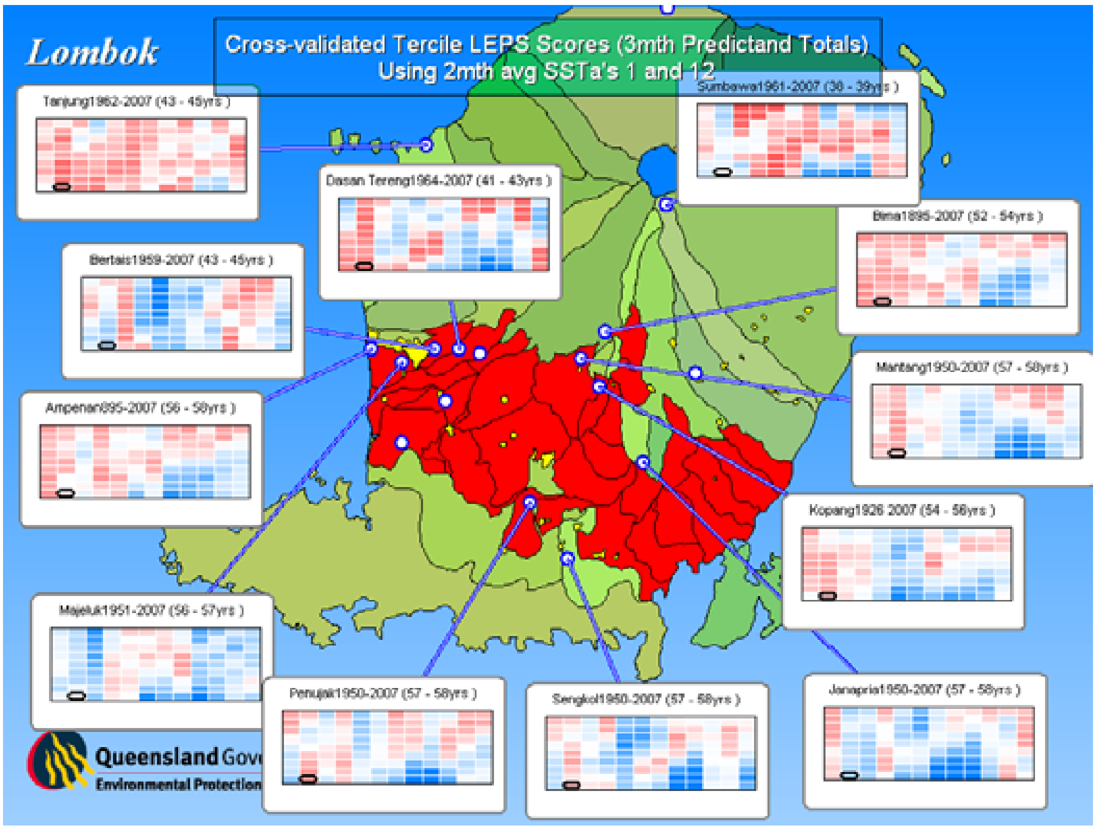

Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa's 1 and 2
Ampenan895-2007 (56 - 58yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (52 - 54yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Janapria1950-2007 (57 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology

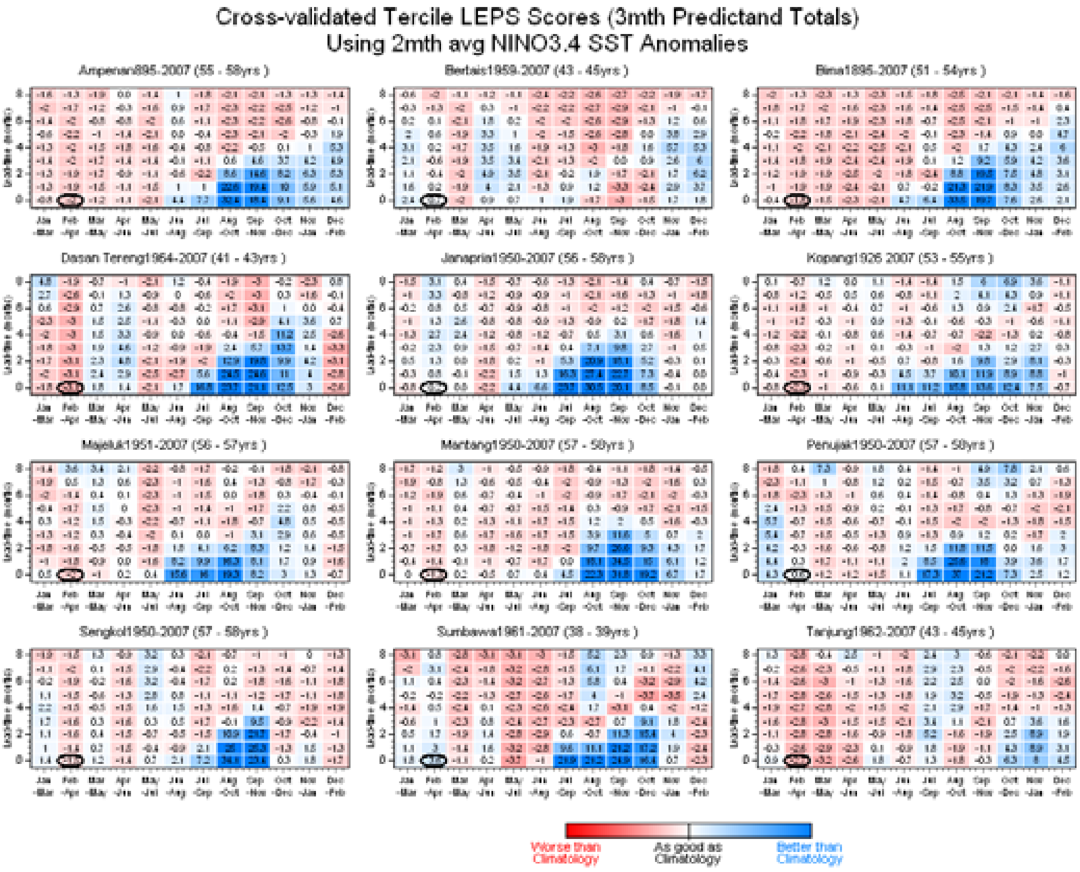

Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa's 1 and 2
Tanjung1962-2007 (43 - 45yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Sumbawa1961-2007 (38 - 39yrs)
Bima1895-2007 (52 - 54yrs)
Bertais1959-2007 (43 - 45yrs)
Ampenan895-2007 (56 - 58yrs)
Mantang1950-2007 (57 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (57 - 58yrs)
Queensland
Environmental Protection

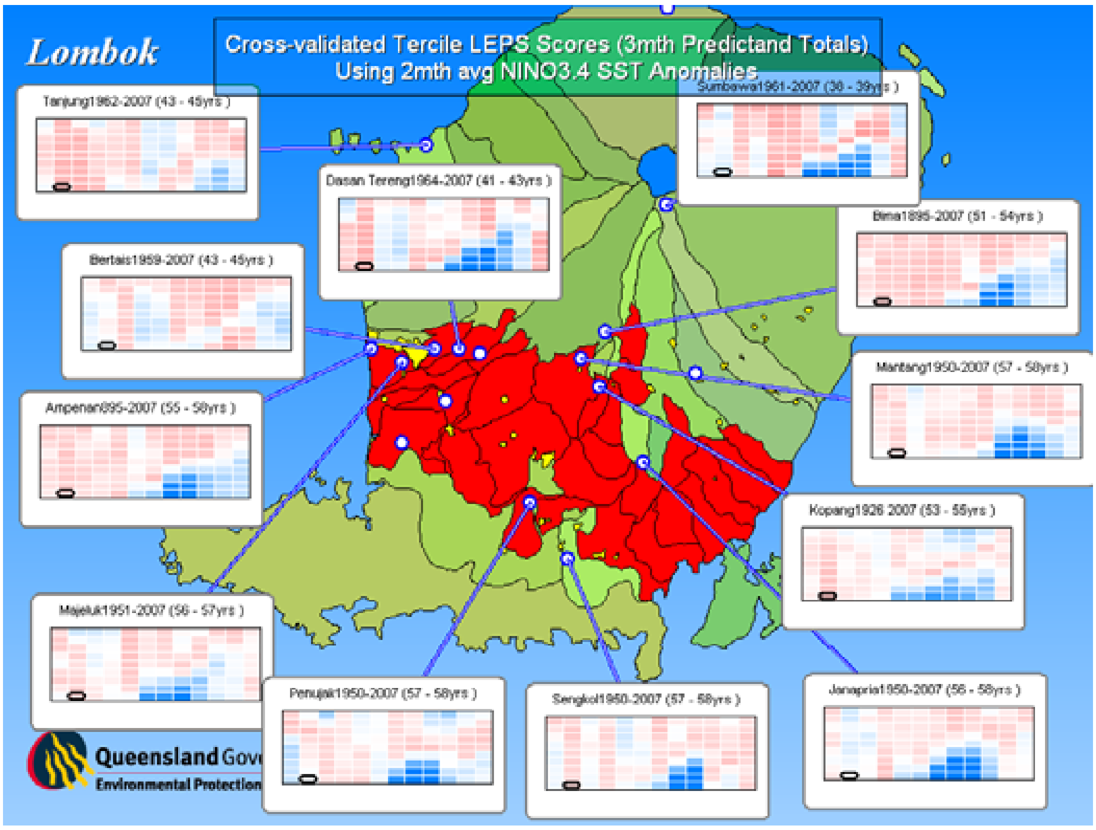

Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa's 1 and 9
Ampenan1895-2007 (56 - 58yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (52 - 54yrs)
Dasan Terengi1964-2007 (41 - 43yrs)
Janapria1950-2007 (57 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology


Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa's 1 and 9
Tanjung1962-2007 (43 - 45yrs)
Sumbawa1961-2007 (38 - 39yrs)
Dasan Terengi1964-2007 (41 - 43yrs)
Bima1895-2007 (52 - 54yrs)
Bertais1959-2007 (43 - 45yrs)
Mantang1950-2007 (57 - 58yrs)
Ampenan1895-2007 (56 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (57 - 58yrs)
Queensland Gov
Environmental Protection


Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa's 1 and 12
Ampenan895-2007 (56 - 58yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (52 - 54yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Janapria1950-2007 (57 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology

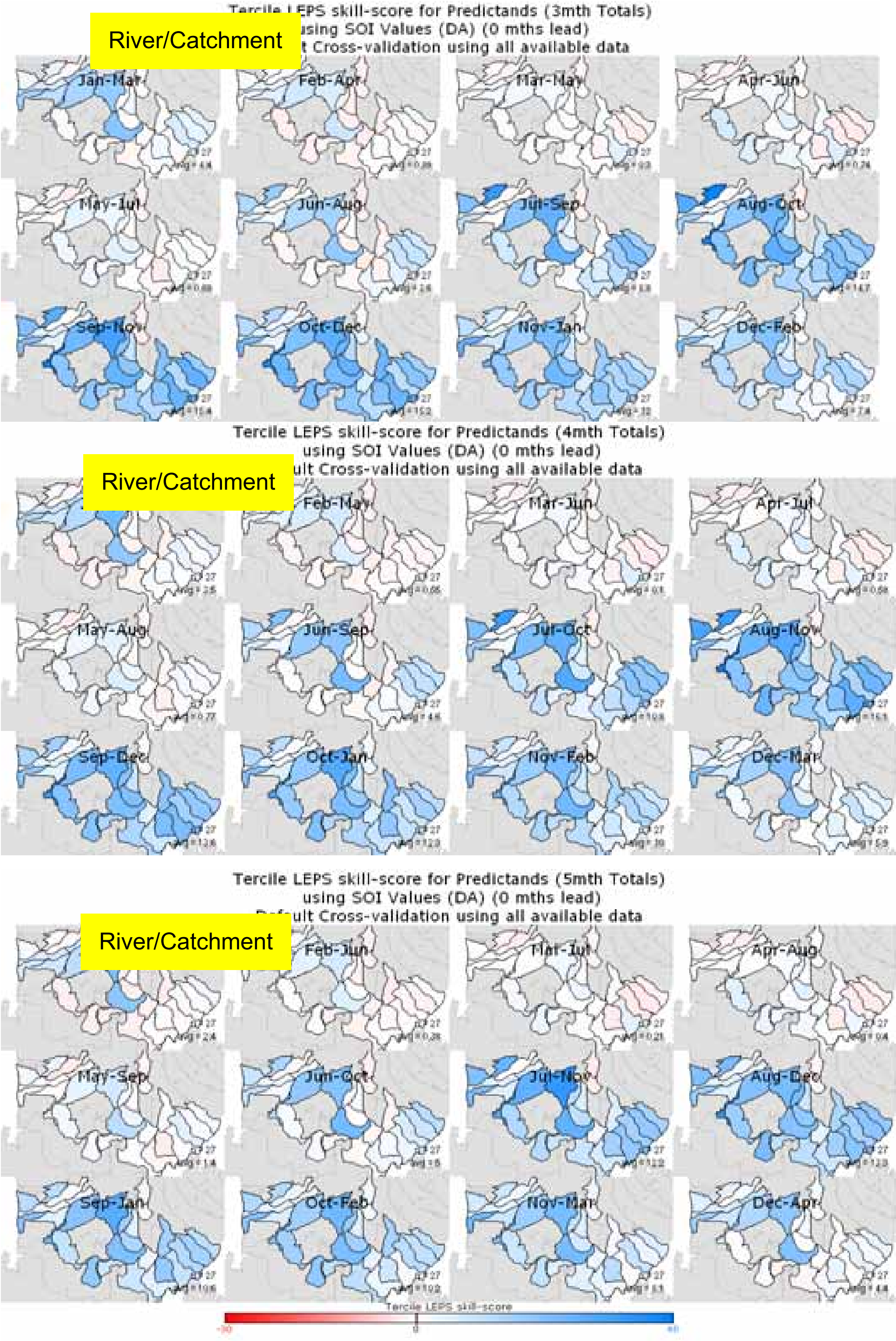

Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg SSTa's 1 and 12
Tanjung1962-2007 (43 - 45yrs)
Sumbawa1961-2007 (38 - 39yrs)
Dasan Tereng1964-2007 (41 - 43yrs)
Bima1895-2007 (52 - 54yrs)
Bertais1959-2007 (43 - 45yrs)
Mantang1950-2007 (57 - 58yrs)
Ampenan895-2007 (56 - 58yrs)
Kopang1926 2007 (54 - 56yrs)
Majeluk1951-2007 (56 - 57yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (57 - 58yrs)
Queensland Gov
Environmental Protection

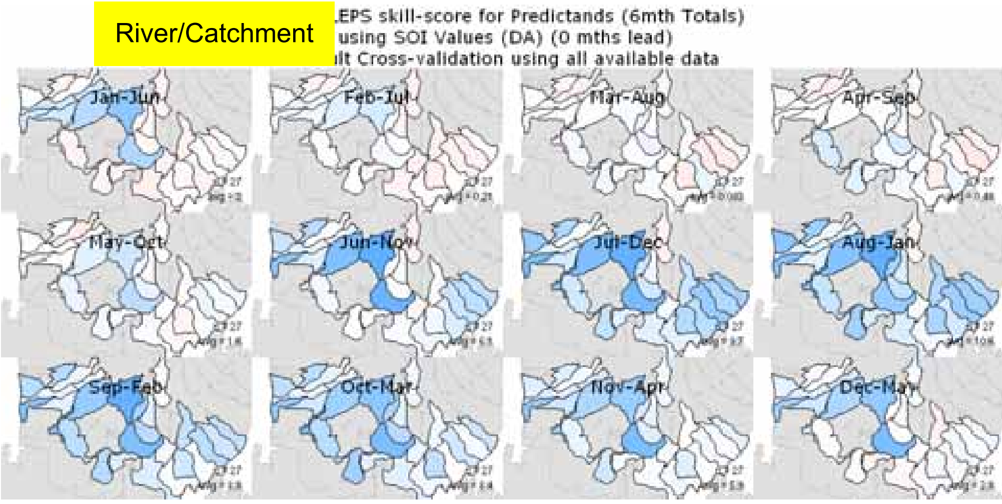

Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg NINO3.4 SST Anomalies
Ampenan895-2007 (55 - 58yrs)
Bertais1959-2007 (43 - 45yrs)
Bima1895-2007 (51 - 54yrs)
Dasan Terengi1964-2007 (41 - 43yrs)
Janapria1950-2007 (56 - 58yrs)
Kopang1926 2007 (53 - 55yrs)
Majeluk1951-2007 (56 - 57yrs)
Mantang1950-2007 (57 - 58yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Sumbawa1961-2007 (38 - 39yrs)
Tanjung1962-2007 (43 - 45yrs)
Worse than Climatology
As good as Climatology
Better than Climatology

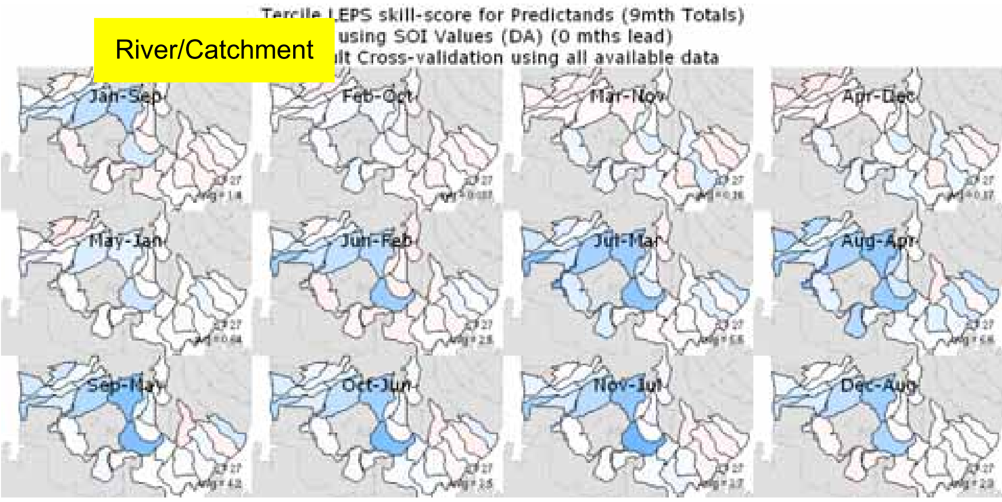

Lombok
Cross-validated Tercile LEPS Scores (3mth Predictand Totals)
Using 2mth avg NINO3.4 SST Anomalies
Tanjung1962-2007 (43 - 45yrs)
Dasan Terengi1964-2007 (41 - 43yrs)
Sumbawa1961-2007 (38 - 39yrs)
Bima1895-2007 (51 - 54yrs)
Bertais1959-2007 (43 - 45yrs)
Ampenan895-2007 (55 - 58yrs)
Mantang1950-2007 (57 - 58yrs)
Kopang1926 2007 (53 - 55yrs)
Majeluk1951-2007 (56 - 57yrs)
Penujak1950-2007 (57 - 58yrs)
Sengkol1950-2007 (57 - 58yrs)
Janapria1950-2007 (56 - 58yrs)

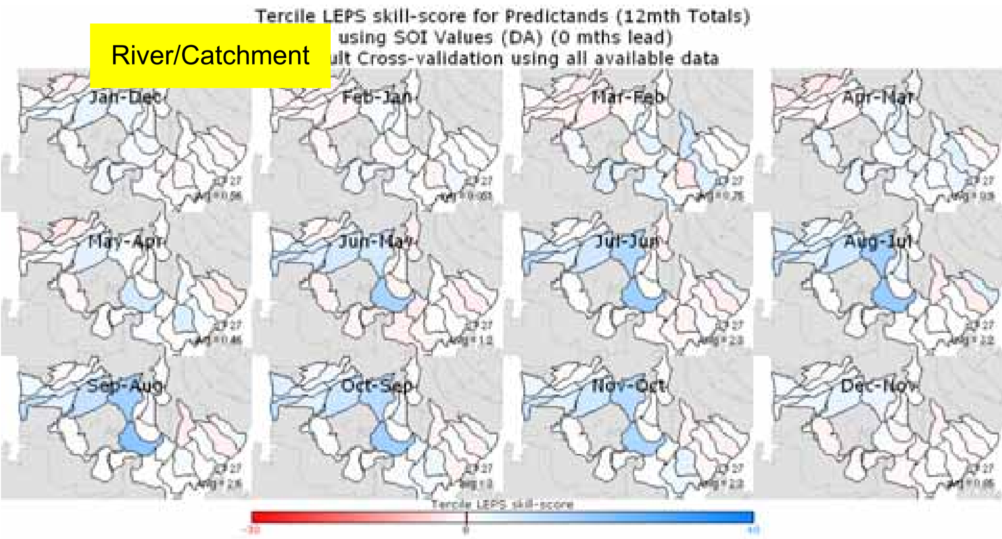
10.5 Appendix 5: Skill assessment of the catchment river inflows and irrigation diversions

10.5.1 Spatial skill assessment of catchment river inflows

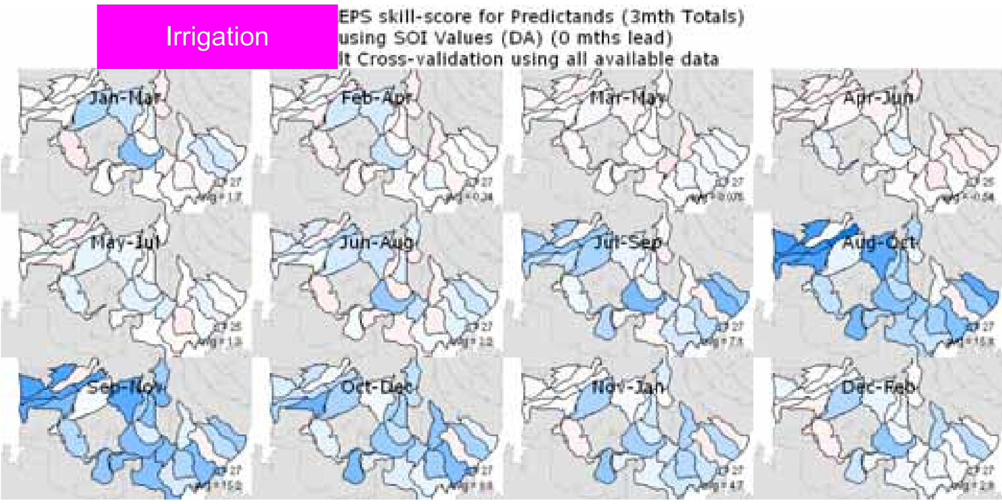


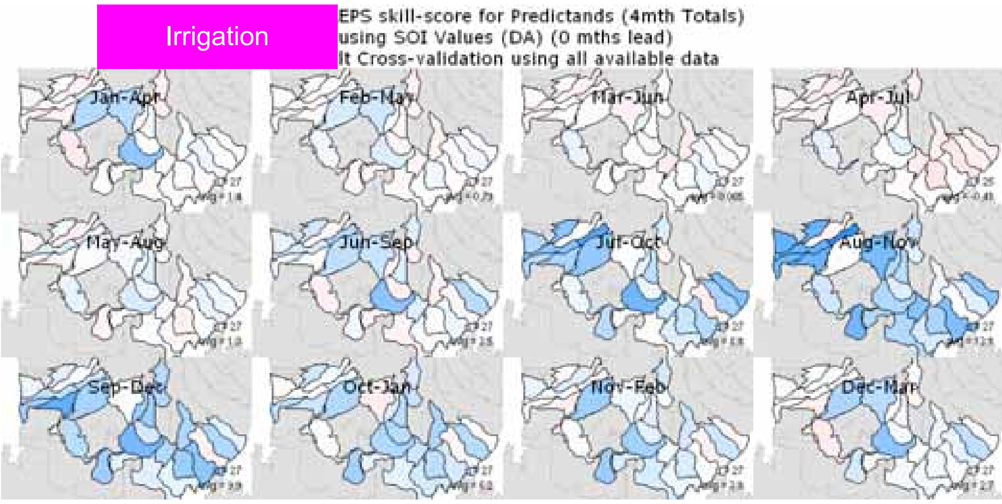

River/Catchment
LEPS skill-score for Predictands (6mth Totals)
using SOI Values (DA) (0 mths lead)
Cross-validation using all available data
Jan-Jun
Feb-Jul
Mar-Aug
Apr-Sep
May-Oct
Jun-Nov
Jul-Dec
Aug-Jan
Sep-Feb
Oct-Mar
Nov-Apr
Dec-May

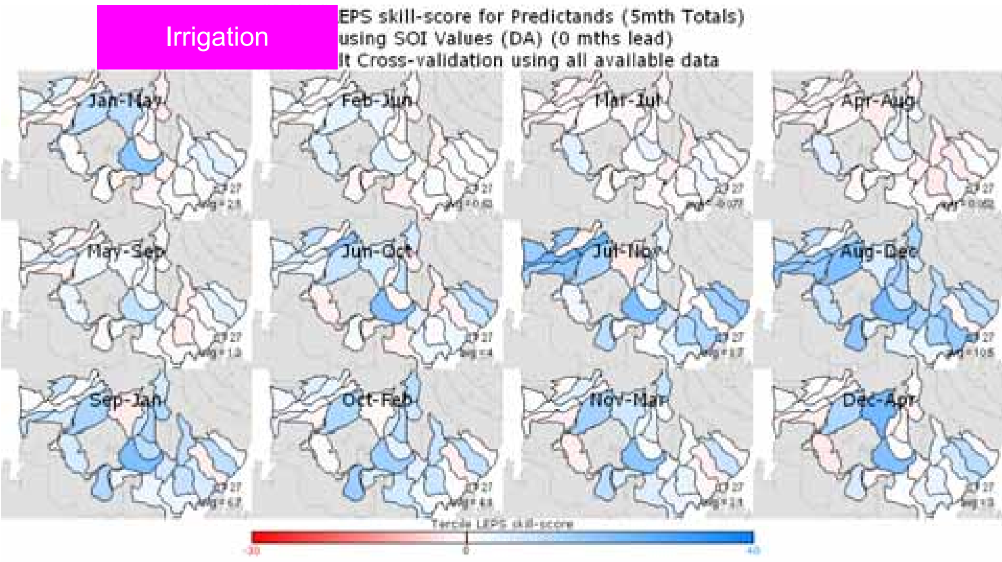

Tercile LEPS skill-score for Predictands (9mth Totals)
River/Catchment
using SOI Values (DA) (0 mths lead)
Cross-validation using all available data
Jan-Sep
Feb-Oct
Mar-Nov
Apr-Dec
May-Jan
Jun-Feb
Jul-Mar
Aug-Apr
Sep-May
Oct-Jun
Nov-Jul
Dec-Aug

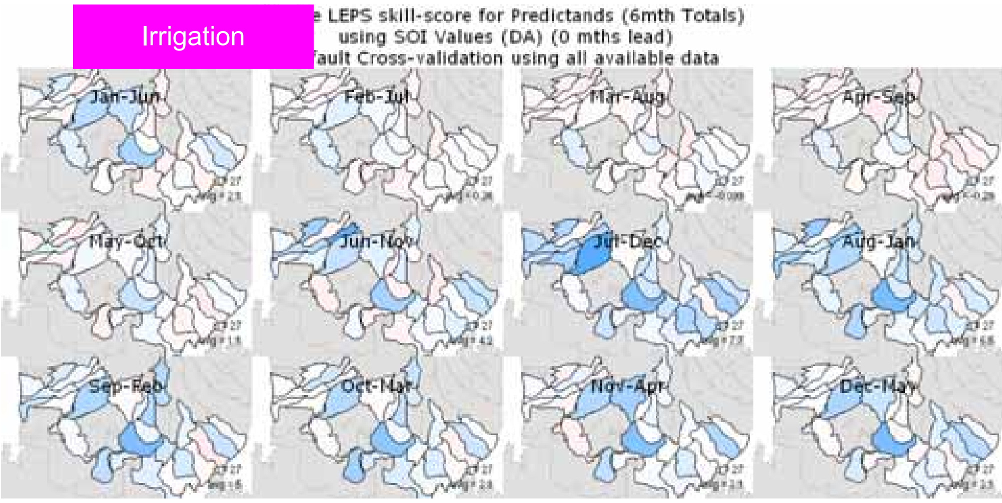

Tercile LEPS skill-score for Predictands (12mth Totals)
River/Catchment
using SOI Values (DA) (0 mths lead)
Cross-validation using all available data
Jan-Dec
Feb-Jan
Mar-Feb
Apr-Mar
May-Apr
Jun-May
Jul-Jun
Aug-Jul
Sep-Aug
Oct-Sep
Nov-Oct
Dec-Nov
Tercile LEPS skill-score

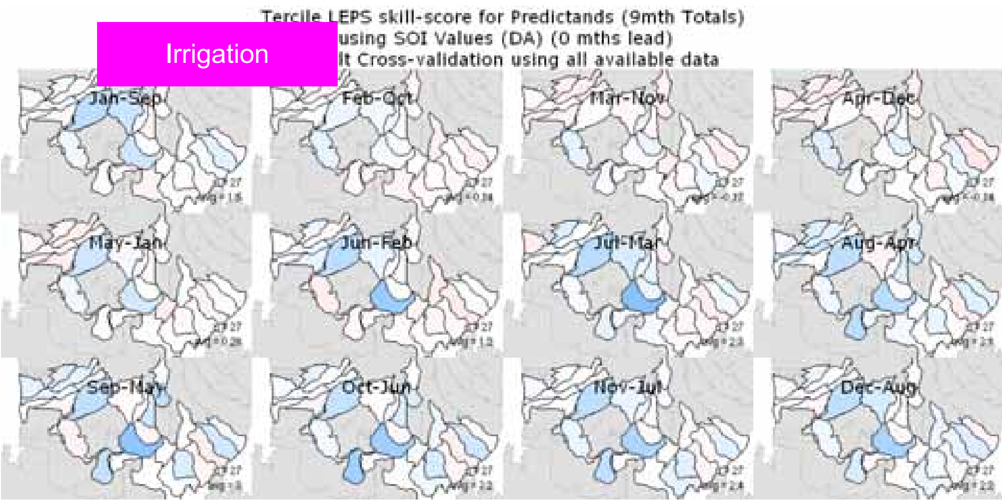
10.5.2 Spatial skill assessment of irrigation diversions

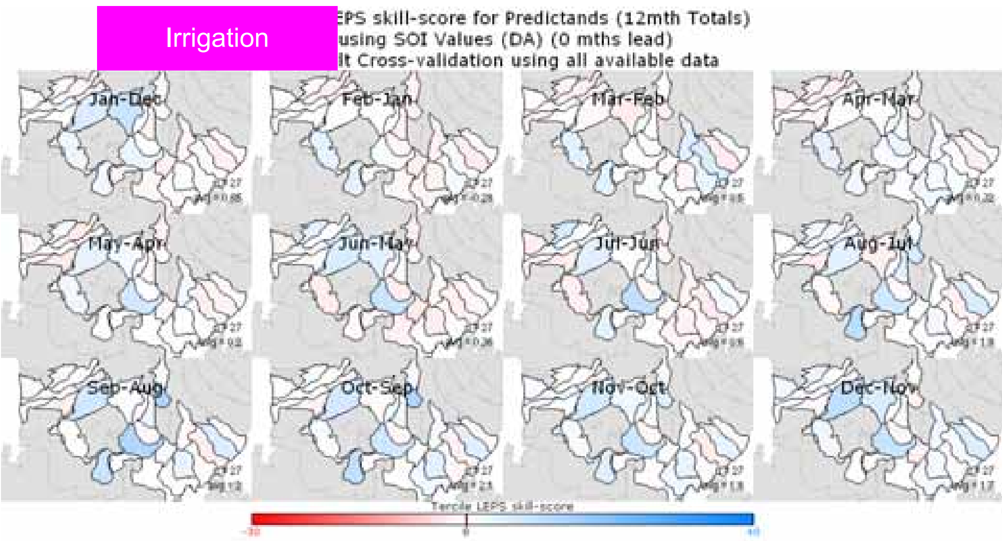




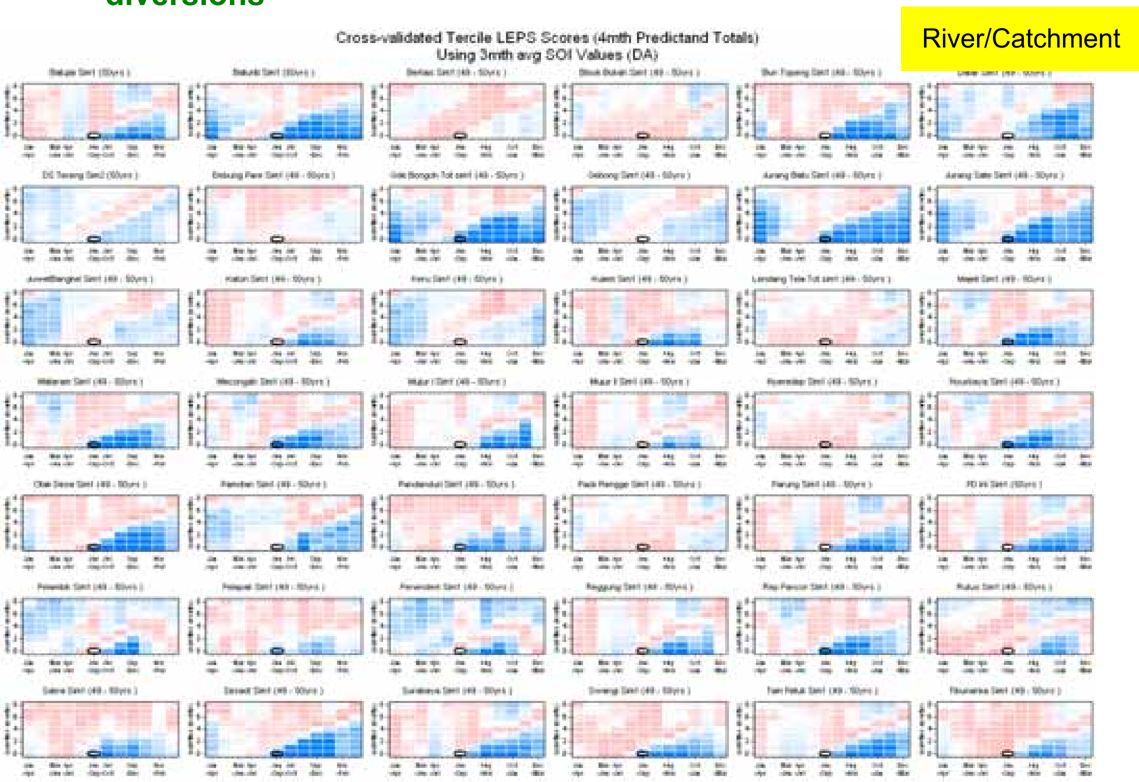


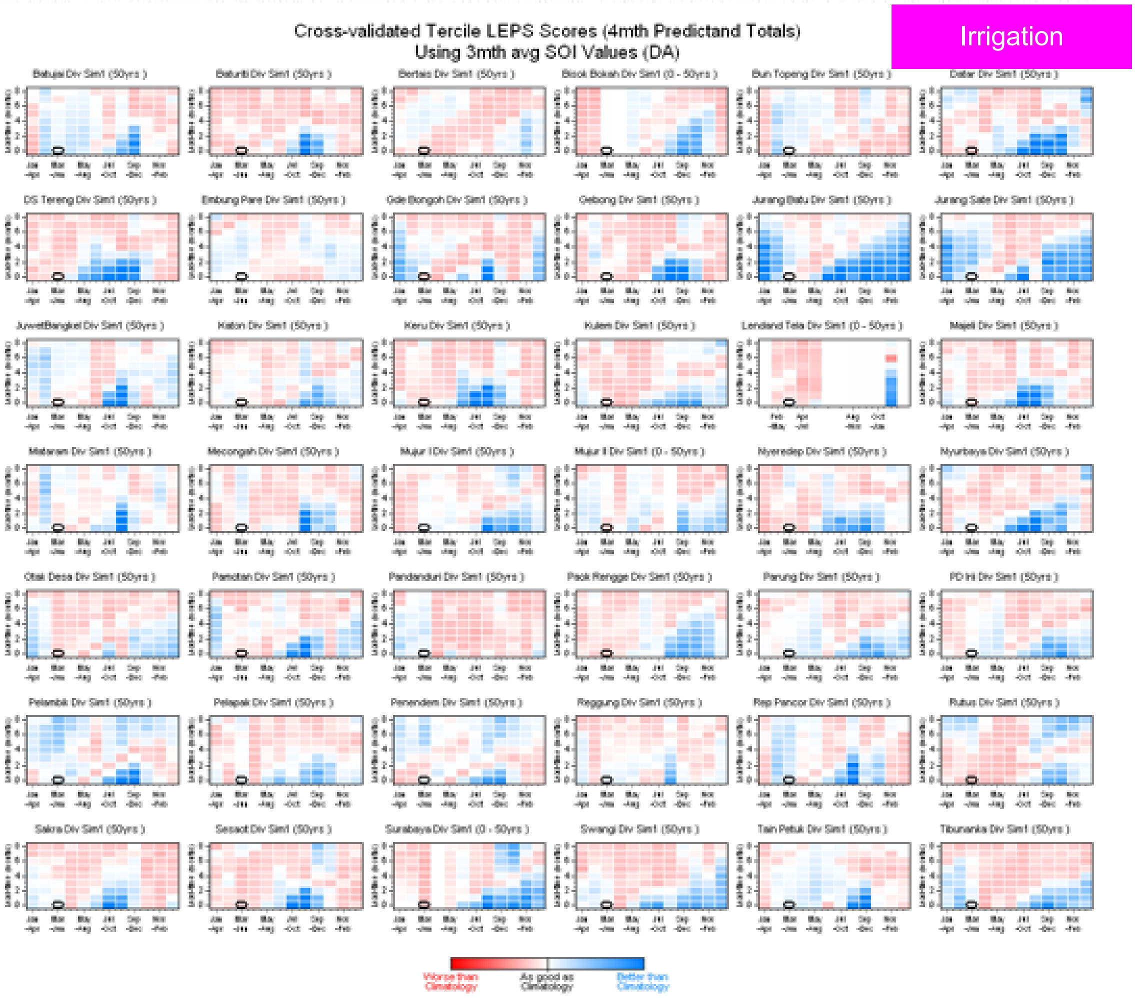

Irrigation
e LEPS skill-score for Predictands (6mth Totals)
using SOI Values (DA) (0 mths lead)
fault Cross-validation using all available data
Jan-Jun
Feb-Jul
Mar-Aug
Apr-Sep
May-Oct
Jun-Nov
Jul-Dec
Aug-Jan
Sep-Feb
Oct-Mar
Nov-Apr
Dec-May


Irrigation
Tercile LEPS skill-score for Predictands (9mth Totals)
using SOI Values (DA) (0 mths lead)
lt Cross-validation using all available data
Jan-Sep
Feb-Oct
Mar-Nov
Apr-Dec
May-Jan
Jun-Feb
Jul-Mar
Aug-Apr
Sep-May
Oct-Jun
Nov-Jul
Dec-Aug


Irrigation
EPS skill-score for Predictands (12mth Totals)
using SOI Values (DA) (0 mths lead)
lt Cross-validation using all available data
Jan-Dec
Feb-Jan
Mar-Feb
Apr-Mar
May-Apr
Jun-May
Jul-Jun
Aug-Jul
Sep-Aug
Oct-Sep
Nov-Oct
Dec-Nov
Tercile LEPS skill-score

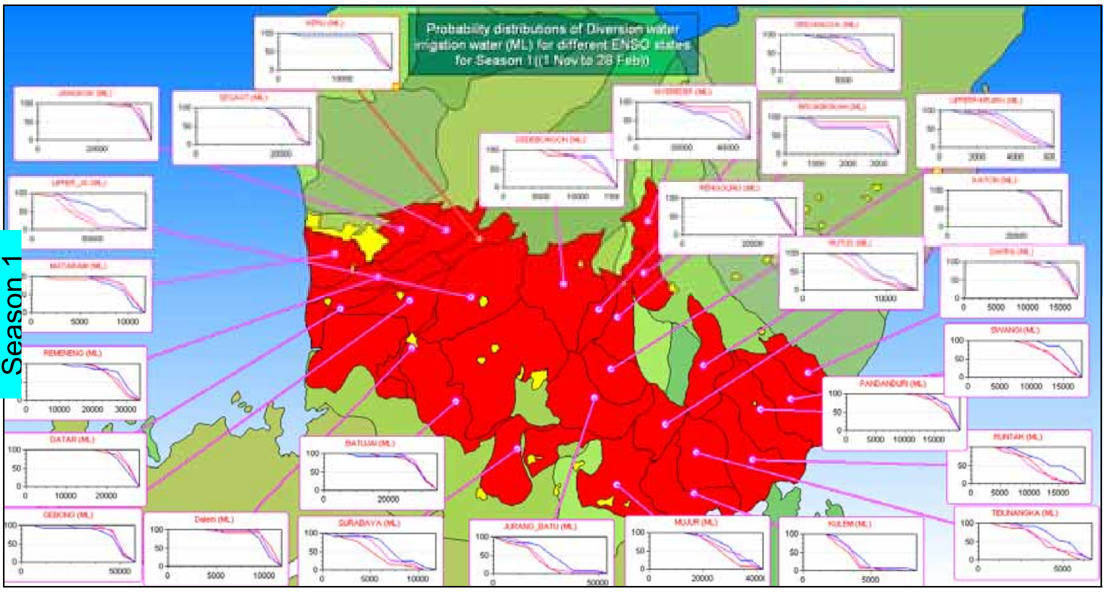
10.5.3 Temporal skill assement for river/catchment inflows and irrigation diversions



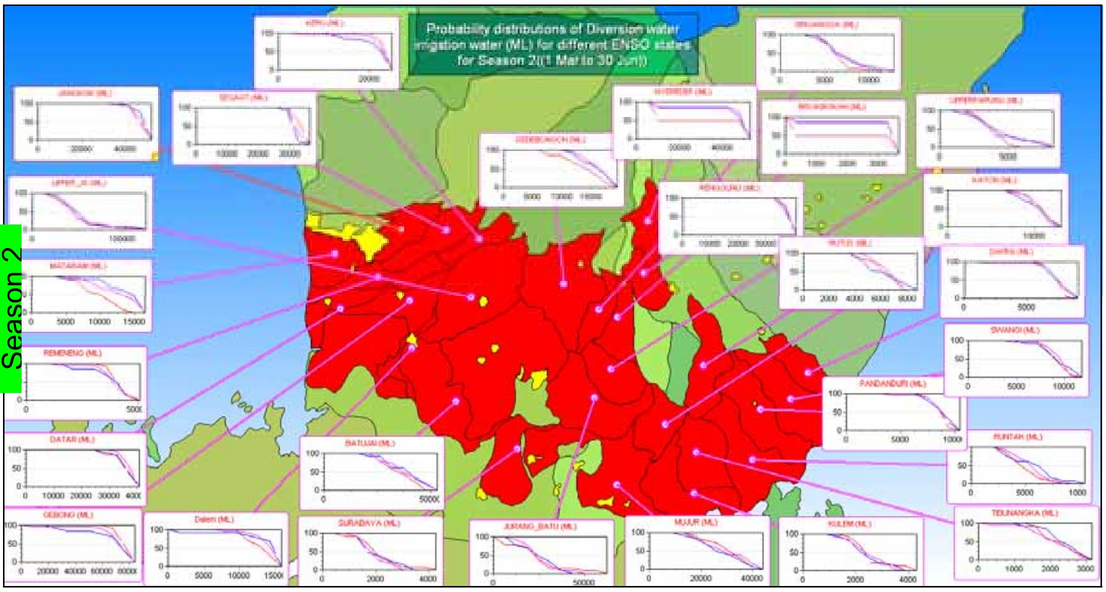


10.5.4 ENSO stratifications of diverted water

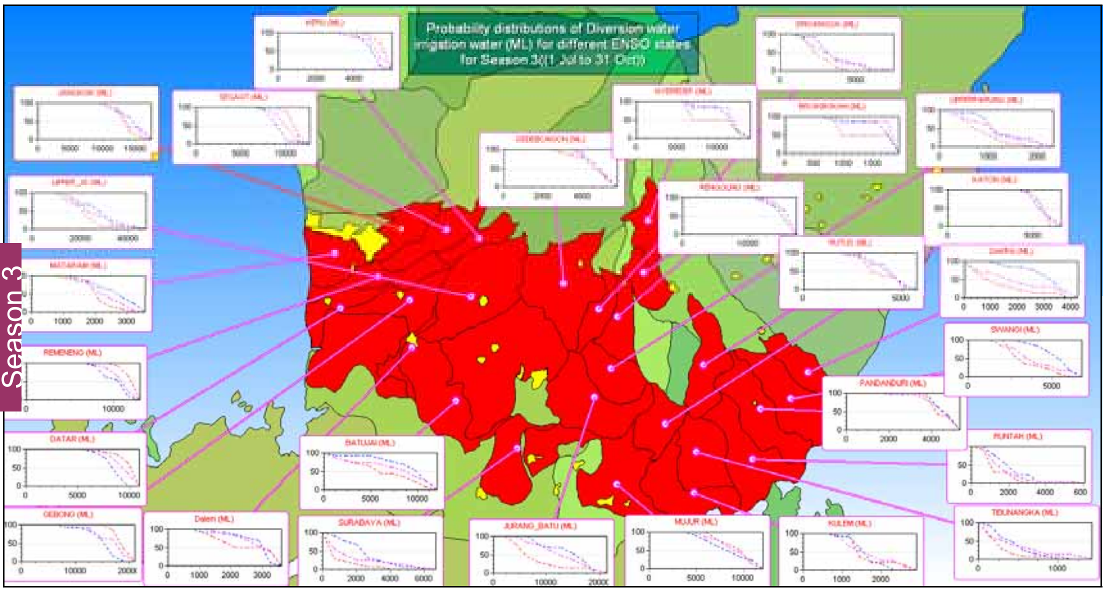
Season 1



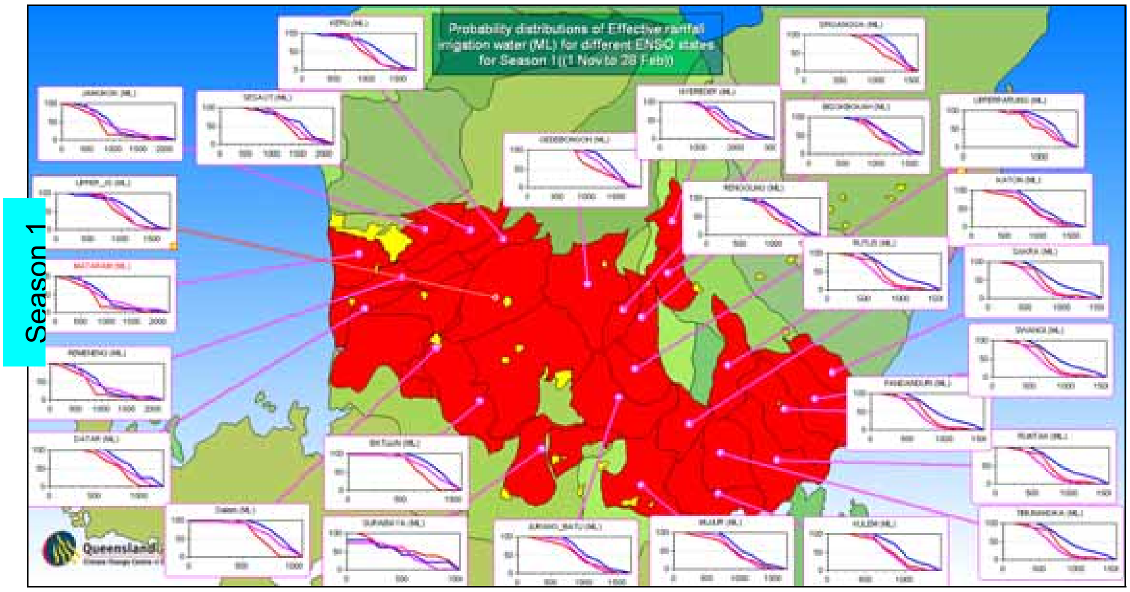
Season 2

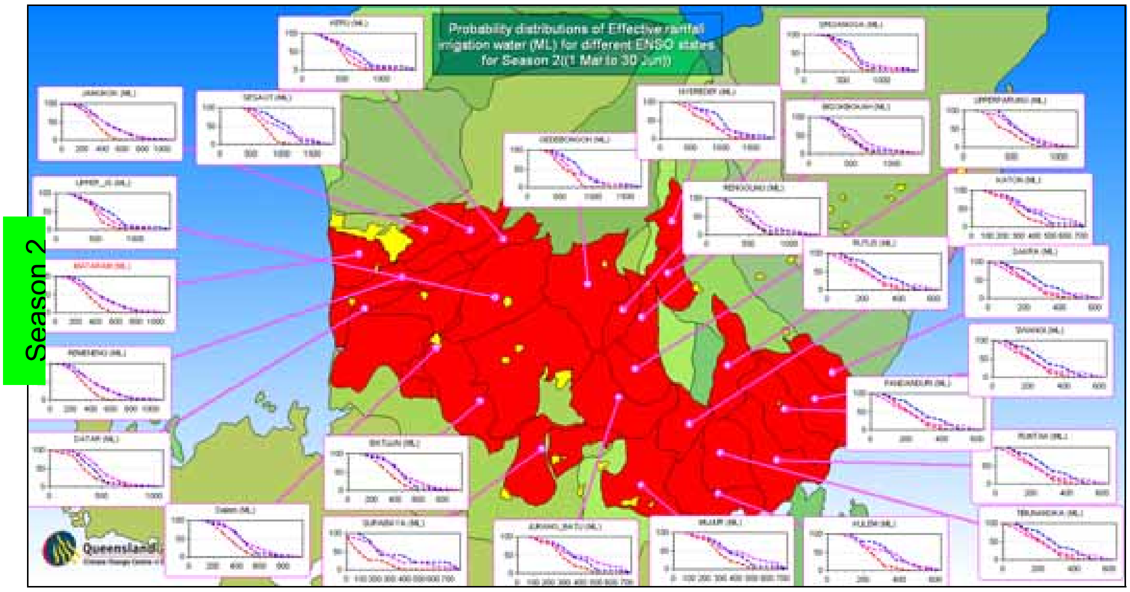


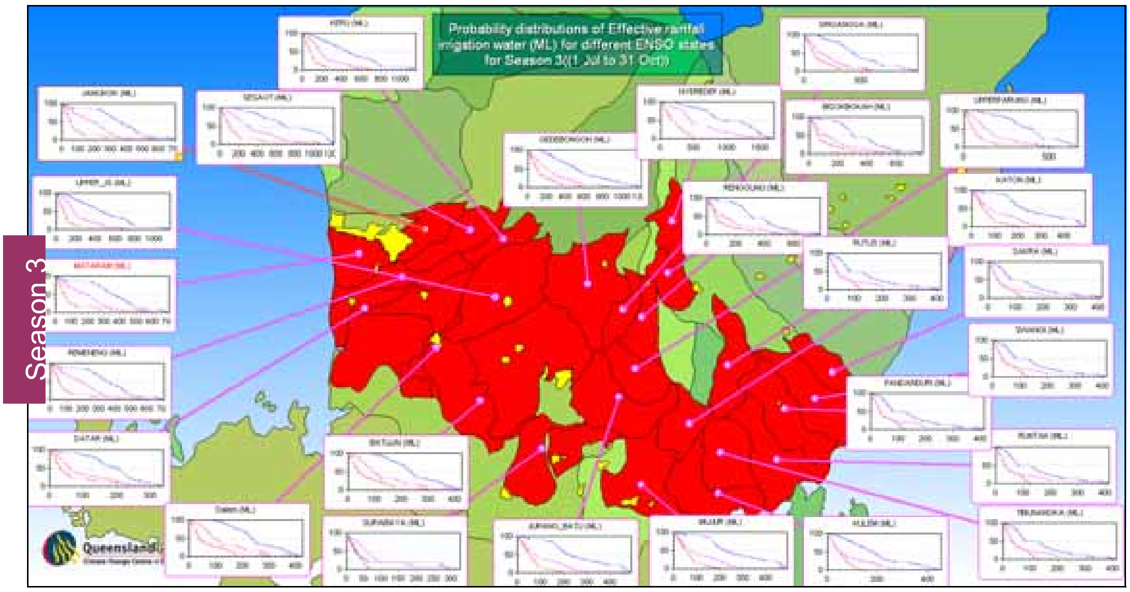
Season 3



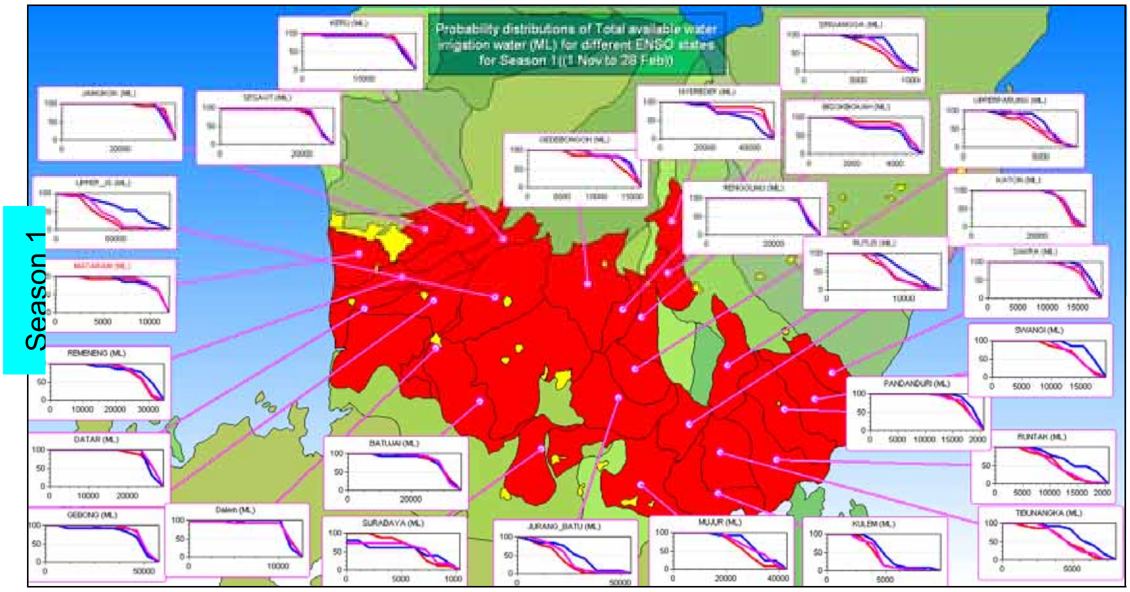
10.5.5 ENSO stratifications of effective rainfall

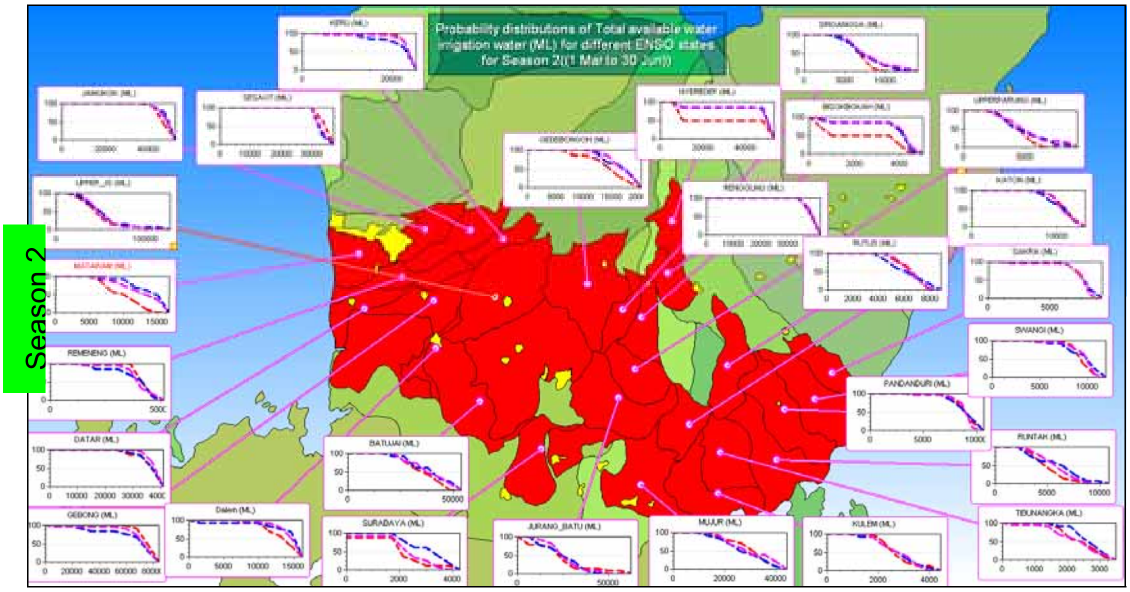


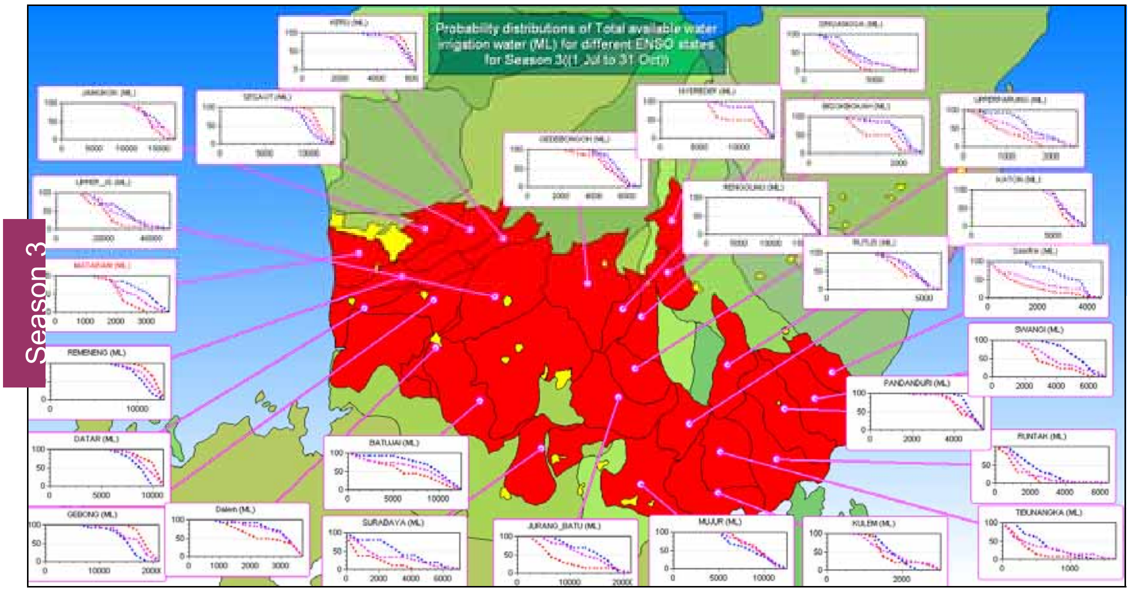




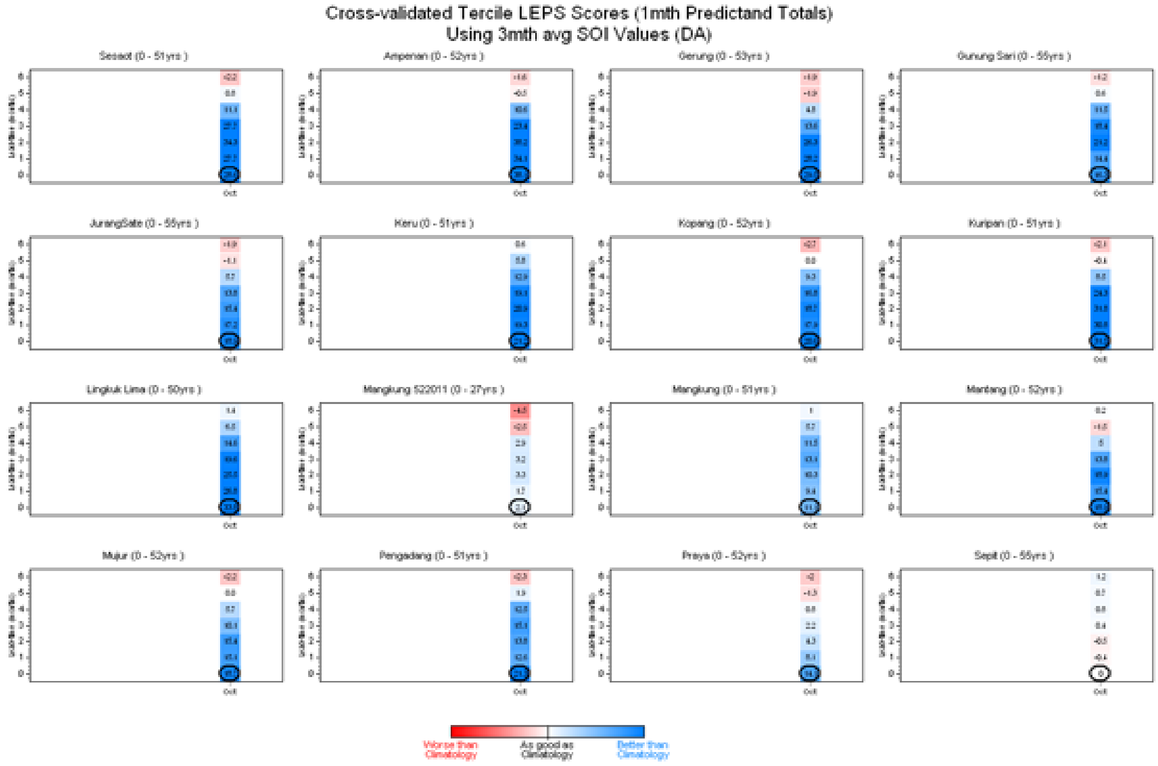
10.5.6 ENSO stratifications of total available water

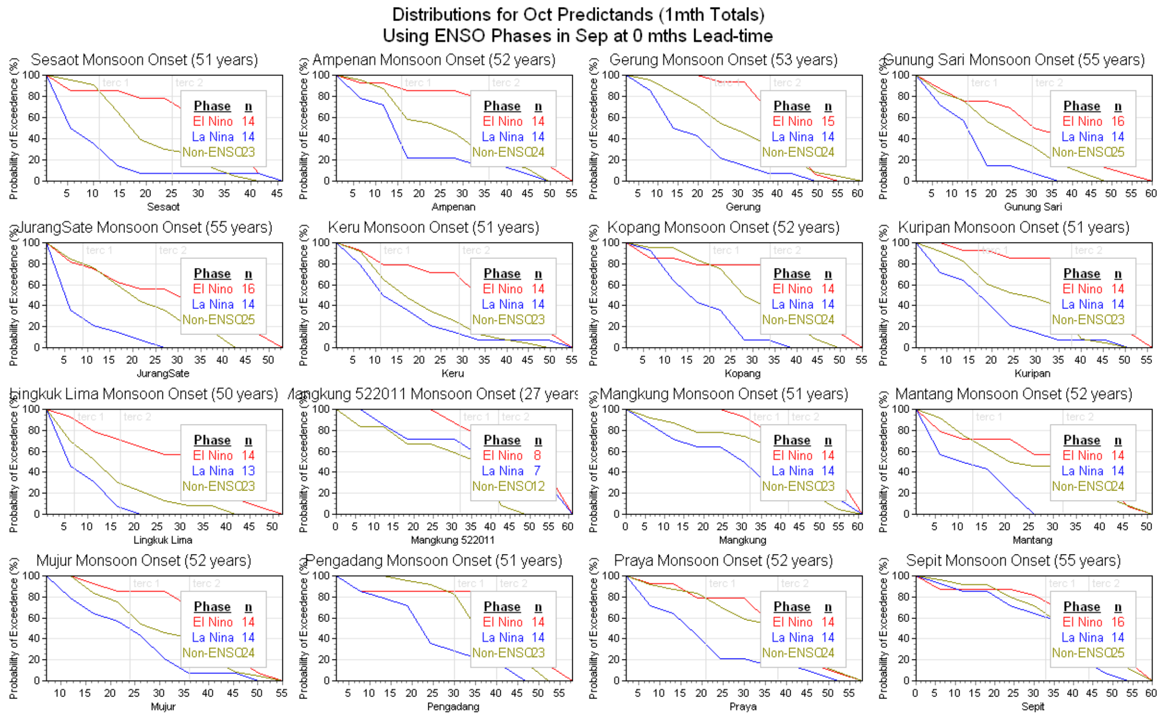






10.6 Appendix 6: Skill assessment of the onset of the monsoon





10.7 Appendix 7: Summary of data collection

Hydroclimatic data collected through this project includes time series of rainfall and discharge data. Monthly rainfall data is available for 104 stations. Most of these stations have data after 1960. Few stations (eight stations) have records since 1916. There was no rainfall record during 1942–1949 which may be due to World War II. The stations with missing monthly data of different durations are shown in A7.1. Daily rainfall data are available for 76 stations. Most of these stations have data recorded after 1990 One station has records since 1961 and another station since 1969. The stations with missing daily data of different durations are shown in A7.2. Intake data are available on a daily basis for 113 stations/gauges. Most of the stations have records since 1994/1995. Only trwo stations have records since 1990. The stations with missing data of different durations are shown in A7.3.

10.7.1 List of stations and collected data for monthly rainfall

No	Station	Available data 1916–2007 (number of years)	Year of available data 1916–2007
1	Ampenan	84	1916–1941, 1950–2007
2	Aikmual	4	2002, 2004, 2006, 2007
3	Aikmel	1	2003
4	Babuak	36	1950–1985
5	Barabali	58	1930–1941, 1950–1995
6	Batukliang	2	2003–2004
7	Batu Kumbung	33	1959–1985, 1998–2003
8	Batu Layar	3	2004, 2006, 2007
9	Batunyale	3	2002–2004
10	Batujai	12	1930–1941
11	Bayan	61	1916–1941, 1970–2004
12	Belanting	7	1994–2000
13	Bertais	46	1959–2004
14	BMG	24	1962–1985
15	Cakranegara	3	2002, 2006, 2007
16	Darek	2	2003, 2004
17	Dasan Geria	1	1974
18	Dasan Lekong	50	1956–1960, 1962–2004, 2006, 2007
19	Dasan Tereng	43	1964–2004, 2006, 2007
20	Desa Anyar	16	1959–1974
21	Gunung mareje	4	1938–1941
22	Gunung Sari	19	1989–2007
23	Gerung	48	1959–2004, 2006, 2007
24	Gondang	33	1972–2004
25	Ijo Balit	23	1983–2005
26	Jurang Sate	30	1968–1975, 1984–2005
27	Janapria	55	1950–2004
28	Jonggat	2	2002, 2003
29	Kabul	6	2000–2005
30	Katon	10	1989–1998
31	Kawo	9	1994–2002
32	Kediri	8	1999–2004, 2006, 2007

33	Kekait	1	1975
34	Keru	24	1982–2005
35	Keruak	49	1956–2004
36	Ketara	12	1929–2004
37	Ketirik	16	1959–1974
38	Kopang	73	1927–1941, 1951–2004, 2006, 2007
39	Korleko	14	1960–1973
40	Kotaraja	54	1932–1941, 1956–1983, 1986–2002, 2006, 2007
41	Kumbung	1	2003
42	Kuripan	22	1984–2005
43	Labuhan Haji	4	2001–2004
44	Labuhan Lombok	39	1916–1941, 1951–1954, 1958, 1959, 1963–1968, 1970, 1973, 1974
45	Labuapi	13	1992–2004
46	Lembar	3	2002–2004
47	Lenek	32	1960–1974, 1989–2005
48	Lingkok Lime	27	1974–1978, 1984–2005
49	Lingsar	3	2002–2004
50	Loangmake	23	1983–2005
51	Majeluk	18	1959–1974, 2006, 2007
52	Mangkung	37	1969–2005
53	Mantang	57	1950–2004, 2006, 2007
54	Masbagik	26	1960–1974, 1994–2004
55	Mataram	83	1916–1941, 1950–2004, 2006, 2007
56	Montong Baan	49	1956–2004
57	Montong Gamang	41	1964–2004
58	Menggala	1	1974
59	Mujur	38	1969–2004, 2006, 2007
60	Narmada	38	1962–1998, 2002
61	Nyur Lembang	33	1962–1994
62	Pegondang	18	1960–1974, 2003, 2006, 2007
63	Pekatan	1	1974
64	Pelambik	7	1992–1998
65	Penendem	7	1994–2000
66	Pengadang	23	1962–1999, 2001–2005
67	Peninjauan	53	1950–1974, 1978–2007
68	Penujak	56	1950–2005
69	Perian	6	2000–2005
70	Persil	15	1960–1974
71	Praya	89	1916–2004
72	Pringgabaya	45	1960–1966, 1968–2005
73	Pringgarata	36	1969–2004
74	Pringgasela	2	2002–2003
75	Puyung	57	1950–2004, 2006, 2007
76	Rambitan	22	1964–2005
77	Ranggagata	14	1965–1975, 1978–1980

78	Rembige	51	1950–1995, 1998–2002
79	Rensing	7	1994–2000
80	Rumak	22	1985–2004, 2006, 2007
81	Saba	17	1969–1985
82	Sakra	49	1956–2004
83	Sakra Timur	1	2002
84	Sambelia	12	1969–1974, 1999–2004
85	Sapit	32	1974–2005
86	Sekotong	48	1959–2004, 2006, 2007
87	Selong	73	1916–1934, 1937–1941, 1956–2004
88	Sembalun	17	1938–1941, 1960–1968, 1971–1974
89	Sengkol	54	1950–2004
90	Sepapan	31	1959–1973, 1968–2001, 2006, 2007
91	Sepit	34	1972–2005
92	Sesaot	28	1974–1978, 1983–2005
93	Sikur	28	1960–1974, 1960–1974, 1992–2002, 2006, 2007
94	Suela	15	1960–1974
95	Suranadi	31	1962–1992
96	Tanjung	69	1916–1941, 1962–2004
97	Tanjung Luar	36	1916–1941, 1951–1954, 1958, 1959, 1970, 1971, 1973, 1974
98	Terara	11	1994–2004
99	Teratak	2	2003, 2004
100	Tibunangka	10	1989–1998
101	Timba Nuh	39	1960–1998
102	Tuntang	1	1974
103	Ubung	40	1964–2003
104	Wanasaba	1	2002

10.7.2 List of stations and collected data for daily rainfall

No	Station	Available data 1961–2007 (number of years)	Year of available data 1961–2007
1	Aikmel	1	2003
2	Aikmual	2	2002, 2004, 2006, 2007
3	Ampenan	26	1961–1986, 1988–2004, 2006, 2007
4	Batukliang	2	2003, 2004
5	Batu Kumbung	1	2002
6	Batu Layar	2	2004, 2006, 2007
7	Batu Nyale	3	2002–2004
8	Bayan	6	1999–2004
9	Belanting	7	1994–2000
10	Bertais	9	1994–2002, 2004
11	Cakranegara	2	2002, 2006, 2007
12	Darek	2	2003, 2004
13	Dasan Geria	1	1974
14	Dasan Lekong	11	1994–2004, 2006, 2007

15	Dasan Tereng	16	1989–2004, 2006, 2007
16	Gerung	14	1991–2004, 2006, 2007
17	Gunung Sari	16	1989–2004, 2006, 2007
18	Gondang	5	2000–2004
19	Janapria	11	1994–2004
20	Jonggat	2	2002, 2003
21	Jurit	1	2003
22	Kawo	8	1995–2002
23	Kediri	6	1999–2004, 2006, 2007
24	Kekait	1	1974
25	Keruak	7	1998–2004
26	Kopang	16	1989–2004, 2006, 2007
27	Kotaraja	14	1989–2002, 2006, 2007
28	Kumbung	1	2003
29	Kuripan	3	2002–2004
30	Labuhan haji	4	2001–2004
31	Labuapi	7	1994–2000
32	Lembar	3	2002–2004, 2006, 2007
33	Lenek	14	1989–2002, 2006, 2007
34	Lingkuk Lime	1	1974
35	Lingsar	3	2002–2004
36	Loangmake	17	1983–1999
37	Mantang	16	1989–2004
38	Masbagik	4	1995, 1998, 2001, 2004
39	Mataram	11	1994–2004, 2006, 2007
40	Menggala	1	1974
41	Montong Baan	8	1994–2001
42	Montong Gamang	7	1994–2000
43	Mujur	10	1989–1992, 1994–2004, 2006, 2007
44	Narmada	1	2002
45	Pegondang	7	1989–1995, 1997, 1999–2004, 2006, 2007
46	Pekatan	1	1974
47	Penendem	7	1994–2000
48	Pengadang	16	1982–1997, 1999
49	Peninjauan	5	1998–2002, 2006, 2007
50	Penujak	9	1994, 1996–2004
51	Persil	1	1974
52	Praya	17	1988–2004
53	Pringgabaya	34	1969–2002
54	Pringgarata	11	1994–2004
55	Pringgasela	2	2002, 2003
56	Puyung	16	1989–2004, 2006, 2007
57	Rambitan	16	1984, 2000
58	Rembige	5	1998–2002
59	Rensing	7	1994–2000, 2004
60	Rumak	9	1994–2002, 2004

61	Sakra Timur	1	2002
62	Sambelia	6	1999–2004
63	Sekotong	16	1989–2004
64	Selong	8	1994–2001
65	Sengkol	7	1996–2002, 2006, 2007
66	Sepapan	14	1989–2002, 2006, 2007
67	Sepit	13	1974–1978, 1983–1985, 1987–1999
68	Sesaot	8	1994–2001
69	Sikur	11	1992–2002, 2006, 2007
70	Tanjung	10	1989–1998, 2001–2004
71	Terara	11	1994–2004
72	Teratak	2	2003, 2004
73	Tibunangka	1	1974
74	Tuntang	1	1974
75	Ubung	8	1994–2001, 2004
76	Wanasaba	1	2002

10.7.3 List of gauge and collected data for discharge data (Mercu and Intake)

No	Station	Available data 1990–2005 (number of years)	Year of Available data 1990–2005
1	Babak	7	1995–2001
2	Bangka	8	1995–2002
3	Bangle	5	1999–2003
4	Batu Kantar	5	1993, 1994, 2002–2004
5	Batu Ngapah	2	2004, 2005
6	Bengkel	6	1995–2000
7	Benjor	8	1996–2003
8	Berambang	10	1994–2003
9	Bertais	6	1993, 1994, 1997–2000
10	BGB5	3	1996–1998
11	Bisok Bokah	11	1995–2005
12	Borok Celet	8	1995–2002
13	Burung	8	1995–1997, 2001–2005
14	Camek	10	1994–2003
15	Dasan Tereng	9	1993, 1994, 1997–2000, 2002–2004
16	Datar	6	1990–1995
17	Embung Dao	9	1995–2003
18	Embung Mare	10	1994–2003
19	Embung Muncan	9	1995–2003
20	Embung Pare	9	1997–2005
21	Embung Saok	2	1999, 2000
22	Endut	5	1995–1997, 2001, 2002
23	Gde Bongoh	8	1996–2003
24	Gebong	9	1990–1998
25	Gege I	10	1994–2003
26	Gege II	10	1994–2003
27	Gege III	10	1994–2003

28	Gegutu	6	1995–2000
29	Ireng Daya	6	1995–2000
30	Iwan I	7	1999–2005
31	Iwan II	7	1999–2005
32	Jaguar	7	1995–2001
33	Jangkok	10	1993–1995, 1997–2000, 2002–2004
34	Jangkok HLD	10	1996–2005
35	Jimsa	8	1995–2002
36	Jogok	9	1994–2002
37	Jowet	8	1995–1997, 2001–2005
38	Jurang Batu	11	1995–2005
39	Juwet	6	1995–2000
40	Kangkek Lepang	8	1995–1997, 2001–2005
41	Katon	9	1997–2005
42	Keluncing	6	1995–2000
43	Kemeang	2	2004–2005
44	Keru Feeder	10	1992–2001
45	Keru Lama	9	1993, 1994, 1997–2000, 2002–2004
46	Kondak	8	1995–1997, 2001–2005
47	Kulem	9	1997–2005
48	Kwang Berore	8	1995–1997, 2001–2005
49	Kwang Derek	8	1995–1997, 2001–2005
50	Lekak	9	1995–2003
51	Lendang Telage	12	1994–2005
52	Lenting	11	1995–2005
53	Majeli	8	1994–2001
54	M.A.R.	7	1994, 1997, 1998, 2000, 2002–2004
55	Mataram	9	1993–2001
56	Medas	6	1995–2000
57	Mencongah	9	1993–2001
58	Menjeli	6	1995–2000
59	Mertak Paok	8	1996–2003
60	Mesone	10	1996–2005
61	Montang	9	1993, 1994, 1997–2000, 2002–2004
62	Montong Tangi	8	1995–1997, 2001–2005
63	Mujur I	4	2001, 2002, 2004, 2005
64	Mujur II	11	1995–2005
65	Nyeredep	12	1994–2005
66	Nyurbaye	9	1996–2004
67	Otak Desa	11	1995–2005
68	Pagutan	3	1996–1998
69	Pamotan	12	1993–2004
70	Pandan Duri	13	1993–2005
71	Paok Dengkol	2	2000, 2001
72	Paok Rengge	12	1994–2005
73	Parung	11	1995–2005

74	Pelambik	10	1994–2003
75	Pelolat	9	1994–2002
76	Penendem	10	1994–2003
77	Penimbung	6	1995–2000
78	Penyonggok	8	1995–2002
79	Perako	8	1995–1997, 2001–2005
80	Peresak Sirem	11	1995–2005
81	Pesongoran	11	1993–2003
82	Petikus	3	1996–1998
83	Petung	8	1996–2003
84	Pondol	8	1995–1997, 2001–2005
85	Pungkang	7	1994–1996, 1999–2002
86	Reban Talat	8	1995–1997, 2001–2005
87	Reban Waru	8	1995–1997, 2001–2005
88	Repok Pancor	6	1995–2000
89	Rungkang	5	1995–1997, 2001, 2002
90	Rutus	8	1997–2004
91	Sadar	8	1995–1997, 2001–2005
92	Sakra	8	1995–1997, 2001–2005
93	Sandik	6	1995–2000
94	Selak Eat	8	1994–1996, 1999–2003
95	Sesaot	9	1993, 1994, 1997–2000, 2002–2004
96	Sesaot Feeder	9	1993, 1994, 1997–2000, 2002–2004
97	Sidemen	8	1994–2001
98	Sikur	8	1995–2002
99	Simbe	8	1996–2003
100	Solong	4	1995, 1996, 2002, 2003
101	Songor Galung	6	1996–2001
102	Sundi	9	1995–2003
103	Surabaya	11	1995–2005
104	Tain Petuk	12	1994–2005
105	Tembelok	6	1995–2000
106	Temiling	8	1994–2001
107	Temusik	12	1994–2005
108	Terara	12	1994–2005
109	Tete Kopong	12	1994–2005
110	Tibunangka	9	1997–2005
111	Tundak	9	1993–2001
112	Unus	12	1993–2004
113	Waduk Dao	9	1996–2004

10.7.4 Rainfall stations for climate data generation

Station	River Basin	Lat	Long	Elv (m)	Daily rainfall	Monthly rainfall
Ampenan	Jangkok	−−8.57	116.08	6	1/1/1957–31/12/1998	1950–2001
Gerung	Babak	−8.68	116.12	16	1/1/1994–20/11/2000	1950–2002
Gunung sari	Meninnting	−8.53	116.1	16	1/1/1983–31/12/1999	1950–2004
Jurang Sate (Perampuan)	Babak	−8.6	116.27	237	1/1/1983–31/12/1999	1950–2004
Keru–Peresak	Babak	−8.57	116.27	218	1/1/1982–31/12/1999	1950–2005
Kopang	Renggung	−8.63	116.37	355	1/1/1989–31/12/1998	1950–2004
Kotaraja	Palung	−8.58	116.4	439	1/1/1989–31/12/1998	1950–2002
Kuripan	Dodokan	−8.68	116.18	52	1/1/1983–31/12/1999	1950–2004
Lingkuk Lima	Babak	−8.55	116.37	674	1/1/1974–31/12/1999	1950–2004
Mangkung	Dodokan	−8.82	116.23	165	1/1/1973–31/12/1999	1950–2004
Mantang	Dodokan	−8.62	116.32	352	1/1/1989–31/12/1998	1950–2001
Mujur	Renggung	−8.75	116.37	114	1/1/1989–31/12/1996	1950–2001
engadang	Dodokan	−8.68	116.17	289	1/1/1983–29/12/2000	1950–2004
Praya	Dodokan	−8.72	116.28	96	1/1/1989–31/12/1998	1950–2004
Rembitan	Dodokan	−8.83	116.3	130	1/1/1984–31/12/1999	1950–2004
Sepanan–Keruak	Gambii	−8.77	116.47	83	1/1/1989–31/12/1998	1950–2004
Sepit	Gambir	−8.29	116.47	119	1/1/1974–31/12/1999	1950–2004
Sesaot	Jangkok	−8.56	116.25	251	1/1/1974–31/12/1999	1950–2005

10.8 Appendix 8: Planting areas adopted in IQQM

Table A8.1: Crop sequence and proportion of planting area in each irrigation area in Lombok

Irrigation area	Seq 1		Seq 2			Seq 3	
	rice %	sec. crop %	rice %	sec. crop %	rice/sec. crop %	rice %	sec. crop %
Montang	100	0	76	0		0	99
Nyurbaya	100	0	100	0		0	86
Mencongah	100	0	99	0		0	43
Menjeli	100	0	93	0		0	95
Repok Pancor	100	0	97	0		0	93
Mataram	100	0	93	0		0	99
Gegutu	100	0	95	0		0	96
Ireng Daya	100	0	91	0		0	98
Sesaot	100	0	99	0		0	91
Bertais	100	0	100	0		0	100
Pamotan	100	0	98	0		0	98
Dasan Tereng	100	0	100	0		0	100
Juwet	100	0	44	0		0	46
Keru	100	0	100	0		0	98
Simbe	100	0	100	0		0	91
Sidemen	100	0	98	0		0	4
Gde Bongoh	100	0	100	0		0	78
Gebong	100	0	100	0		0	100
Datar	100	0	100	0		0	100
Baturiti	100	0	100	0		0	100
Jurang Sate Hulu	85	0	77	0		0	100
BT/PK Buntopeng	100	0			87	0	100
Jurang Sate Hilir	100	0			70	0	43
Pk Dengkol	100	0	93	0		0	92
Parung	100	0	100	0		0	100
Surabaya	100	0	0	20		0	80
Otak Desa	100	0	100	0		0	79
Renggung	67	0	71	0		0	100
Jurang Batu	100	0	94	0		0	87
Mujur I	25	0	0	100		0	25
Mujur II	87	0	0	100		0	0
Katon	100	0	0	100		0	100
Tibunangka	91	0	0	100		0	67
Kulem	100	0	0	100		0	97
EP/BR	100	0	0	100		0	0
Rutus	100	0			76	0	86
Pandanduri	100	0			64	0	23
Swangi	100	0			48	0	31
Pelapak	100	0			76	0	15
Tundak	100	0			40	0	33

Penendem	100	0			65	0	13
Pelambik	100	0	0	99		0	99
Sakra/RT	100	0	0	39		0	20

10.9 Appendix 9: Guidelines for evaluating the quality of streamflow and diversion calibration

A general guideline has been established for evaluating the quality of an achieved calibration by NSW Department of Land and Water Conservation, Australia (Border Rivers System: IQQM Implementation, 1999). Table A9.1 summarises the statistical indicators of the calibration quality. This guideline was derived from the Border Rivers System in Australia where quality hydrological and meteorological data exist for the IQQM modelling. When this guideline is applied to Lombok where the data are limited either in length of record or quality of the record, some statistical criteria in the guideline are too strict, especially the determination coefficient (r2) and the slope (m) of the daily time series of flow. The guidelines define the range of 0.75–0.89 as “Adequate”, 0.90–0.94 as “Fair” and 0.95–1.0 as “Good”. In the Lombok situation, as the recorded daily time series are often incomplete and statistical patching is needed in most cases, it was difficult to achieve the value of 0.75 for r2. So in this study which has the main aim for agricultural decision–making rather than a hydrological infrastructure purpose (which needs high accuracy in IQQM modelling), we use the range of 0.60–0.74 as “Adequate” for r2, and 0.75–0.89 as “Fair” and 0.90–1.0 as “Good” when assessing the match between the simulated daily time series and the recorded one. For the slope, we modified the value range of “Adequate” from 0.75–1.25 to 0.70–1.30, which responds to the changes in the determination coefficient. Other ranges of slope remain the same.

Table A9.1 Guidelines for quality of flow calibration.

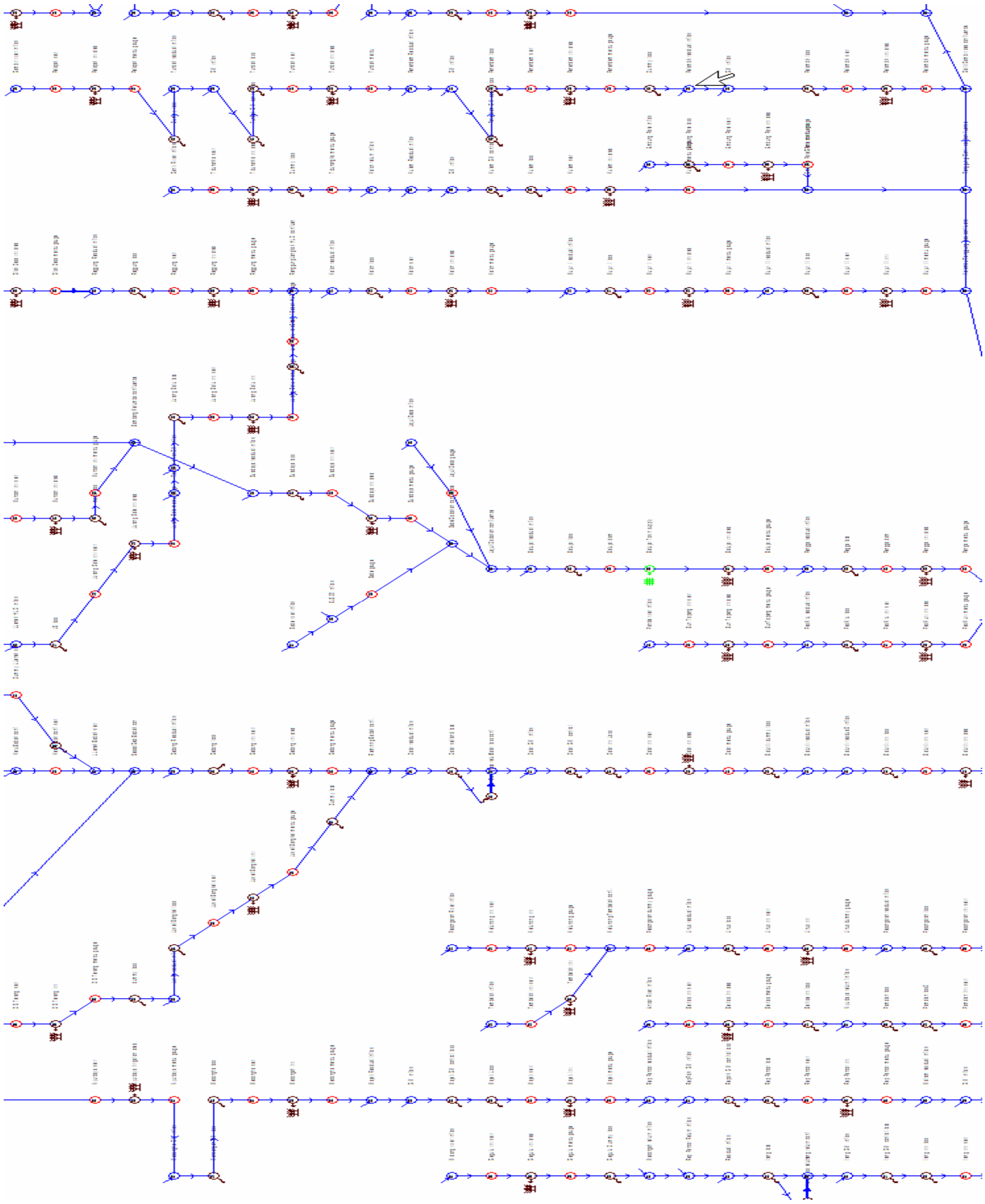
Data compared	Quality indicator		Good result	Fair result	Adequate result
Flow frequency (ranked daily flow)	Volume ratio	Whole range	99<ratio>101	95<ratio>105	90<ratio>110
		Low flows	95<ratio>105	90<ratio>110	75<ratio>125
		Mid-flows	95<ratio>105	90<ratio>110	75<ratio>125
		High flows	95<ratio>10	90<ratio>110	75<ratio>125
	Spot check	5% point	Difference<5%	Difference<10%	Difference<25%
		50% point	Difference<5%	Difference<10%	Difference<25%
		95% point	Difference<5%	Difference<10%	Difference<25%
Time series daily pattern	Volume match, using the line of the best fit: y=mx+b	Degree of deviation from m=1	0.95<m>1.05	0.90<m>1.10	0.75<m>1.25 0.70<m>1.30 (in the current study)
		Degree of deviation from b=0% of average flow	b<10% of average	b<25% of average	b<50% of average
		Proportion of scatter by line, r2	r2>0.95 r2>0.90 (in the current study)	r2>0.90 r2>0.75 (in the current study)	r2>0.75 r2>0.60 (in the current study)

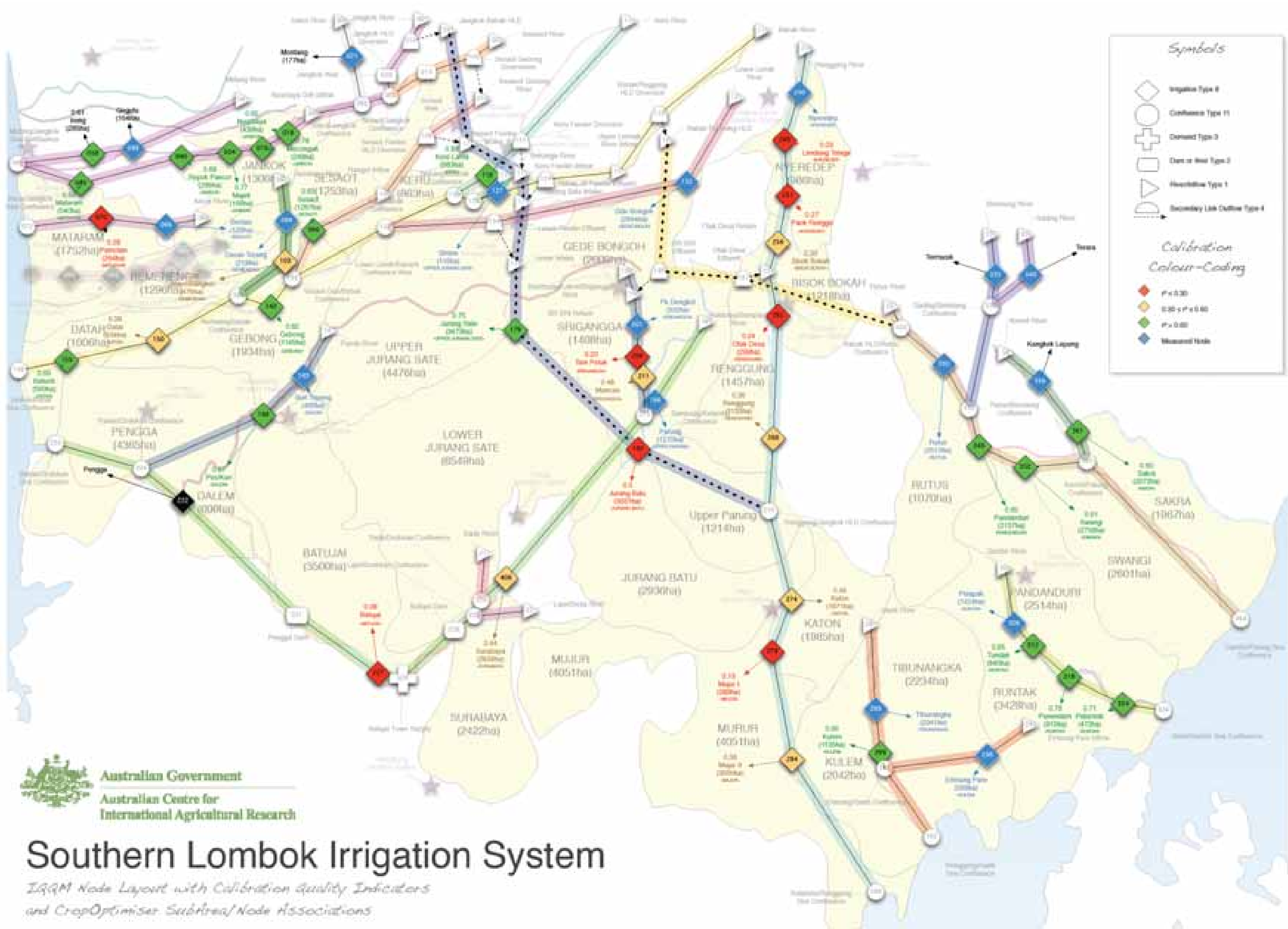
Table A9.2 Guidelines for diversion calibration quality rating. (Border Rivers System: IQQM implementation, NSW DLWC, 1999)

Behaviour replicated	Performance indicator	Sub–aspect	Good	Fair	Adequate
Annual diversion volume	Statistics of annual volume ratio	Overall volume %	99~101	95~105	85~115
Monthly diversion frequency	Volume ratio in diversion ranges	Low, Mid and High Ranges	90~110	80~120	60~140

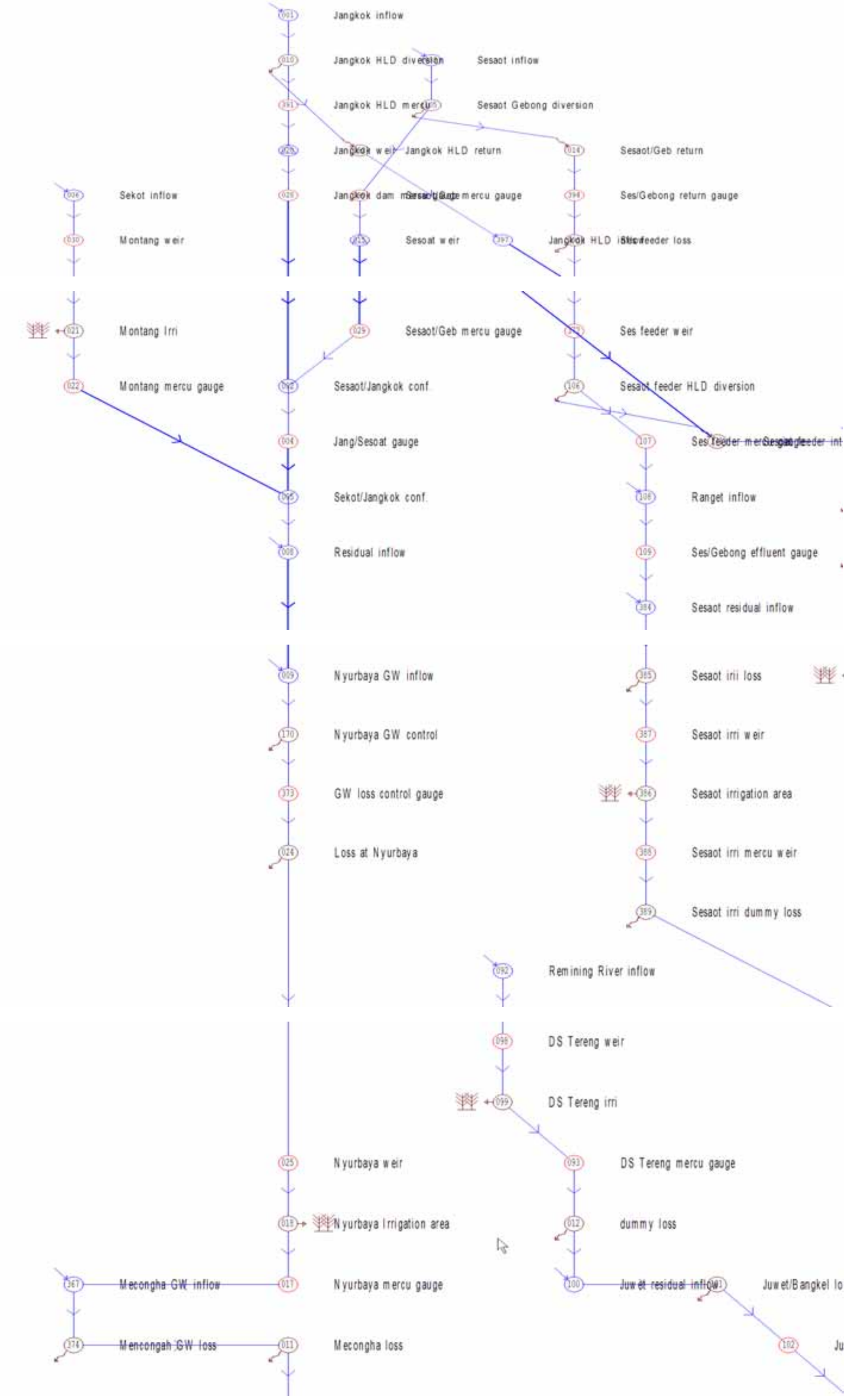
10.10 Appendix 10: IQQM Lombok node network diagrams

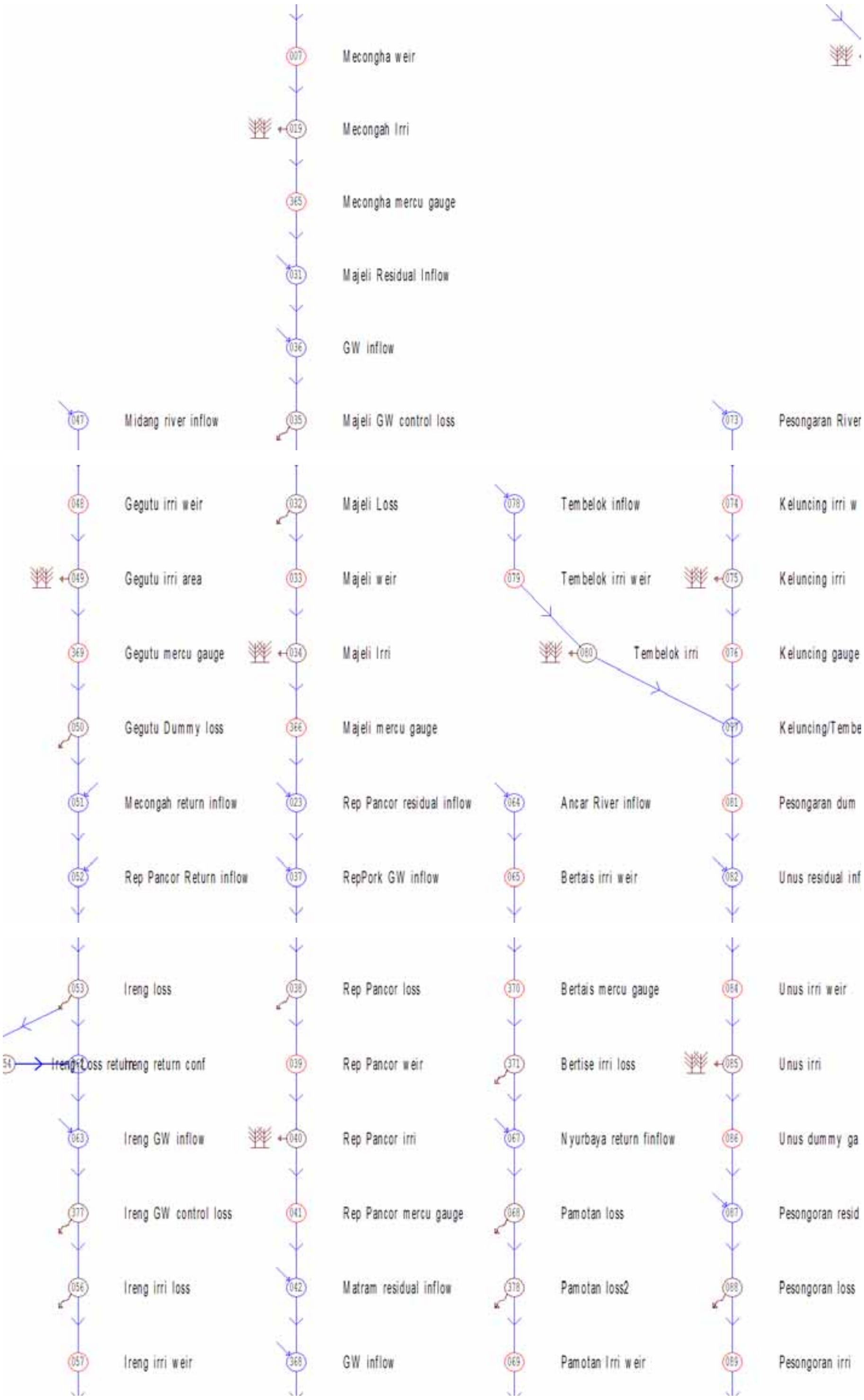
10.10.1 Overview of IQQM node network diagram

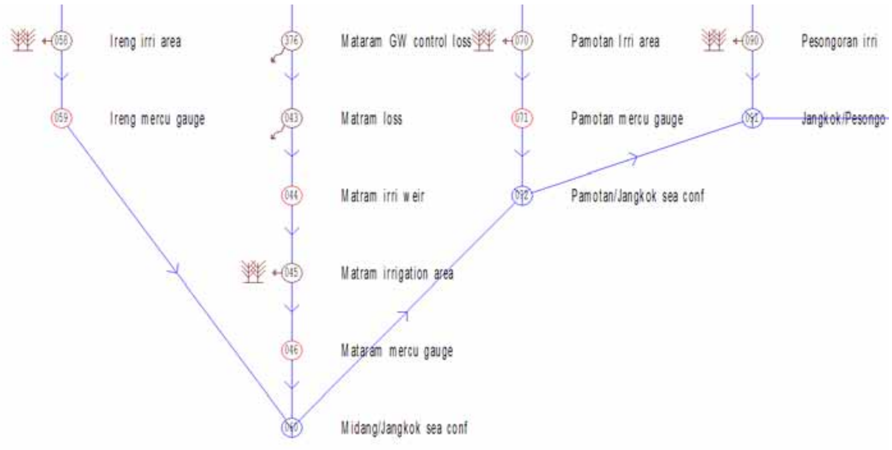



Symbols
Calibration Colour-Coding
MATARAM
DATAR
GEBONG
UPPER JURANG SATE
LOWER JURANG SATE
PENGGA
DALEM
BATUJAI
SURABAYA
MUJUR
GEDE BONGOH
SRIGANGGA
RENGGUNG
NYEREDEP
BISOK BOKAH
Upper Panang
JURANG BATU
KATON
MURUR
KULEM
TIBUNANGKA
RUTUS
SAKRA
SWANGI
PANDANDURI
RUNTAK
Australian Government
Australian Centre for International Agricultural Research
Southern Lombok Irrigation System
IQQM Node Layout with Calibration Quality Indicators
and CropOptimiser SubArea/Node Associations

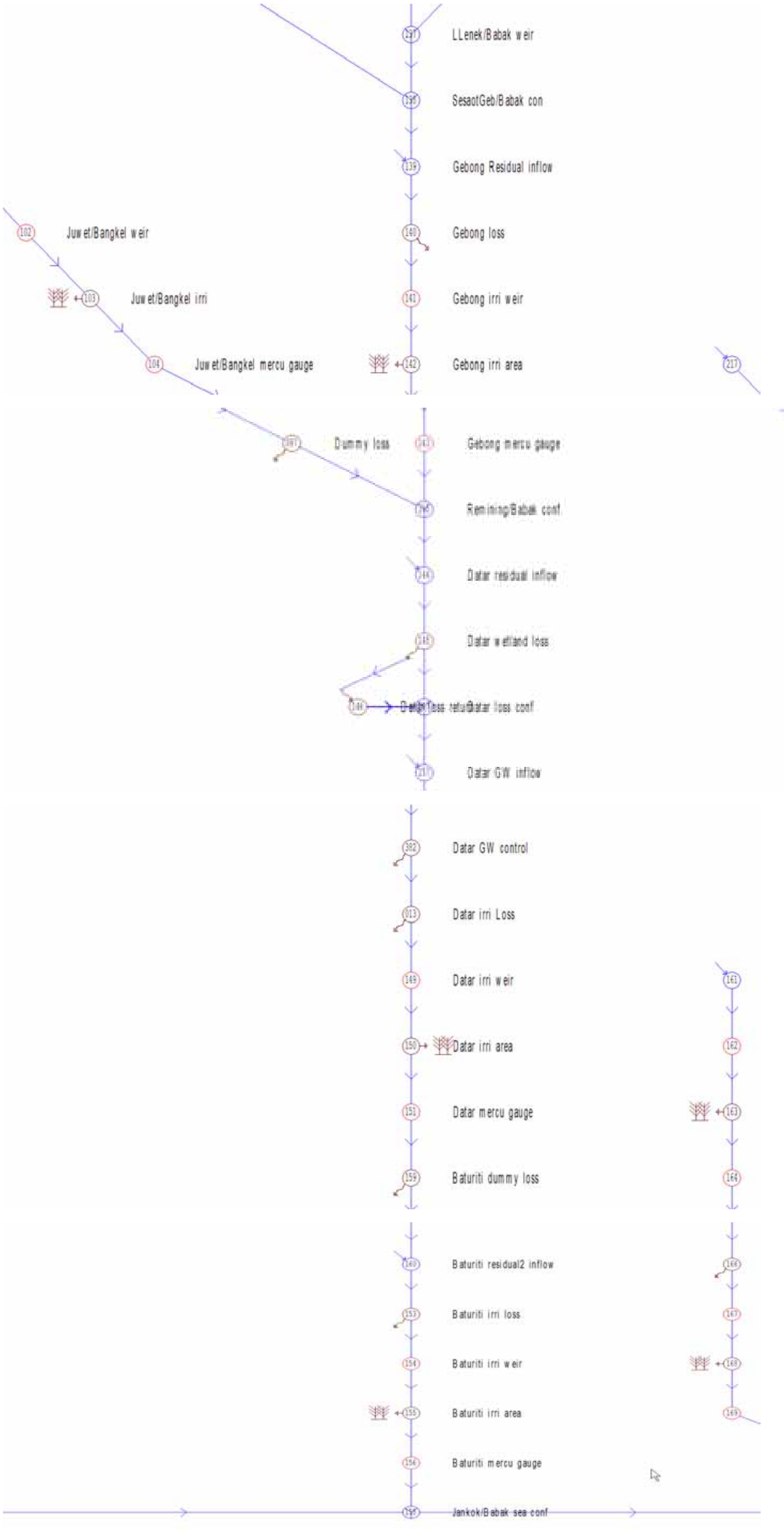
10.10.2 Configuration of Lombok IQQM: Jangkok/Sesoat River sub-basin.



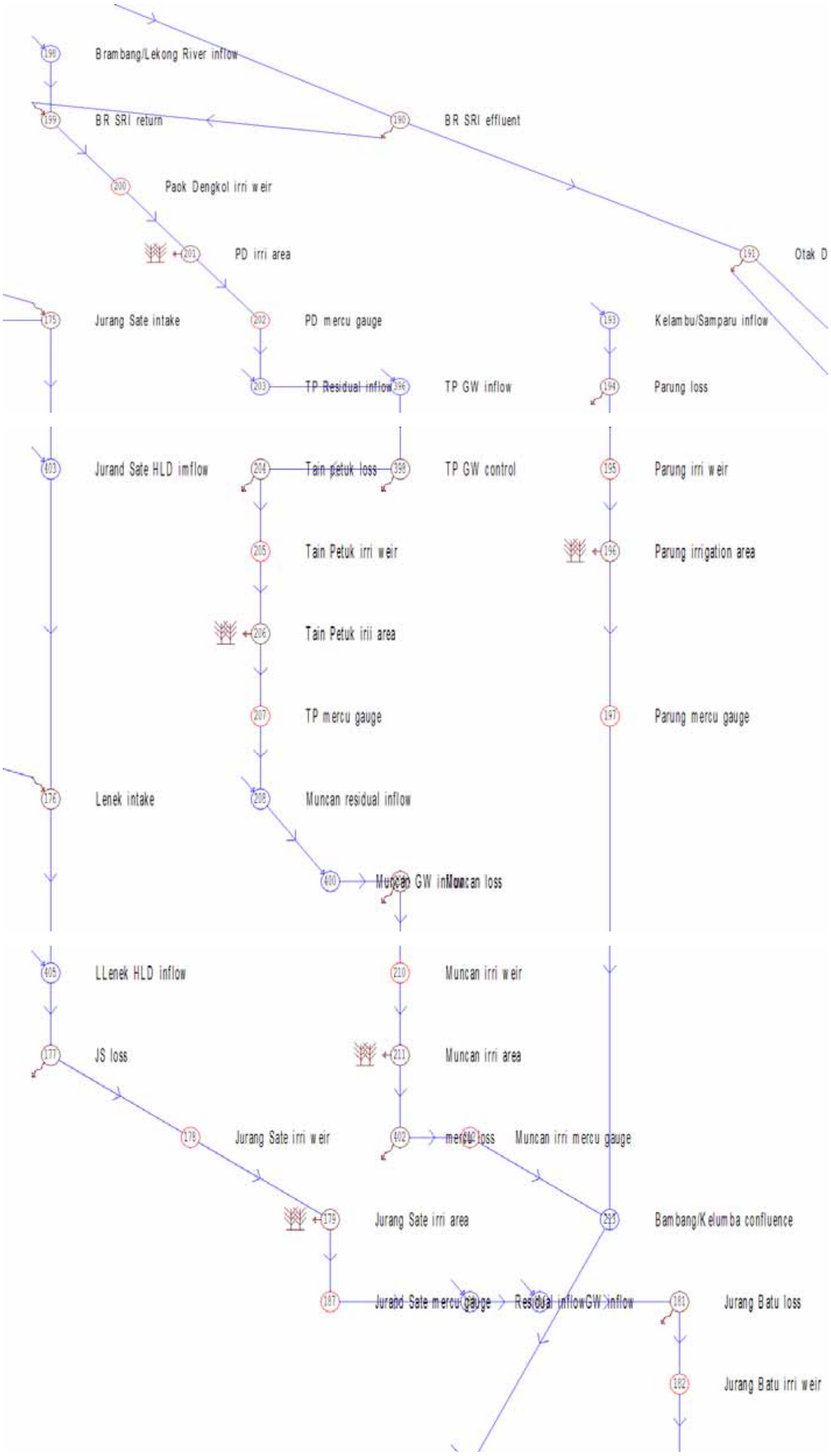

Mecongha weir
Mecongah Irri
Mecongha mercu gauge
Majeli Residual Inflow
GW inflow
Midang river inflow
Majeli GW control loss
Pesongaran River
Gegutu irri weir
Majeli Loss
Tembelok inflow
Keluncing irri w
Gegutu irri area
Majeli weir
Tembelok irri weir
Kelucing irri
Gegutu mercu gauge
Majeli Irri
Tembelok irri
Kelucing gauge
Gegutu Dummy loss
Majeli mercu gauge
Keluncing/Tembe
Mecongah return inflow
Rep Pancor residual inflow
Ancar River inflow
Pesongaran dum
Rep Pancor Return inflow
RepPork GW inflow
Bertais irri weir
Unus residual inf
Ireng loss
Rep Pancor loss
Bertais mercu gauge
Unus irri weir
Ireng return conf
Rep Pancor weir
Bertise irri loss
Unus irri
Ireng GW inflow
Rep Pancor irri
Nyurbaya return finflow
Unus dummy ga
Ireng GW control loss
Rep Pancor mercu gauge
Pamotan loss
Pesongoran resid
Ireng irri loss
Matram residual inflow
Pamotan loss2
Pesongoran loss
Ireng irri weir
GW inflow
Pamotan Irri weir
Pesongoran irri

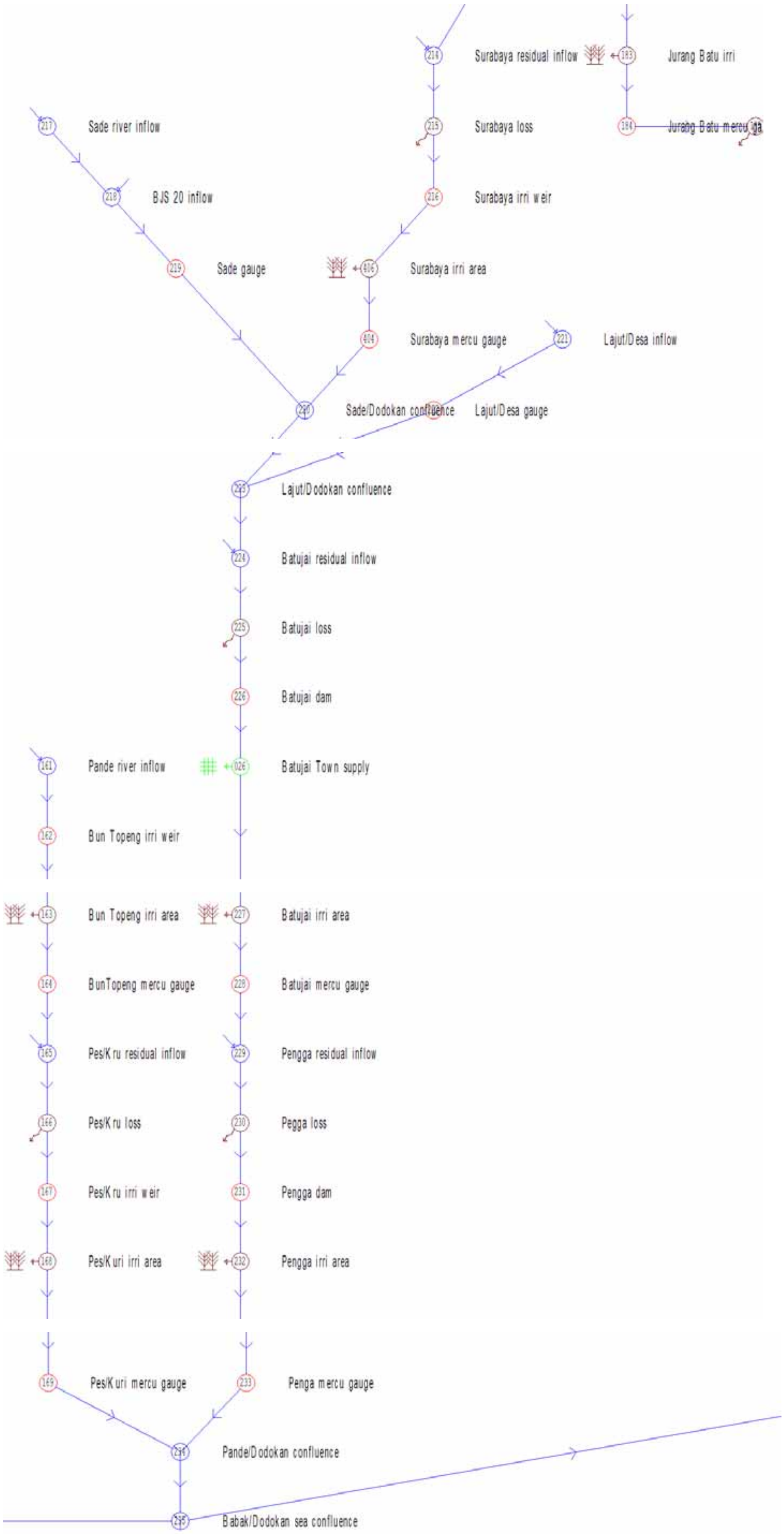

058
Ireng irri area
059
Ireng mercu gauge
376
Mataram GW control loss
043
Matram loss
044
Matram irri weir
045
Matram irrigation area
046
Mataram mercu gauge
Midang/Jangkok sea conf
070
Pamotan Irri area
071
Pamotan mercu gauge
Pamotan/Jangkok sea conf
090
Pesongoran irri
Jangkok/Pesongo

10.10.3 Configuration of Lombok IQQM: Babak River sub-basin.

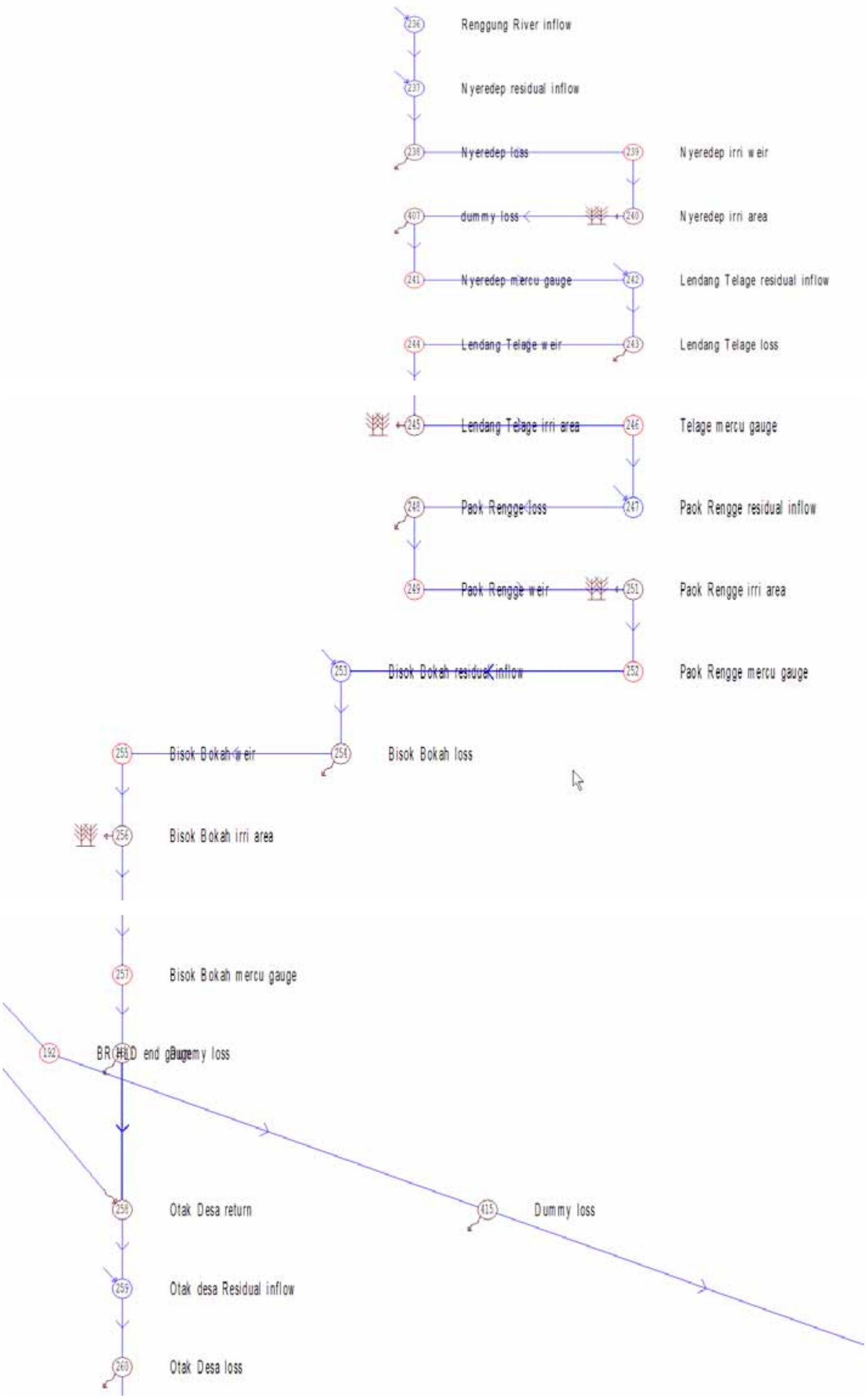

LLenek/Babak weir
SesaotGeb/Babak con
Gebong Residual inflow
Juwet/Bangkel weir
Gebong loss
Juwet/Bangkel irri
Gebong irri weir
Juwet/Bangkel mercu gauge
Gebong irri area
Dummy loss
Gebong mercu gauge
Remining/Babak conf
Datar residual inflow
Datar wetland loss
Datar loss conf
Datar GW inflow
Datar GW control
Datar irri Loss
Datar irri weir
Datar irri area
Datar mercu gauge
Baturiti dummy loss
Baturiti residual2 inflow
Baturiti irri loss
Baturiti irri weir
Baturiti irri area
Baturiti mercu gauge
Jankok/Babak sea conf

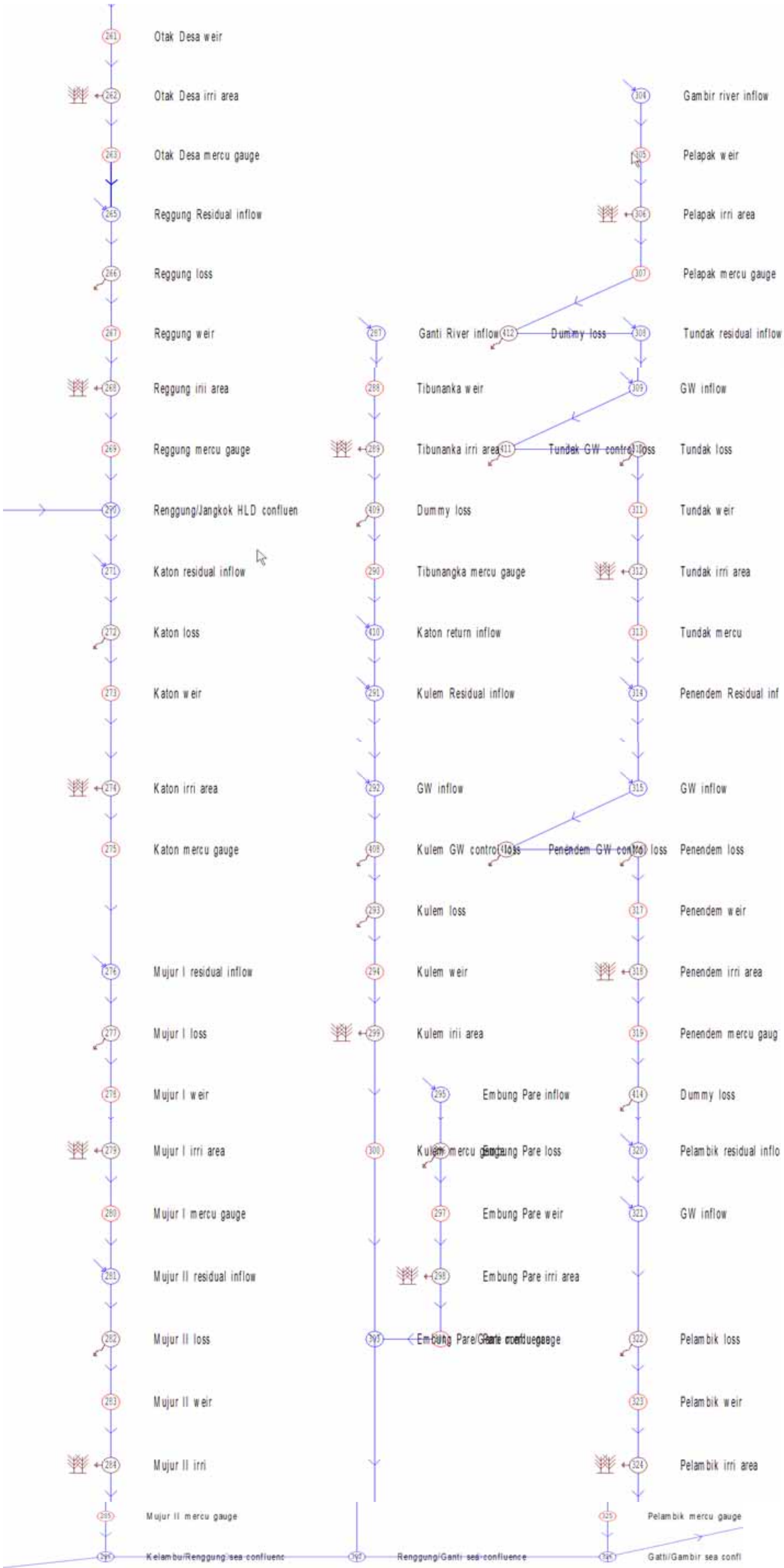
10.10.4 Configuration of Lombok IQQM: Kelambu/Semparu River sub-basin



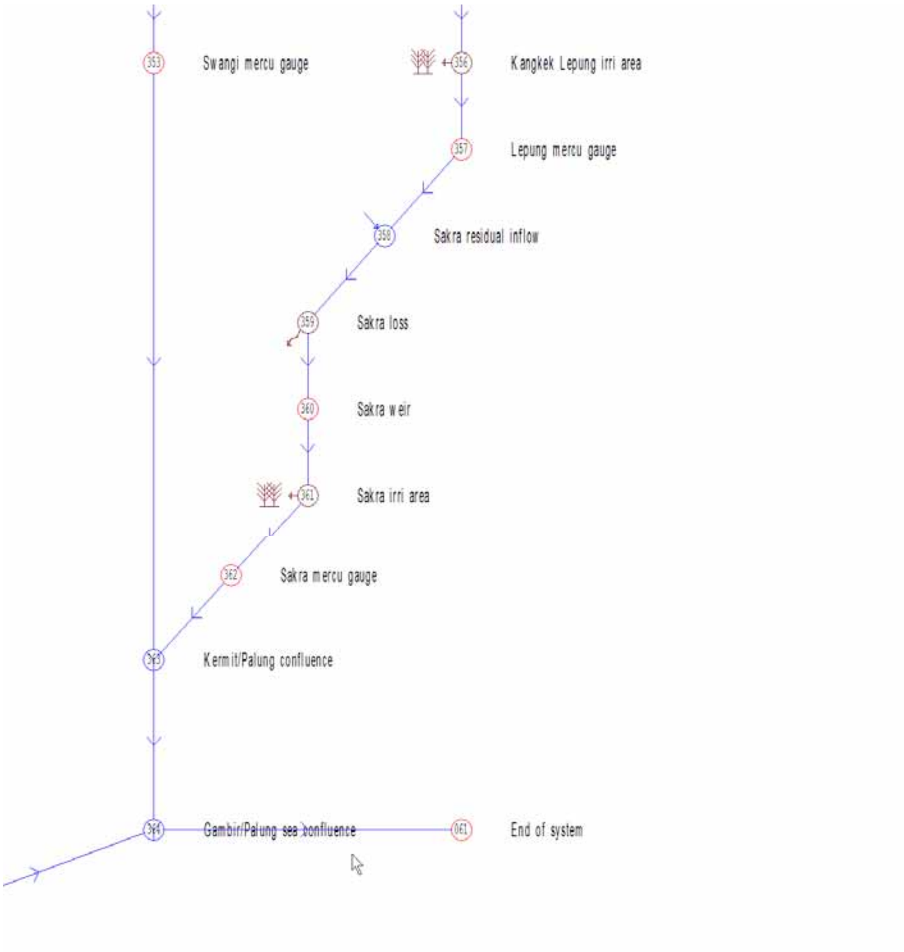

Surabaya residual inflow
Jurang Batu irri
Sade river inflow
Surabaya loss
Jurang Batu mercu ga
BJS 20 inflow
Surabaya irri weir
Sade gauge
Surabaya irri area
Surabaya mercu gauge
Lajut/Desa inflow
Sade/Dodokan confluence
Lajut/Desa gauge
Lajut/Dodokan confluence
Batujai residual inflow
Batujai loss
Batujai dam
Pande river inflow
Batujai Town supply
Bun Topeng irri weir
Bun Topeng irri area
Batujai irri area
BunTopeng mercu gauge
Batujai mercu gauge
Pes/Kru residual inflow
Pengga residual inflow
Pes/Kru loss
Pegga loss
Pes/Kru irri weir
Pengga dam
Pes/Kuri irri area
Pengga irri area
Pes/Kuri mercu gauge
Penga mercu gauge
Pande/Dodokan confluence
Babak/Dodokan sea confluence

10.10.5 Configuration of Lombok IQQM: Reggung River sub-basin




Otak Desa weir
Otak Desa irri area
Otak Desa mercu gauge
Reggung Residual inflow
Reggung loss
Reggung weir
Reggung irri area
Reggung mercu gauge
Renggung/Jangkok HLD confluen
Katon residual inflow
Katon loss
Katon weir
Katon irri area
Katon mercu gauge
Mujur I residual inflow
Mujur I loss
Mujur I weir
Mujur I irri area
Mujur I mercu gauge
Mujur II residual inflow
Mujur II loss
Mujur II weir
Mujur II irri
Mujur II mercu gauge
Kelambu/Renggung sea confluenc
Ganti River inflow
Dummy loss
Tibunanka weir
Tibunanka irri area
Tundak GW control loss
Dummy loss
Tibunangka mercu gauge
Katon return inflow
Kulem Residual inflow
GW inflow
Kulem GW control loss
Penendem GW control loss
Kulem loss
Kulem weir
Kulem irri area
Embung Pare inflow
Kulem mercu gauge
Embung Pare loss
Embung Pare weir
Embung Pare irri area
Embung Pare/Ganti confluence
Renggung/Ganti sea confluence
Gambir river inflow
Pelapak weir
Pelapak irri area
Pelapak mercu gauge
Tundak residual inflow
GW inflow
Tundak loss
Tundak weir
Tundak irri area
Tundak mercu
Penendem Residual inf
GW inflow
Penendem loss
Penendem weir
Penendem irri area
Penendem mercu gaug
Dummy loss
Pelambik residual inflo
GW inflow
Pelambik loss
Pelambik weir
Pelambik irri area
Pelambik mercu gauge
Gatti/Gambir sea confl

10.10.6 Configuration of Lombok IQQM: Rutus River sub-basin



353
Swangi mercu gauge
356
Kangkek Lepung irri area
357
Lepung mercu gauge
358
Sakra residual inflow
359
Sakra loss
360
Sakra weir
361
Sakra irri area
362
Sakra mercu gauge
363
Kermit/Palung confluence
364
Gambir/Palung sea confluence
061
End of system

10.11 Appendix 11: IHACRES calibration outputs

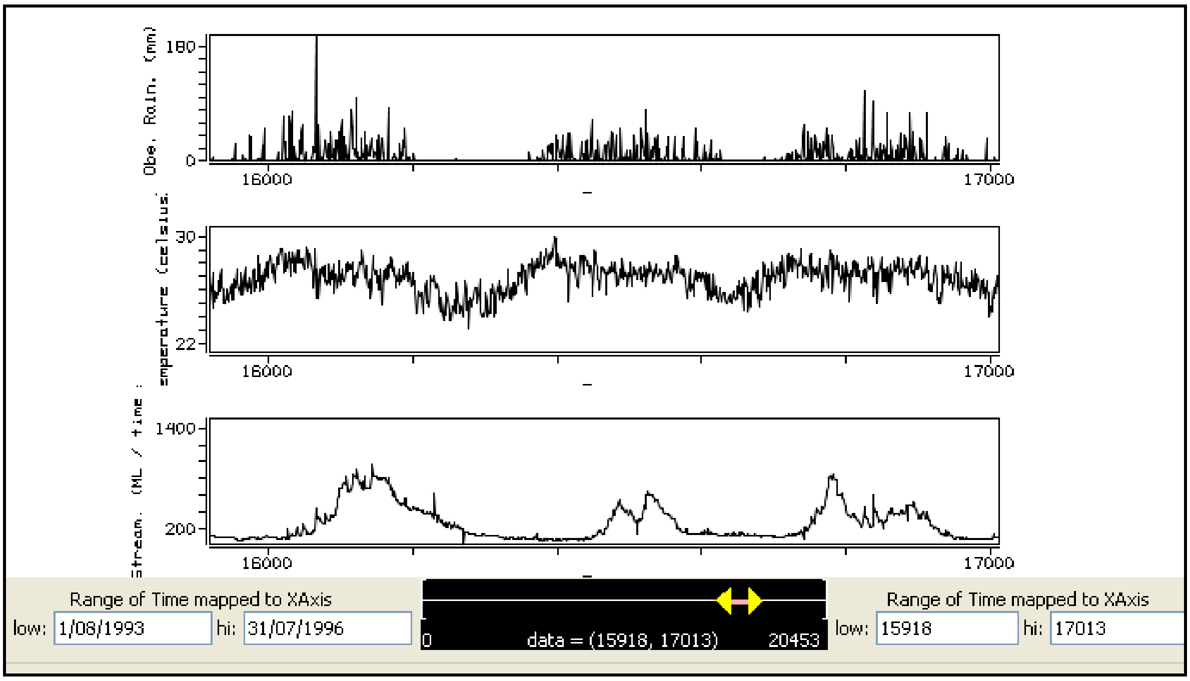


Figure A11.1 Calibration period selection for Sesaot River at Kelling.

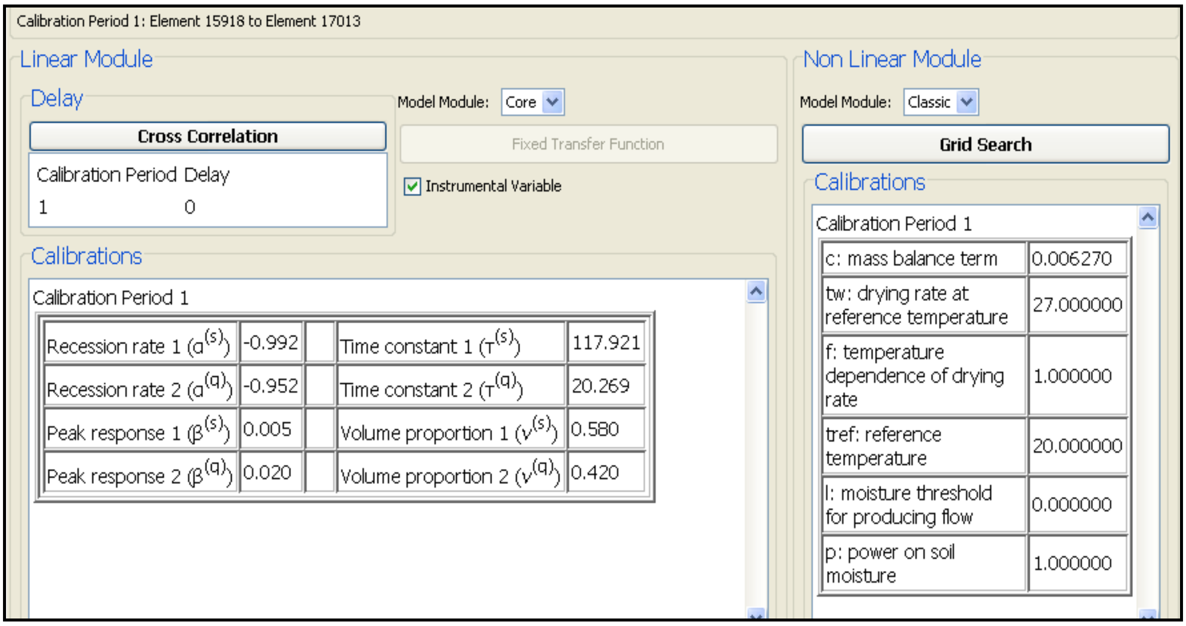


Figure A11.2 Calibration parameters for Sesaot River at Kelling accepted for simulation.

Period	Numbe...	P (mm/yr)	Q (mm/...	Bias (m...	Rel. Bias	R Squa...	R2_sqrt	R2_log	R2_inv	Monthl...	U 1	X 1	(U > R)...
Calibratio...	1096	2754	3936	-98.512	-0.026	0.756	0.741	0.731	0.678	0.797	0.029	-0.008	351.000
Rest	1826	2647	3473	515.549	0.154	0.244	0.412	NaN	NaN	0.294	-0.066	-0.225	4549.000
Year 1	0	3203	3111	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	102.000
Year 2	0	2033	2729	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	49.000
Year 3	0	2551	2937	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	104.000
Year 4	0	2464	3029	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	73.000
Year 5	0	3608	4888	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	146.000
Year 6	0	4047	5955	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	152.000
Year 7	0	3185	4888	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	114.000
Year 8	0	2441	3133	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	95.000
Year 9	0	2212	2072	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	30.000
Year 10	0	2730	2703	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	79.000
Year 11	0	2634	3994	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	77.000
Year 12	0	1472	1251	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	10.000
Year 13	0	2702	3284	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	87.000
Year 14	0	1979	2209	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	42.000
Year 15	0	3365	4044	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	97.000
Year 16	0	2419	4154	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	75.000
Year 17	0	2045	2394	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	43.000
Year 18	0	2072	2174	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	74.000
Year 19	0	4395	7602	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	133.000
Year 20	0	1783	2417	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	53.000
Year 21	0	3109	3751	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	105.000
Year 22	0	2863	4175	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	90.000
Year 23	0	1609	1583	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	33.000
Year 24	0	3793	4323	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	140.000

Figure A11.3 Statistical summary of calibration of Sesaot River at Kelling.

Date and Time	Obs. Rain. (...	Temperatur...	Obs. Strea...	Eff. Rain. (...	Mod. Strea...	Drying time ...	Wetness in...
1950/01/01 1...	0.000000	26.250000	-1.000000	0.000000	0.000000	18.326294	0.000000
1950/01/02 1...	0.000000	25.750000	-1.000000	0.000000	0.000000	18.903307	0.000000
1950/01/03 1...	51.599998	25.950001	-1.000000	16.692976	10.480891	18.670353	0.323507
1950/01/04 1...	0.000000	26.900000	-1.000000	0.000000	10.057495	17.602428	0.305129
1950/01/05 1...	0.000000	27.500000	-1.000000	0.000000	9.653796	16.959648	0.287137
1950/01/06 1...	0.000000	26.950001	-1.000000	0.000000	9.268850	17.547945	0.270774
1950/01/07 1...	0.000000	27.100000	-1.000000	0.000000	8.901762	17.385506	0.255200
1950/01/08 1...	0.000000	25.100000	-1.000000	0.000000	8.551677	19.680668	0.242233
1950/01/09 1...	0.000000	25.700001	-1.000000	0.000000	8.217781	18.961996	0.229458
1950/01/10 1...	0.000000	25.750000	-1.000000	0.000000	7.899302	18.903307	0.217319
1950/01/11 1...	0.000000	27.049999	-1.000000	0.000000	7.595504	17.439486	0.204858
1950/01/12 1...	14.500000	27.500000	-1.000000	4.113461	9.888371	16.959648	0.283687
1950/01/13 1...	0.000000	28.299999	-1.000000	0.000000	9.507530	16.138971	0.266109
1950/01/14 1...	0.000000	27.500000	-1.000000	0.000000	9.144217	16.959648	0.250418
1950/01/15 1...	15.900000	27.299999	-1.000000	5.334772	12.147101	17.171257	0.335520
1950/01/16 1...	0.000000	28.000000	-1.000000	0.000000	11.681067	16.441965	0.315114
1950/01/17 1...	1.700000	27.400000	-1.000000	0.522421	11.564474	17.065125	0.307307
1950/01/18 1...	0.000000	28.799999	-1.000000	0.000000	11.127030	15.646338	0.287666
1950/01/19 1...	0.000000	27.950001	-1.000000	0.000000	10.709637	16.493013	0.270224
1950/01/20 1...	0.500000	27.450001	-1.000000	0.128737	10.392167	17.012304	0.257475
1950/01/21 1...	5.300000	27.850000	-1.000000	1.458501	10.924524	16.595587	0.275189
1950/01/22 1...	13.100000	28.000000	-1.000000	4.461631	13.322908	16.441965	0.340583
1950/01/23 1...	13.200000	29.100000	-1.000000	5.295364	16.149956	15.358006	0.401164
1950/01/24 1...	70.699997	28.900000	-1.000000	57.876446	51.879124	15.549631	0.818620
1950/01/25 1...	0.100000	27.700001	-1.000000	0.077038	49.878162	16.750647	0.770376
1950/01/26 1...	3.500000	27.100000	-1.000000	2.618028	49.565510	17.385506	0.748008

Calibration Period	
P (mm/yr)	2754.066650
Q (mm/yr)	3936.878418
Bias (mm/yr)	-98.511795
Rel. Bias	-0.025679
R Squared	0.755549
R2_sqrt	0.741079
R2_log	0.731344
R2_inv	0.677822
MonthlyR2	0.797382
U 1	0.028929
X 1	-0.008232
(U > R) steps	351.000000

Figure A11.4 Simulation summary for Sesaot River at Kelling.

10.12 Appendix 12: Selected calibration results of Lombok IQQM

The calibration has been conducted for each irrigation node in the Lombok River irrigation management system. Here below are the results of several nodes which represent different sub-basins.

10.12.1 Calibration of total flow and diversion flow at Nyurbay airrigation area in Jangkok sub-basin

The simulated daily time series and ranked daily flow frequency against recorded flows are shown Figure A12.1 and Figure A12.2. Table A12.1 shows that the calibration has achieved a quality rating from 'Adequate' to 'Good' for the flow frequency. Among the three parameters which indicate the quality rating of the daily time series, the intercept (b), the slope (m) and the coefficient of determination (r2) have all achieved 'Adequate'.

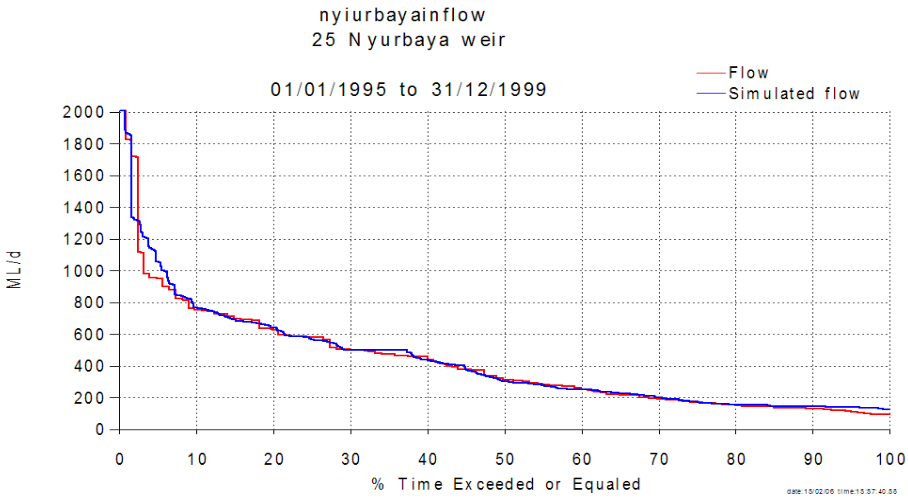


Figure A12.1 Flow frequency comparison at Nyurbaya irrigation weir (01/01/1996–31/12/1999).

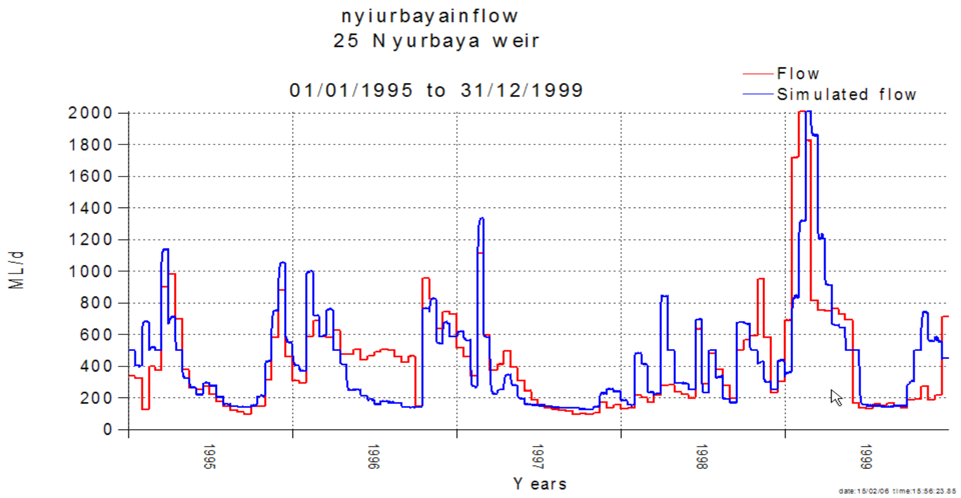


Figure A12.2 Simulated and observed daily time series at Nyurbaya irrigation weir (01/01/1996–31/12/1999).

Table A12.1 Calibration quality indicators (01/01/1996–31/12/1999) for total flow at Nyurbaya irrigation weir.

Flow frequency – volume ratio percentages							Time series match (y=mx+b)		
Whole range	**Low range**	**Middle range**	**High range**	**5%ile point**	**50%ile point**	**95%ile point**	**m(slope)**	**b (intercept)**	**r2 coefficient**
101.9%	109.1%	100.2%	103.0 %	111.0%	97.5%	123.7%	0.75	115.1 (35.1%)	0.60
Fair	Fair	Good	Good	Fair	Good	Adequate	Adequate	Adequate	Adequate

The size of the irrigation is 439 ha. In one growing season (12 months), one rice crop is grown from November to February, another is from March to June, and the third crop is normally a secondary crop grown from July to October. Figure A12.3 shows overestimates of annual diversion during the five year period. Further quality assessment of the calibration shown in Table A12.2 suggests that the calibration quality of annual diversion volume is “Adequate”. In the middle range of the monthly diversion frequency curve the calibration quality rating is “Adequate”; however in the low and high ranges the quality ratings are less than “Adequate”. The reason for the discrepancy has been discussed in the Montang.

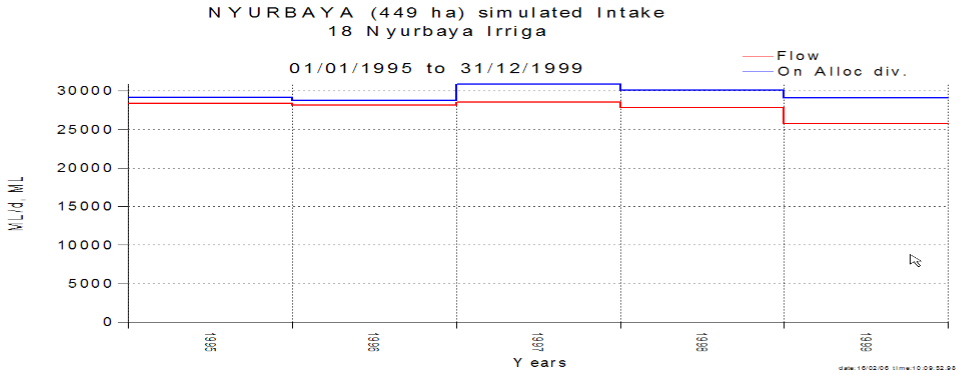


Figure A12.3 Simulated and observed annual diversion at Nyurbaya irrigation weir.

Table A12.2 Diversion calibration quality indicators for Nyurbaya irrigation area.

Annual diversion (volume ratio, %)	Monthly diversion frequency (volume ratio, %)		
106.8 Adequate	Low range	Mid range	High range
	18.9	136.2	156.9
	<Adequate	Adequate	<Adequate

10.12.2 Calibration of total flow and diversion flow at JurangSate irrigation area (10,449 ha) in HLD

Figure A12.4 and Figure A12.5 show the simulated daily time series and ranked daily flow frequency against recorded ones. Table A12.3 shows that the calibration has achieved a quality rating of “Good” for all ranges and checkpoints of the flow frequency. Among the three parameters which indicate the quality rating of the daily time series, the slope (m) is “Adequate”, and both the intercept (b) and the coefficient of determination (r2) are “Fair”.

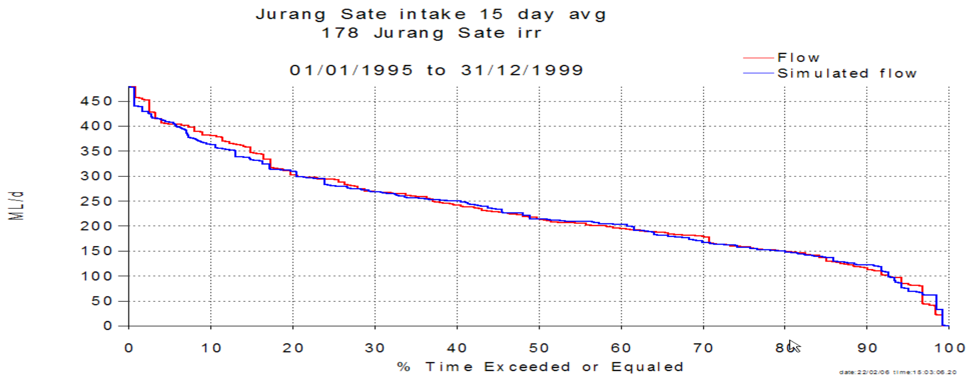


Figure A12.4 Simulated and observed flow frequency of total flow at Jurang Sate irrigation weir (01/01/1996–31/12/1999).

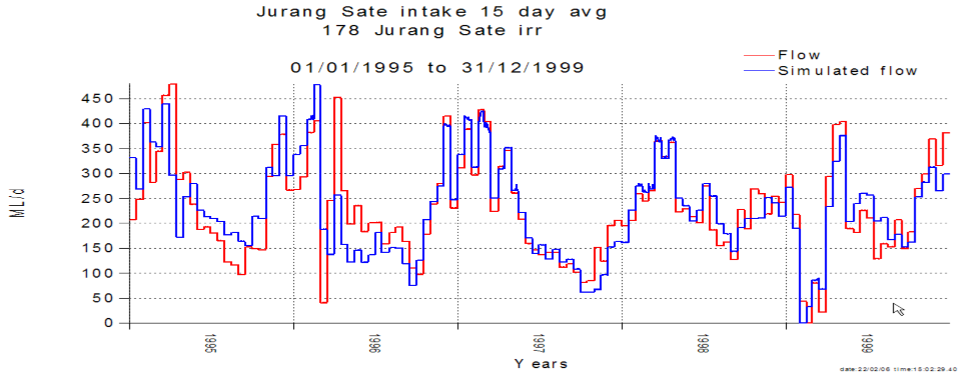


Figure A12.5 Simulated and observed daily time series of total flow at Jurang Sate irrigation weir (01/01/1996–31/12/1999).

Table A12.3 Calibration quality indicators (01/01/1996 – 31/12/1999) for total flow at Jurang Sate irrigation weir.

Flow frequency – volume ratio percentages							Time series match (y=mx+b)		
Whole range	**Low range**	**Middle range**	**High range**	**5%ile point**	**50%ile point**	**95%ile point**	**m(slope)**	**b (intercept)**	**r2 coefficient**
99.2%	100.8%	99.3%	97.6%	100.9%	100.0%	88.1%	0.82	38.7 (16.8%)	0.75
Good	Good	Good	Good	Good	Good	Adequate	Adequate	Fair	Fair

Figure A12.6 shows underestimates of annual diversion over the 5 year period. Table A12.4 suggests that the calibration quality of annual diversion volume is “Fair”. For the flow frequency of monthly diversion, in the low range the quality rating is “Fair”, and in the middle and high ranges they are “Good”.

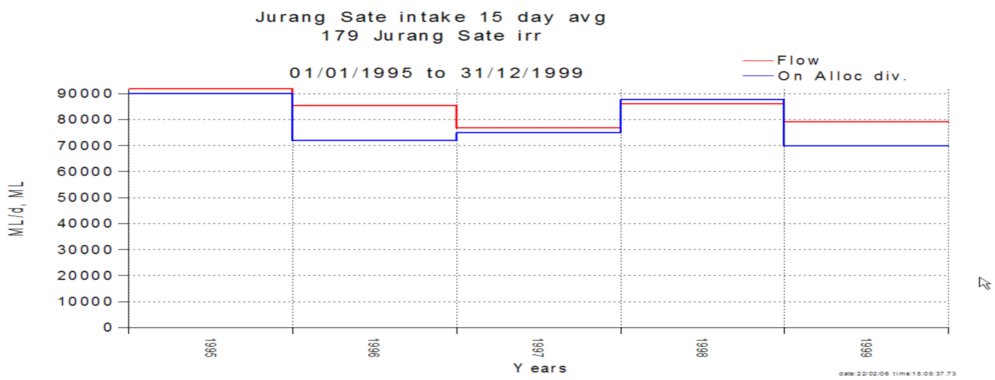


Figure A12.6 Simulated and observed annual diversion at Jurang Sate irrigation weir.

Table A12.4 Diversion calibration quality indicators for Jurang Sate irrigation area.

Annual diversion (volume ratio, %)	Monthly diversion frequency (volume ratio, %)		
94.1 Fair	Low range	Mid range	High range
	84.5	94.8	102.4
	Fair	Good	Good

10.12.3 Calibration of total flow and diversion flow at Surabaya irrigation area in Kelambu/Semparu/Dodokan River sub-basin

Figure A12.7 and Figure A12.8 show the simulated daily time series and ranked daily flow frequency against recorded ones. Table A12.5 shows that the calibration has achieved a quality rating from ‘Adequate’ to ‘Good’ for the flow frequency. Among the three parameters which indicate the quality rating of the daily time series, the intercept (b) achieved ‘Adequate’; however the slope (m) and the coefficient of determination (r2) are less than ‘Adequate’.

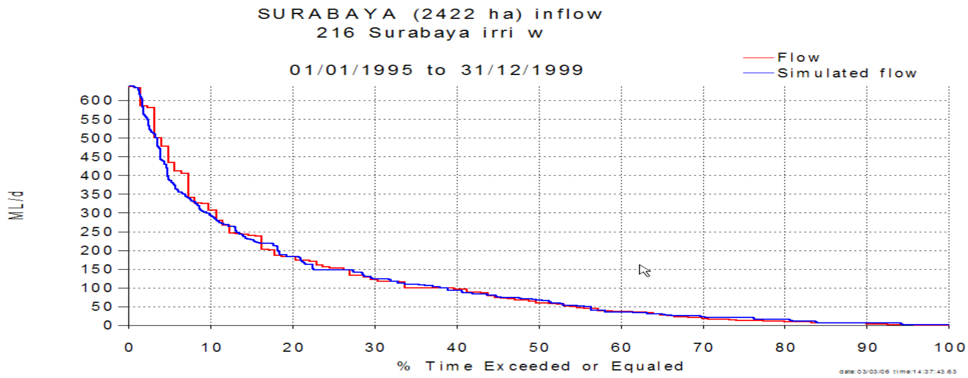


Figure A12.7 Simulated and observed flow frequency of total flow at Surabaya irrigation weir (01/01/1995–31/12/1999).

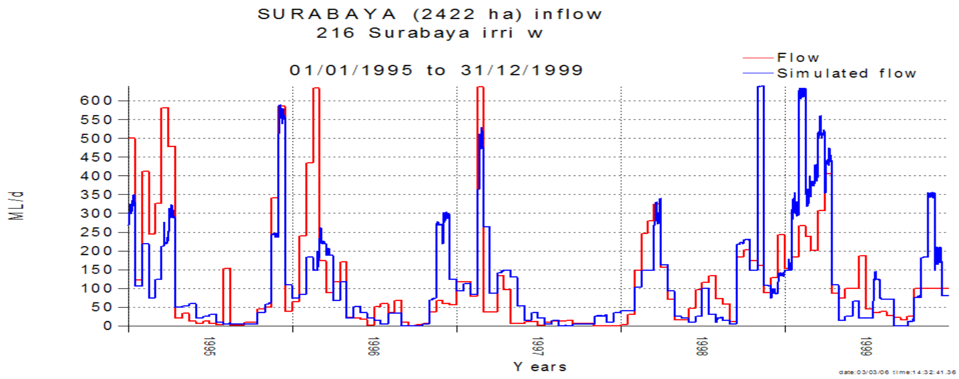


Figure A12.8 Simulated and observed daily time series of total flow at Surabaya irrigation weir (01/01/1995–31/12/1999).

Table A12.5 Calibration quality indicators (01/01/1995–31/12/1999) for total flow at Surabaya irrigation weir.

Flow frequency – volume ratio percentages							Time series match (y=mx+b)		
Whole range	**Low range**	**Middle range**	**High range**	**5%ile point**	**50%ile point**	**95%ile point**	**m(slope)**	**b (intercept)**	**r2 coefficier**
98.7%	125.0%	100.7%	94.0%	89.6%	112.7%	100.0%	0.63	40.0 (35.3%)	0.44
Fair	Adequate	Good	Fair	Adequate	Adequate	Good	Less than Adequate	Adequate	Less than Adequate

Figure A12.9 shows both overestimates and underestimates of annual diversion over the 5 year period. Table A12.6 suggests that the calibration quality of annual diversion volume is “Good”. For the flow frequency of monthly diversion, in the middle and high ranges the quality ratings are “Good” and “Adequate”, respectively; however in the low range it is less than “Adequate”.

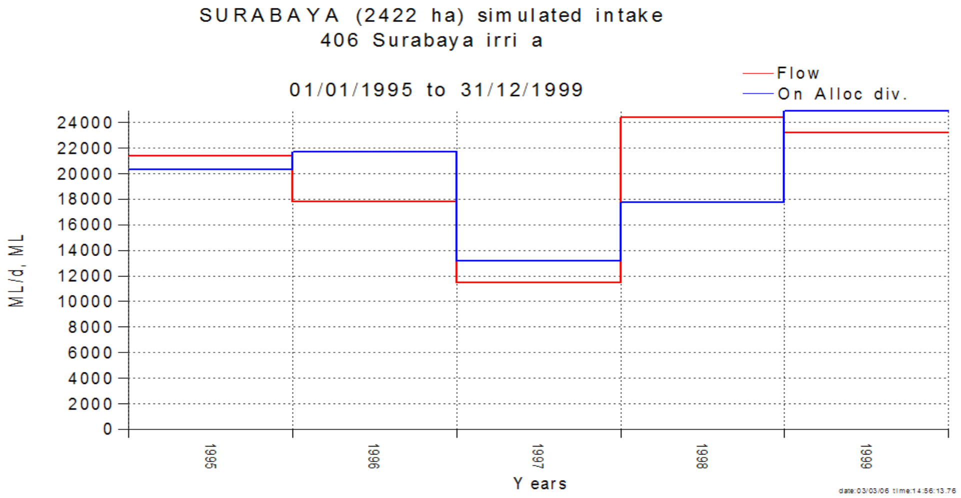


Figure A12.9 Simulated and observed annual diversion at Surabaya irrigation weir.

Table A12.6 Diversion calibration quality indicators for Surabaya irrigation area.

Annual diversion (volume ratio, %)	Monthly diversion frequency (volume ratio, %)		
99.6 Good	Low range	Mid range	High range
	0.0	101.8	127.8
	<Adequate	Good	Adequate

10.12.4 Calibration of total flow and diversion flow calibration at Katon irrigation area in Reggung River sub-basin

Figure A12.10 and Figure A12.11 show the simulated daily time series and ranked daily flow frequency against recorded ones. Table 12.7 shows that the calibration has achieved a quality rating from “Adequate” to “Good” for the flow frequency. Among the three parameters which indicate the quality rating of the daily time series, the intercept (b) and the slope (m) achieved “Adequate”; however the coefficient of determination (r2) is less than “Adequate”.

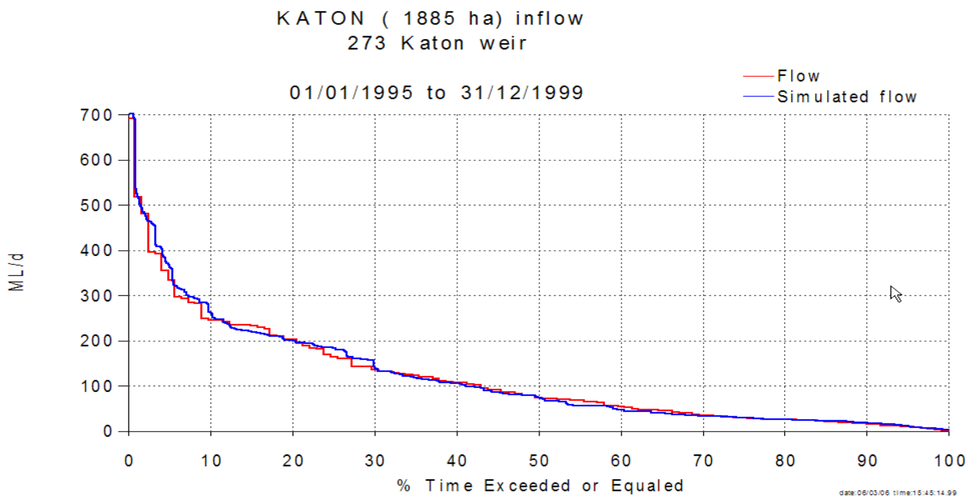


Figure A12.10 Simulated and observed flow frequency of total flow at Katon irrigation weir (01/01/1995–31/12/1999).

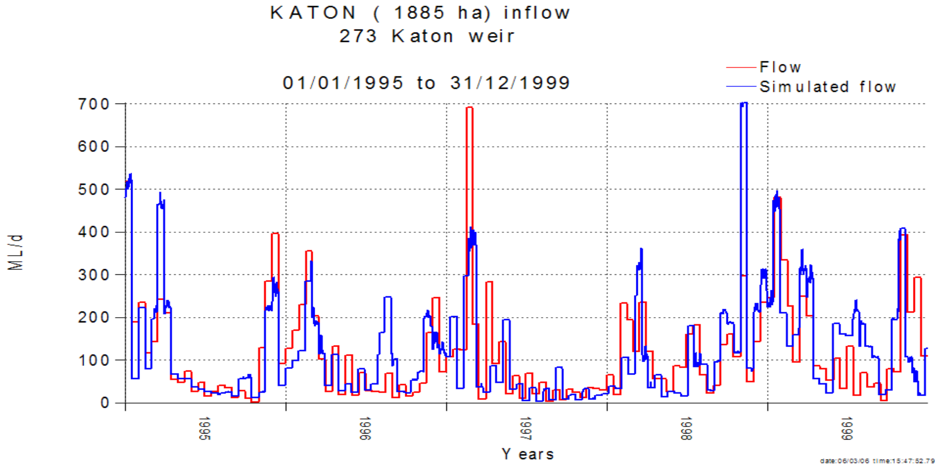


Figure A12.11 Simulated and observed daily time series of total flow at Katon irrigation weir (01/01/1995–31/12/1999).

Table A12.7 Calibration quality indicators (01/01/1995–31/12/1999) for total flow at Katon irrigation weir.

Flow frequency – volume ratio percentages							Time series match (y=mx+b)		
Whole range	**Low range**	**Middle range**	**High range**	**5%ile point**	**50%ile point**	**95%ile point**	**m(slope)**	**b (intercept)**	**r2 coefficient**
100.9%	104.2%	98.3%	105.5%	110.0%	100.0%	116.1%	0.71	34.6 (29.6%)	0.46
Good	Good	Good	Fair	Fair	Good	Adequate	Adequate	Adequate	Less than Adequate

Figure A12.12 shows both overestimates and underestimates of annual diversion over the 5 year period. Table A12.8 suggests that the calibration quality of annual diversion volume is “Good”. For the flow frequency of monthly diversion, in the low range the quality rating is “Adequate”, in the middle it is “Good”; however in the high range it is less than “Adequate”.

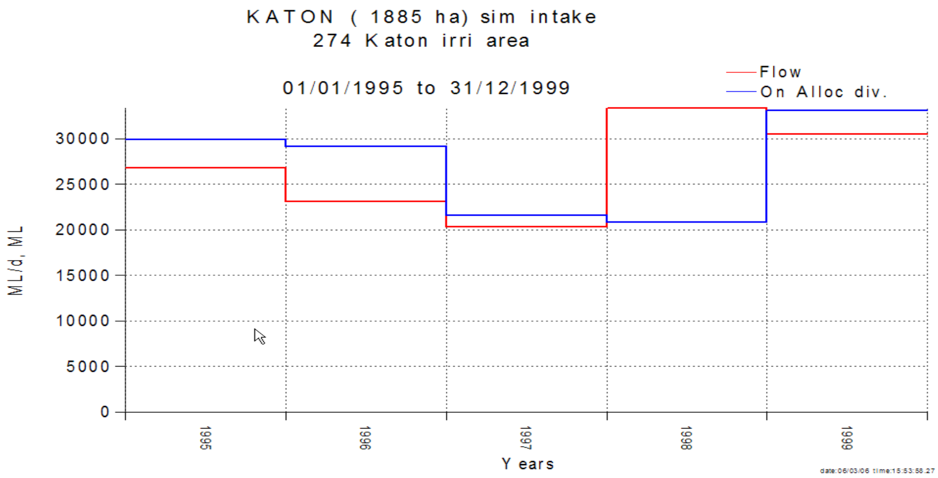


Figure A12.12 Simulated and observed annual diversion at Katon irrigation weir.

Table A12.8 Diversion calibration quality indicators for Katon irrigation area.

Annual diversion (volume ratio, %)	Monthly diversion frequency (volume ratio, %)		
100.3 Good	Low range	Mid range	High range
	60.0	91.6	153.7
	Adequate	Good	<Adequate

10.12.5 Calibration of total flow and diversion flow at Gebong irrigation area in Babak sub-basin

Figure A12.13 and Figure A12.14 show the simulated daily time series and ranked daily flow frequency against recorded ones. Table A12.9 shows that the calibration has achieved a quality rating from "Adequate" to "Good" for the flow frequency. Among the three parameters which indicate the quality rating of the daily time series, the intercept (b), the slope (m) and the determination coefficient (r2) have all achieved "Adequate".

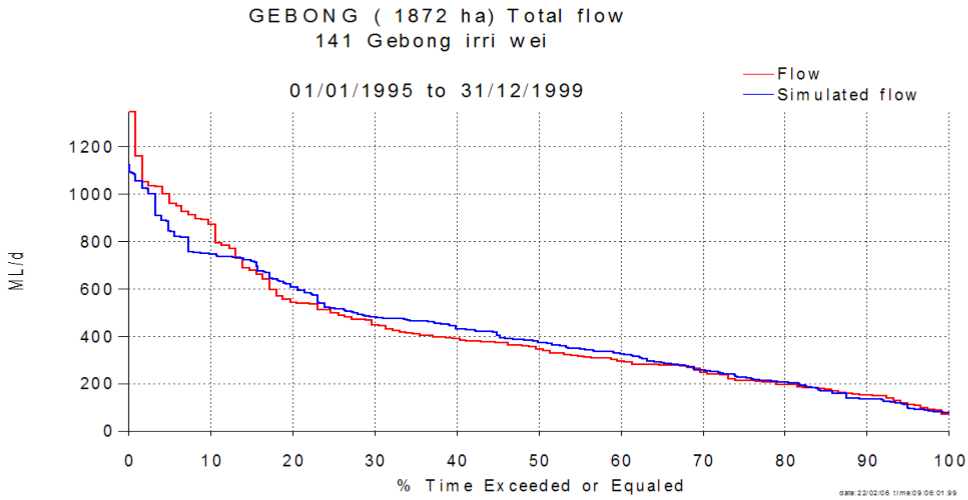


Figure A12.13 Simulated and observed flow frequency of total flow at Gebong irrigation weir (01/01/1995–31/12/1999).

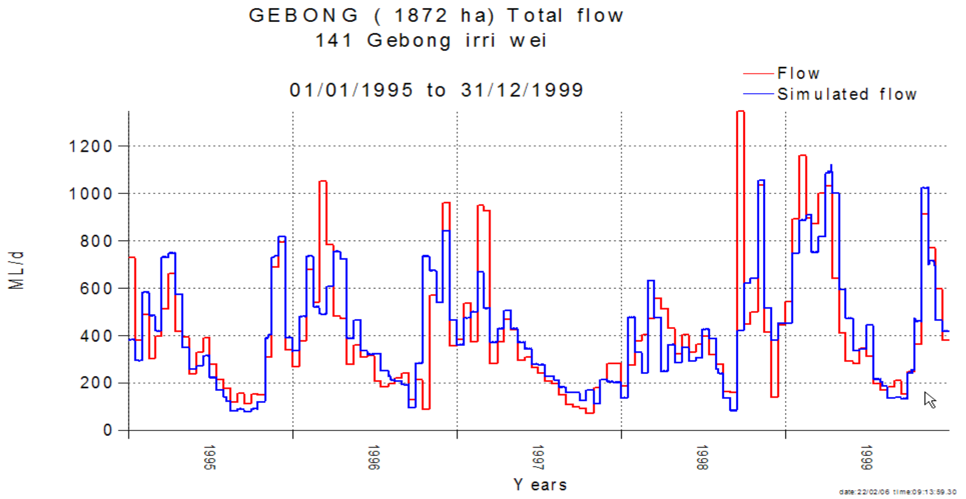


Figure A12.14 Simulated and observed daily time series of total flow at Gebong irrigation weir (01/01/1995–31/12/1999).

Table A12.9 Calibration quality indicators (01/01/1995–31/12/1999) for total flow at Gebong irrigation weir

Flow frequency – volume ratio percentages							Time series match (y=mx+b)		
Whole range	Low range	Middle range	High range	5%ile point	50%ile point	95%ile point	m(slope)	b (intercept)	r2 coefficient
101.0%	99.2%	106.5 %	87.8%	86.0%	108.1%	95.6%	0.71	124.0 (30.0%)	0.62
Good	Good	Fair	Adequate	Adequate	Fair	Good	Adequate	Adequate	Adequate

Figure A12.15 shows both overestimates and underestimates of annual diversion over the 5 year period. Table A12.10 suggests that the calibration quality of annual diversion volume is "Good". For the flow frequency of monthly diversion, in the middle range the quality rating is “Good”; however in the low and high ranges they are less than “Adequate”.

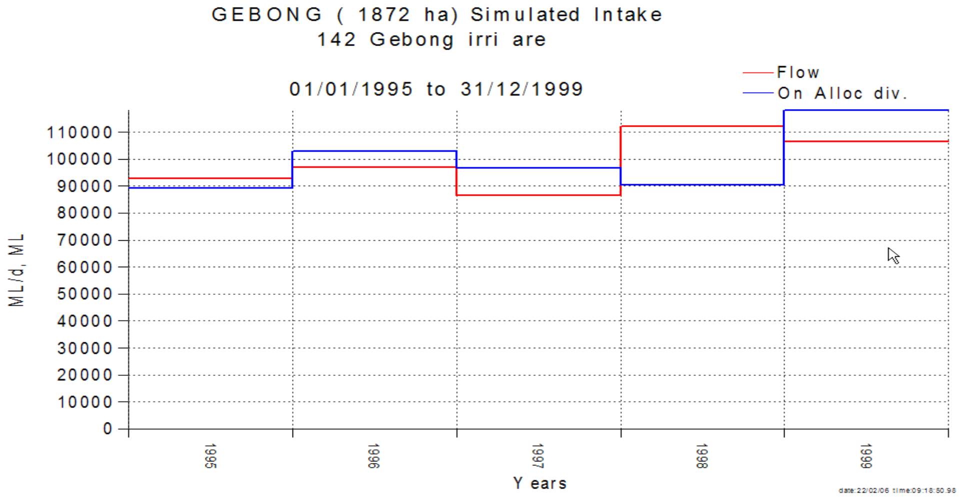


Figure A12.15 Simulated and observed annual diversion at Gebong irrigation.

Table A12.10 Diversion calibration quality indicators for Gebong irrigation area

Annual diversion (volume ratio, %)	Monthly diversion frequency (volume ratio, %)		
100.5 Good	Low range	Mid range	High range
	31.2	110.0	148.3
	<Adequate	Good	<Adequate

10.13 Appendix 13: Water balance formulation

The total amount of water required by a crop [seasonal water demand, (SWD)] depends on the precipitation during cropping sequence, and rooting depth and hydraulic properties of the soils (Jensen, 1980). Using the water balance model this can be written as:

$$SWD \cong ET + RO + SP = I + RF + GW + ASW \qquad \text{(A13.1)}$$

Where SWD is seasonal water demand, ET, RO and SP are water loss through evapotranspiration, runoff and seepage and percolation respectively, ASW is available soil water stored in the rooting zone, I is irrigation, RF is rainfall, and GW is groundwater contribution. The left hand side of the equation is water loss through evapotranspiration seepage and percolation while the right hand side is water gain from precipitation, irrigation and groundwater. All water loss is equivalent to irrigation demand or water demand that should be provided through irrigation and rainfall.

Groundwater contribution (GW), available soil water (ASW), runoff (RO) and seepage and percolation (SP) are determined by physical soil characteristics (mainly soil texture), and they are estimated using hydraulic properties of the soil; therefore, their relationship can be estimated using hydraulic properties of the soil such as infiltration and hydraulic conductivity of the soils.

Crop type will refer the Kc value of ETc as described by Doorenboss and Pruitt (1977) at FAO ID 24. Since the inter-annual rainfall may vary irregularly affecting Streamflow and water supply for cropping. The amount of water requirement to fulfil evapotranspiration (ET) and percolation depends on the crop type, the initial amount of water supply and its distribution during cropping sequence, and the soil texture and rooting depth and land properties. This will be calculated by implementing FAO–ID 24 (Doorenboss and Pruitt, 1977).

In irrigation practice, estimation of gross water demand of crops includes water use (ET) evapotranspiration, water loss through percolation, seepage and surface runoff; and water gain from irrigation and rainfall and groundwater. We adopt FAO ID 24 (Doorenboss and Pruitt, 1977) for estimating seasonal irrigation demand.

$$SWD = \frac{10}{\xi i} \sum_{i=1}^{N} \left[A_i (ETc_i + DPi - \mathrm{Re}_i - Gw_i - AWS_i \right] \qquad \text{(A13.2)}$$

SWD is seasonal water demand, i represent growing days (in month), A is crop area, Re is effective rainfall, DPi is water loss due to drainage and percolation, Gw is groundwater, AWS is water storage in soil and ξ is irrigation efficiency, which is the product of water conveyance efficiency (ξc), water use efficiency, (ξa) and water distribution efficiency (ξd) (Doorenboss and Pruitt, 1977).

$$ETc = Kc * ETo \qquad \text{(A13.3)}$$

The value of Kc changes at each growth stage. Usually the value of 0.4 at initial stage, 0,75 at development stage, 1.15 at mid season and 0.60 at late season. Crop coefficient (Kc) value and the length of every growth stage are unique for every crop depending on how the crop responds to water.

Seasonal crop water demand for rice cultural practice is higher than for other crops because more than half of the total water demand is needed for land preparation and water layer replacement. Soil preparation for lowland rice requires 300 mm for wet season rice, which is 250 mm for pre-saturation and puddling, and 50 mm for water layer placement after transplanting (MMPA, 1986). In the case of the second rice crop (immediately following the harvesting of wet season rice) the total requirement for land preparation is reduced to 250 mm. Additional water layer replacement is required after the water level has been drawn down for fertilizer application or weeding. Two replacements, each of 50 mm, have been allowed for one and two months after transplanting. In each case this is converted to a rate i mm/day over a half-month period.

Hence the overall seasonal water requirement for rice is calculated as follows:

$$SWD = \frac{10}{\xi i} \sum_{i=1}^{N} \left[A_i (LPi + WLRi + ETc_i + DPi - \mathrm{Re}_i - Gw_i - AWS_i \right] \qquad \text{(A13.4)}$$

Where: LP=land preparation, WLR = water layer replacement.

Therefore in the LP model, the cumulative water requirement for lowland rice is formulated by the following equation:

$$ETc_{rice} = 350 + \sum_{i=1}^{N} ETc_i \qquad \text{(A13.5)}$$

Where 350 is the amount of water (mm) required for land preparation (250 mm) and for water layer replacement after transplanting (100 mm).

For other crops cumulative water consumption can be defined by the following equation:

$$ETc = 0.35 \sum_{i=0}^{t1} ETo + 0.75 \sum_{t1}^{t2} ETo + 1.15 \sum_{t2}^{t3} ETo + 0.65 \sum_{t3}^{h} ETo \qquad \text{(A13.6)}$$

Where ETo is daily reference ET for grass; 0–t1, t1–t2, t2 –t3 and t3–h are number of growing days for initial, development, middle and late stages respectively; and 0.35, 1.15 and 0.65 represent value of crop coefficients at the growth stages.

The depth of effective rainfall stored in the soil profile during a period of time is estimated using Jensen Formula (Jensen, 1980) as follows:

Re = f(d)[1.25*(Rt)0.824 – 2.93][100.000955ETo] (A13.7)

f(d) = 0.53+0.0116 d –8.94 x 10–5 d 2 + 2.32 x 10–7 d 3 (A13.8)

The Re is monthly total expected rainfall, and f(d) expresses rainfall depth as a function of rainfall characteristics. Jensen (1980) used the value at 75 mm for d. GWs is negligible since most parts of southern Lombok do not have groundwater shallower than 2 m, therefore, it is unlikely the groundwater has a direct effect on crop water consumption.

A summary of water demand for each crop is as follows: pounded rice is 1500 mm in Entisols, 1400 mm in Inceptisols, 1100 mm in Alfisols and 1000 mm in Vertisols; while maize requires 440 mm, soybean 390 mm, chillies 625 mm, vegetables 450 mm and tobacco requires 450 mm in all type of soils.

10.14 Appendix 14: Mathematical formulation of user-defined constraints

10.14.1 User-defined constraint affecting SELECTED seasons SELECTED sub-areas SELECTED crops

This pattern effectively places limits on individual constraint elements. Practical examples include statements such as “Crop Areas (in each season) > 5% of each sub-area” or “Rice Area (S1,S2) > 10% of MATARAM area”. Mathematically, this is represented by:

$$\text{For each combination } (n) \text{ of } SELECTED(*) \left| \begin{array}{r} \text{season}, i^* \\ \text{subarea}, j^* \\ \text{crop}, k^* \end{array} \right. \text{ then, } \left[a_{ijk} x_{i^* j^* k^*} \leq RHS_n \right]$$
(A14.1)

where, $n = count(i^*) \times count(j^*) \times count(k^*)$ (A14.2)

Matrix-building (Figure A14.1) can be in any order of seasons, sub–area, and then crop type.

First Iterations	Season 1				Season 2					
Second	Area 1		Area 2		Area 1		Area 2			
Third Iterations	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2		
Constraint 1	$a_{1,1,1}$	0	0	0	0	0	0	0		RHS_1
Constraint 2	0	$a_{1,1,2}$	0	0	0	0	0	0		RHS_2
Constraint 3	0	0	$a_{1,2,1}$	0	0	0	0	0		RHS_3
Constraint 4	0	0	0	$a_{1,2,2}$	0	0	0	0		RHS_4
Constraint 5	0	0	0	0	$a_{2,1,1}$	0	0	0	$X \leq$	RHS_5
Constraint 6	0	0	0	0	0	$a_{2,1,2}$	0	0		RHS_6
Constraint 7	0	0	0	0	0	0	$a_{2,2,1}$	0		RHS_7
Constraint 8	0	0	0	0	0	0	0	$a_{2,2,2}$		RHS_8

Figure A14.1 Constraint matrix formulation: ‘SELECTED seasons SELECTED sub–areas SELECTED crops’ for the test case of 2 seasons, 2 sub-areas and 2 crops.

10.14.2 User-defined constraint affecting SELECTED seasons SELECTED sub-areas ALL crops

This pattern adjusts total crop production in selected sub-areas and seasons to an (in)equality. Practical examples include statements such as “Total Cropping Area (S1) < 90% of sub–area totals” or “Total Cropping WaterUse (S2,S3) < 80% of MATARAM total”. Mathematically, this is represented by:

$$\text{For each combination } (n) \text{ of } SELECTED\ (*) \left| \begin{array}{r} \text{season}, i^* \\ \text{subarea}, j^* \end{array} \right. \text{ then, } \left[\sum_{k=1}^{No.Crops} a_{ijk} x_{i^* j^* k} \leq RHS_n \right]$$
(A14.3)

where, $n = count(i^*) \times count(j^*)$ (A14.4)

Matrix-building (Figure A14.2) should be in the order of seasons, sub-area, and then crop type.

First Iterations	Season 1				Season 2					
Second	Area 1		Area 2		Area 1		Area 2			
Third Iterations	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2		
Constraint 1	$a_{1,1,1}$	$a_{1,1,2}$	0	0	0	0	0	0		RHS_1
Constraint 2	0	0	$a_{1,2,1}$	$a_{1,2,2}$	0	0	0	0	$X \leq$	RHS_2
Constraint 3	0	0	0	0	$a_{2,1,1}$	$a_{2,1,2}$	0	0		RHS_3
Constraint 4	0	0	0	0	0	0	$a_{2,2,1}$	$a_{2,2,2}$		RHS_4

Figure A14.2 Constraint matrix formulation: 'SELECTED seasons SELECTED sub-areas ALL crops' for the test case of 2 seasons, 2 sub-areas and 2 crops.

10.14.3 User-defined constraint affecting SELECTED seasons ALL sub-areas SELECTED crops

This pattern sets scheme-wide constraints for selected seasons and crops. Practical examples include statements such as "Total Rice Area (S1) > 5000 ha" or "Total Corn Area (S1,S2) < 20% of combined sub-areas". Mathematically, this is represented by:

$$\text{For each combination } (n) \text{ of } SELECTED\ (*)\ \Big|_{\substack{\text{season, } i^* \\ \text{crop, } k^*}} \text{ then, } \left[\sum_{j=1}^{No.Areas} a_{ijk} x_{i^* j k^*} \leq RHS_n \right] \qquad \text{(A14.5)}$$

where, $n = count(i^*) \times count(k^*)$ (A14.6)

Matrix–building (Figure A14.3) should be in the order of seasons, crops, and then sub-areas.

First Iterations	Season 1				Season 2					
Second	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2		
Third Iterations	Area 1		Area 2		Area 1		Area 2			
Constraint 1	$a_{1,1,1}$	0	$a_{1,2,1}$	0	0	0	0	0		RHS_1
Constraint 2	0	$a_{1,1,2}$	0	$a_{1,2,2}$	0	0	0	0	$X \leq$	RHS_2
Constraint 3	0	0	0	0	$a_{2,1,1}$	0	$a_{2,2,1}$	0		RHS_3
Constraint 4	0	0	0	0	0	$a_{2,1,2}$	0	$a_{2,2,2}$		RHS_4

Figure A14.3 Constraint matrix formulation: 'SELECTED seasons ALL sub-areas SELECTED crops' for the test case of 2 seasons, 2 sub-areas and 2 crops.

10.14.4 User-defined constraint affecting ALL seasons SELECTED sub-areas SELECTED crops

This pattern places annual constraints on selected sub-areas and crops. Practical examples include statements such as "Rice Area (Annual) <80% of MATARAM totals" or "Corn Area (Annual) >20% of sub–area totals". Mathematically, this is represented by:

$$\text{For each combination } (n) \text{ of } SELECTED\,(*)\ \Big|_{\substack{\text{subarea, } j^* \\ \text{crop, } k^*}} \text{ then, } \left[\sum_{i=1}^{No.Seasons} a_{ijk} x_{i j^* k^*} \leq RHS \right] \qquad \text{(A14.7)}$$

where, $n = count(j^*) \times count(k^*)$ (A14.8)

Matrix–building (Figure A14.4) should be in the order of sub-areas, crops, and then seasons.

First Iterations	Area 1		Area 2		Area 1		Area 2			
Second Iterations	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2		
Third Iterations	Season 1				Season 2					
Constraint 1	$a_{1,1,1}$	0	0	0	$a_{2,1,1}$	0	0	0	$X \leq$	RHS_1
Constraint 2	0	$a_{1,1,2}$	0	0	0	$a_{2,1,2}$	0	0		RHS_2
Constraint 3	0	0	$a_{1,2,1}$	0	0	0	$a_{2,2,1}$	0		RHS_3
Constraint 4	0	0	0	$a_{1,2,2}$	0	0	0	$a_{2,2,2}$		RHS_4

Figure A14.4 Constraint matrix formulation: 'ALL seasons SELECTED sub-areas SELECTED crops' for the test case of 2 seasons, 2 sub-areas and 2 crops.

10.14.5 User-defined constraint affecting SELECTED seasons ALL sub-areas ALL crops

This pattern constrains scheme-wide total crop production around an (in)equality for selected seasons. Practical examples include statements such as "Total Cropping Area (S1) <90% of combined sub-area" or "Total Cropping Area (S2,S2) >50% of combined sub-area". Mathematically, this is represented by:

$$\text{For each combination } (n) \text{ of } SELECTED\ (*)\ {}_{\text{season, } i^*}\Big| \text{ then, } \left[\sum_{j=1}^{No.Areas}\ \sum_{k=1}^{No.Crops} a_{ijk}x_{i^*jk} \leq RHS\right]$$

(A14.9)

where, $n = count(i^*)$ (A14.10)

Matrix-building (Figure A14.5) should be in the order of seasons, sub-areas, and then crop type.

First Iterations	Season 1				Season 2					
Second	Area 1		Area 2		Area 1		Area 2			
Third Iterations	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2		
Constraint 1	$a_{1,1,1}$	$a_{1,1,2}$	$a_{1,2,1}$	$a_{1,2,2}$	0	0	0	0	$X \leq$	RHS_1
Constraint 2	0	0	0	0	$a_{2,1,1}$	$a_{2,1,2}$	$a_{2,2,1}$	$a_{2,2,2}$		RHS_2

Figure A14.5 Constraint matrix formulation: 'SELECTED seasons ALL sub-areas ALL crops' for the test case of 2 seasons, 2 sub-areas and 2 crops.

10.14.6 User-defined constraint affecting ALL seasons SELECTED sub-areas ALL crops

This pattern constrains annual total crop production around an (in)equality for selected sub-areas. Practical examples include statements such as "Total Cropping Area (Annual) <95% of MATARAM total" or "Total Cropping WaterUse (Annual) >50% of MATARAM total". Mathematically, this is represented by:

$$\text{For each combination } (n) \text{ of } SELECTED\ (*)\ {}_{\text{subarea, } j^*}\Big| \text{ then, } \left[\sum_{i=1}^{No.Seasons}\ \sum_{k=1}^{No.Crops} a_{ijk}x_{ij^*k} \leq RHS\right]$$

(A14.11)

where, $n = count(j^*)$ (A14.12)

Matrix-building (Figure A14.6) should be in the order of sub-areas, seasons, and then crop type.

First Iterations	Area 1		Area 2		Area 1		Area 2	

Second	Season 1				Season 2					
Third Iterations	Crop 1	Crop 1	Crop 1	Crop 1	Crop 1	Crop 1	Crop 1	Crop 1		
Constraint 1	$a_{1,1,1}$	$a_{1,1,2}$	0	0	$a_{2,1,1}$	$a_{2,1,2}$	0	0	$X \leq$	RHS_1
Constraint 2	0	0	$a_{1,2,1}$	$a_{1,2,2}$	0	0	$a_{2,2,1}$	$a_{2,2,2}$		RHS_2

Figure A14.6 Constraint matrix formulation: ‘ALL seasons SELECTED sub-areas ALL crops’ for the test case of 2 seasons, 2 sub-areas and 2 crops.

10.14.7 User-defined constraint affecting ALL seasons ALL sub-areas SELECTED crops

This pattern constrains annual scheme-wide production of selected crops around an (in) equality. Practical examples include statements such as “Total Corn Area (Annual) > 10% of combined sub-areas” or “Total Rice Area (Annual) < 9000 ha”. Mathematically, this is represented by:

$$\text{For each combination } (n) \text{ of } SELECTED\ (*)\ {}_{\text{crop},\,k^*}\big| \text{ then, } \left[\sum_{i=1}^{No.Seasons} \sum_{j=1}^{No.Areas} a_{ijk} x_{ijk^*} \leq RHS \right]$$

(A14.13)

where, $n = count(k^*)$ (A14.14)

Matrix-building (Figure A14.7) should be in the order of crops, seasons, and then sub-areas.

First Iterations	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2		
Second	Season 1				Season 2					
Third Iterations	Area 1		Area 2		Area 1		Area 2			
Constraint 1	$a_{1,1,1}$	0	$a_{1,2,1}$	0	$a_{2,1,1}$	0	$a_{2,2,1}$	0	$X \leq$	RHS_1
Constraint 2	0	$a_{1,1,2}$	0	$a_{1,2,2}$	0	$a_{2,1,2}$	0	$a_{2,2,2}$		RHS_2

Figure A14.7 Constraint matrix formulation: ‘ALL seasons ALL sub-areas SELECTED crops’ for the test case of 2 seasons, 2 sub-areas and 2 crops.

10.14.8 User-defined constraint affecting ALL seasons ALL sub-area ALL crops

This pattern constrains the annual, scheme-wide, total crop production around an (in) equality. Practical examples include statements such as “Total Cropping Area (Annual) <12,000 ha” or “Total Cropping WaterUse (Annual) >50% total available”. Mathematically, this is represented by a single equation:

$$\sum_{i=1}^{No.Seasons} \sum_{j=1}^{No.Areas} \sum_{k=1}^{No.Crops} a_{ijk} x_{ijk} \leq RHS \qquad \text{(A14.15)}$$

Matrix-building (Figure A14.8) can be undertaken in any order of seasons, sub-areas, and crop type.

First Iterations	Season 1				Season 2					
Second	Area 1		Area 2		Area 1		Area 2			
Third Iterations	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2	Crop 1	Crop 2		
Constraint 1	$a_{1,1,1}$	$a_{1,1,2}$	$a_{1,2,1}$	$a_{1,2,2}$	$a_{2,1,1}$	$a_{2,1,2}$	$a_{2,2,1}$	$a_{2,2,2}$	$X \leq$	RHS_1

Figure A14.8 Constraint matrix formulation: ‘ALL seasons ALL sub-areas ALL crops’ for the test case of 2 seasons, 2 sub-areas and 2 crops.

10.15 Appendix 15: LP model validation-Comparison of Solver vs CropOptimiser outputs

10.15.1 No constraints

Solver Output				
		S1	S2	S3
	Rice	0.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Mataram	Legumes	0.0%	0.0%	0.0%
	Chillies	100.0%	0.0%	0.0%
	Veges	0.0%	100.0%	100.0%
	Tobacco	0.0%	0.0%	0.0%
	Rice	0.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Jankok	Legumes	0.0%	0.0%	0.0%
	Chillies	100.0%	0.0%	0.0%
	Veges	0.0%	100.0%	100.0%
	Tobacco	0.0%	0.0%	0.0%
	Rice	0%	0.0%	0%
	Corn	0%	0.0%	0%
Jurang Batu	Legumes	0%	0.0%	0%
	Chillies	100%	0.0%	0%
	Veges	0%	100.0%	40%
	Tobacco	0%	0.0%	0%
	Rice	0.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Rutus	Legumes	0.0%	0.0%	0.0%
	Chillies	100.0%	0.0%	0.0%
	Veges	0.0%	100.0%	100.0%
	Tobacco	0.0%	0.0%	0.0%
		Total Profit		30,048,775

CropOptimiser 2.3.0					
Name	**Area**	**Crop**	**S1**	**S2**	**S3**
MATARAM	1752	Rice	0.0%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	100.0%	0.0%	0.0%
		Vegetable	0.0%	100.0%	100.0%
		Tobacco	0.0%	0.0%	0.0%

JANGKOK	1306	Rice Corn Legumes Chillies Vegetable Tabacco	0.0% 0.0% 0.0% 100.0% 0.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%
JURANG_BATU	2936	Rice Corn Legumes Chillies Vegetable Tabacco	0.0% 0.0% 0.0% 100.0% 0.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%	0.0% 0.0% 0.0% 0.0% 40.2% 0.0%
RUTUS	1070	Rice Corn Legumes Chillies Vegetable Tabacco	0.0% 0.0% 0.0% 100.0% 0.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%

El Niño optimisation:Finished with optimal solution. Gross Margin $30,048,775 (Rp270,438,974,321)

10.15.2 One constraint

Total rice (S1) must be at least 50% of combined areas

Solver Output				
		S1	**S2**	**S3**
	Rice	0.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Mataram	Legumes	0.0%	0.0%	0.0%
	Chillies	100.0%	0.0%	0.0%
	Veges	0.0%	100.0%	100.0%
	Tobacco	0.0%	0.0%	0.0%
	Rice	0.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Jankok	Legumes	0.0%	0.0%	0.0%
	Chillies	100.0%	0.0%	0.0%
	Veges	0.0%	100.0%	100.0%
	Tobacco	0.0%	0.0%	0.0%
	Rice	84%	0.0%	0%
	Corn	0%	0.0%	0%
Jurang Batu	Legumes	0%	0.0%	0%
	Chillies	16%	0.0%	0%
	Veges	0%	100.0%	40%
	Tobacco	0%	0.0%	0%

	Rice	100.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Rutus	Legumes	0.0%	0.0%	0.0%
	Chillies	0.0%	0.0%	0.0%
	Veges	0.0%	100.0%	100.0%
	Tobacco	0.0%	0.0%	0.0%
		Total Profit		26,681,912

CropOptimiser 2.3.0					
Name	**Area**	**Crop**	**S1**	**S2**	**S3**
MATARAM	1752	Rice Corn Legumes Chillies Vegetable Tabacco	0.0% 0.0% 0.0% 100.0% 0.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%
JANGKOK	1306	Rice Corn Legumes Chillies Vegetable Tabacco	0.0% 0.0% 0.0% 100.0% 0.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%
JURANG_BATU	2936	Rice Corn Legumes Chillies Vegetable Tabacco	83.9% 0.0% 0.0% 16.1% 0.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%	0.0% 0.0% 0.0% 0.0% 40.2% 0.0%
RUTUS	1070	Rice Corn Legumes Chillies Vegetable Tabacco	100.0% 0.0% 0.0% 0.0% 0.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%

El Niño optimisation:Finished with optimal solution. Gross Margin $26,681,912 (Rp240,137,209,121)

10.15.3 Two constraints

Total rice (S1) must be at least 50% of combined areas

Total corn (S1) area must be at least 10% of combined areas

Solver Output				
		S1	**S2**	**S3**
	Rice	33.4%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Mataram	Legumes	0.0%	0.0%	0.0%
	Chillies	66.6%	0.0%	0.0%
	Veges	0.0%	100.0%	100.0%
	Tobacco	0.0%	0.0%	0.0%
	Rice	0.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Jankok	Legumes	0.0%	0.0%	0.0%
	Chillies	100.0%	0.0%	0.0%
	Veges	0.0%	100.0%	100.0%
	Tobacco	0.0%	0.0%	0.0%
	Rice	64%	0.0%	0%
	Corn	36%	0.0%	0%
Jurang Batu	Legumes	0%	0.0%	0%
	Chillies	0%	0.0%	0%
	Veges	0%	100.0%	40%
	Tobacco	0%	0.0%	0%
	Rice	100.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Rutus	Legumes	0.0%	0.0%	0.0%
	Chillies	0.0%	0.0%	0.0%
	Veges	0.0%	100.0%	100.0%
	Tobacco	0.0%	0.0%	0.0%
		Total Profit		25,452,265

Tal Corn (S1) area must be at least 10% of mbined areas

CropOptimiser 2.3.0					
Name	**Area**		**S1**	**S2**	**S3**
MATARAM	1752	Rice	33.4%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	66.6%	0.0%	0.0%
		Vegetable	0.0%	100.0%	100.0%
		Tabacco	0.0%	0.0%	0.0%
JANGKOK	1306	Rice	0.0%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	100.0%	0.0%	0.0%
		Vegetable	0.0%	100.0%	100.0%
		Tabacco	0.0%	0.0%	0.0%

JURANG_BATU	2936	Rice	63.9%	0.0%	0.0%
		Corn	36.1%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	0.0%	0.0%	0.0%
		Vegetable	0.0%	100.0%	40.2%
		Tabacco	0.0%	0.0%	0.0%
RUTUS	1070	Rice	100.0%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	0.0%	0.0%	0.0%
		Vegetable	0.0%	100.0%	100.0%
		Tabacco	0.0%	0.0%	0.0%

El Niño optimisation:Finished with optimal solution. Gross Margin $25,452,271 (Rp229,070,436,485)

10.15.4 Three constraints

Total rice (S1) must be at least 50% of combined areas

Total corn (S1) area must be at least 10% of combined areas

Veg area (S2) must be less than 20% of each area

Solver Output				
		S1	**S2**	**S3**
	Rice	33.4%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Mataram	Legumes	0.0%	0.0%	0.0%
	Chillies	66.6%	0.0%	0.0%
	Veges	0.0%	20.0%	100.0%
	Tobacco	0.0%	80.0%	0.0%
	Rice	0.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Jankok	Legumes	0.0%	0.0%	0.0%
	Chillies	100.0%	0.0%	0.0%
	Veges	0.0%	20.0%	100.0%
	Tobacco	0.0%	80.0%	0.0%
	Rice	64%	0.0%	0%
	Corn	36%	0.0%	0%
Jurang Batu	Legumes	0%	0.0%	0%
	Chillies	0%	0.0%	0%
	Veges	0%	20.0%	40%
	Tobacco	0%	80.0%	0%
	Rice	100.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Rutus	Legumes	0.0%	0.0%	0.0%
	Chillies	0.0%	0.0%	0.0%
	Veges	0.0%	20.0%	100.0%

	Tobacco	0.0%	80.0%	0.0%
		Total Profit		24,670,887

CropOptimiser 2.3.0					
Name	**Area**	**Crop**	**S1**	**S2**	**S3**
MATARAM	1752	Rice	33.4%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	66.6%	0.0%	0.0%
		Vegetable	0.0%	20.0%	100.0%
		Tabacco	0.0%	80.0%	0.0%
JANGKOK	1306	Rice	0.0%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	100.0%	0.0%	0.0%
		Vegetable	0.0%	20.0%	100.0%
		Tabacco	0.0%	80.0%	0.0%
JURANG_BATU	2936	Rice	63.9%	0.0%	0.0%
		Corn	36.1%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	0.0%	0.0%	0.0%
		Vegetable	0.0%	20.0%	40.2%
		Tabacco	0.0%	80.0%	0.0%
RUTUS	1070	Rice	100.0%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	0.0%	0.0%	0.0%
		Vegetable	0.0%	20.0%	100.0%
		Tabacco	0.0%	80.0%	0.0%

El Niño optimisation:Finished with optimal solution. Gross Margin $24,670,892 (Rp222,038,028,869)

10.15.5 Four constraints

Total rice (S1) must be at least 50% of combined areas

Total corn (S1) area must be at least 10% of combined areas

Veg area (S2) must be less than 20% of each area

Chillies area (all seasons) must be less than 10% of each areas

Solver Output				
		S1	**S2**	**S3**
	Rice	56.3%	0.0%	0.0%

	Corn	0.0%	0.0%	0.0%
Mataram	Legumes	0.0%	0.0%	0.0%
	Chillies	10.0%	0.0%	0.0%
	Veges	33.7%	20.0%	100.0%
	Tobacco	0.0%	80.0%	0.0%
	Rice	0.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Jankok	Legumes	0.0%	0.0%	0.0%
	Chillies	10.0%	0.0%	0.0%
	Veges	90.0%	20.0%	100.0%
	Tobacco	0.0%	80.0%	0.0%
	Rice	54%	0.0%	0%
	Corn	36%	0.0%	0%
Jurang Batu	Legumes	0%	0.0%	0%
	Chillies	10%	0.0%	0%
	Veges	0%	20.0%	40%
	Tobacco	0%	80.0%	0%
	Rice	90.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Rutus	Legumes	0.0%	0.0%	0.0%
	Chillies	10.0%	0.0%	0.0%
	Veges	0.0%	20.0%	100.0%
	Tobacco	0.0%	80.0%	0.0%
		Total Profit		24,456,242

CropOptimiser 2.3.0					
Name	**Area**	**Crop**	**S1**	**S2**	**S3**
MATARAM	1752	Rice	56.3%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	10.0%	0.0%	0.0%
		Vegetable	33.7%	20.0%	100.0%
		Tabacco	0.0%	80.0%	0.0%
JANGKOK	1306	Rice	0.0%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	0.0%	0.0%
		Chillies	10.0%	0.0%	0.0%
		Vegetable	90.0%	20.0%	100.0%
		Tabacco	0.0%	80.0%	0.0%

JURANG_BATU	2936	Rice Corn Legumes Chillies Vegetable Tabacco	53.9% 36.1% 0.0% 10.0% 0.0% 0.0%	0.0% 0.0% 0.0% 0.0% 20.0% 80.0%	0.0% 0.0% 0.0% 0.0% 40.2% 0.0%
RUTUS	1070	Rice Corn Legumes Chillies Vegetable Tabacco	90.0% 0.0% 0.0% 10.0% 0.0% 0.0%	0.0% 0.0% 0.0% 0.0% 20.0% 80.0%	0.0% 0.0% 0.0% 0.0% 100.0% 0.0%

El Niño optimisation:Finished with optimal solution. Gross Margin $24,456,247 (Rp220,106,224,805)

10.15.6 Five constraints

Total rice (S1) must be at least 50% of combined areas

Total corn (S1) area must be at least 10% of combined areas

Veg area (S2) must be less than 20% of each area

Chillies area (all seasons) must be less than 10% of each area

Legumes area (S2) must be at least 10% in each sub–area

Solver Output				
		S1	**S2**	**S3**
	Rice	56.3%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Mataram	Legumes	0.0%	10.0%	0.0%
	Chillies	10.0%	0.0%	0.0%
	Veges	33.7%	20.0%	100.0%
	Tobacco	0.0%	70.0%	0.0%
	Rice	0.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%
Jankok	Legumes	0.0%	10.0%	0.0%
	Chillies	10.0%	0.0%	0.0%
	Veges	90.0%	20.0%	100.0%
	Tobacco	0.0%	70.0%	0.0%
	Rice	54%	0.0%	0%
	Corn	36%	0.0%	0%
Jurang Batu	Legumes	0%	10.0%	0%
	Chillies	10%	0.0%	0%
	Veges	0%	20.0%	40%
	Tobacco	0%	70.0%	0%
	Rice	90.0%	0.0%	0.0%
	Corn	0.0%	0.0%	0.0%

Rutus	Legumes	0.0%	10.0%	0.0%
	Chillies	10.0%	0.0%	0.0%
	Veges	0.0%	20.0%	100.0%
	Tobacco	0.0%	70.0%	0.0%
		Total Profit		24,017,599

CropOptimiser 2.3.0					
Name	**Area**	**Crop**	**S1**	**S2**	**S3**
MATARAM	1752	Rice	56.3%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	10.0%	0.0%
		Chillies	10.0%	0.0%	0.0%
		Vegetable	33.7%	20.0%	100.0%
		Tabacco	0.0%	70.0%	0.0%
JANGKOK	1306	Rice	0.0%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	10.0%	0.0%
		Chillies	10.0%	0.0%	0.0%
		Vegetable	90.0%	20.0%	100.0%
		Tabacco	0.0%	70.0%	0.0%
JURANG_BATU	2936	Rice	53.9%	0.0%	0.0%
		Corn	36.1%	0.0%	0.0%
		Legumes	0.0%	10.0%	0.0%
		Chillies	10.0%	0.0%	0.0%
		Vegetable	0.0%	20.0%	40.2%
		Tabacco	0.0%	70.0%	0.0%
RUTUS	1070	Rice	90.0%	0.0%	0.0%
		Corn	0.0%	0.0%	0.0%
		Legumes	0.0%	10.0%	0.0%
		Chillies	10.0%	0.0%	0.0%
		Vegetable	0.0%	20.0%	100.0%
		Tabacco	0.0%	70.0%	0.0%

El Niño optimisation:Finished with optimal solution. Gross Margin $24,017,604 (Rp216,158,439,965)

10.16Appendix 16: Overview of FlowCast analyses

10.16.1 Browser analyses

Six analyses have been included in FlowCast to explore the predictor and predictand time series input data (Figure A16.1). Analyses include:

Time series explorer analysis: This allows the user to zoom, pan, inspect, compare and overlay different time series data. To help compare multiple data, the horizontal axes are automatically synchronized, while synchronization of the vertical axes is optional.

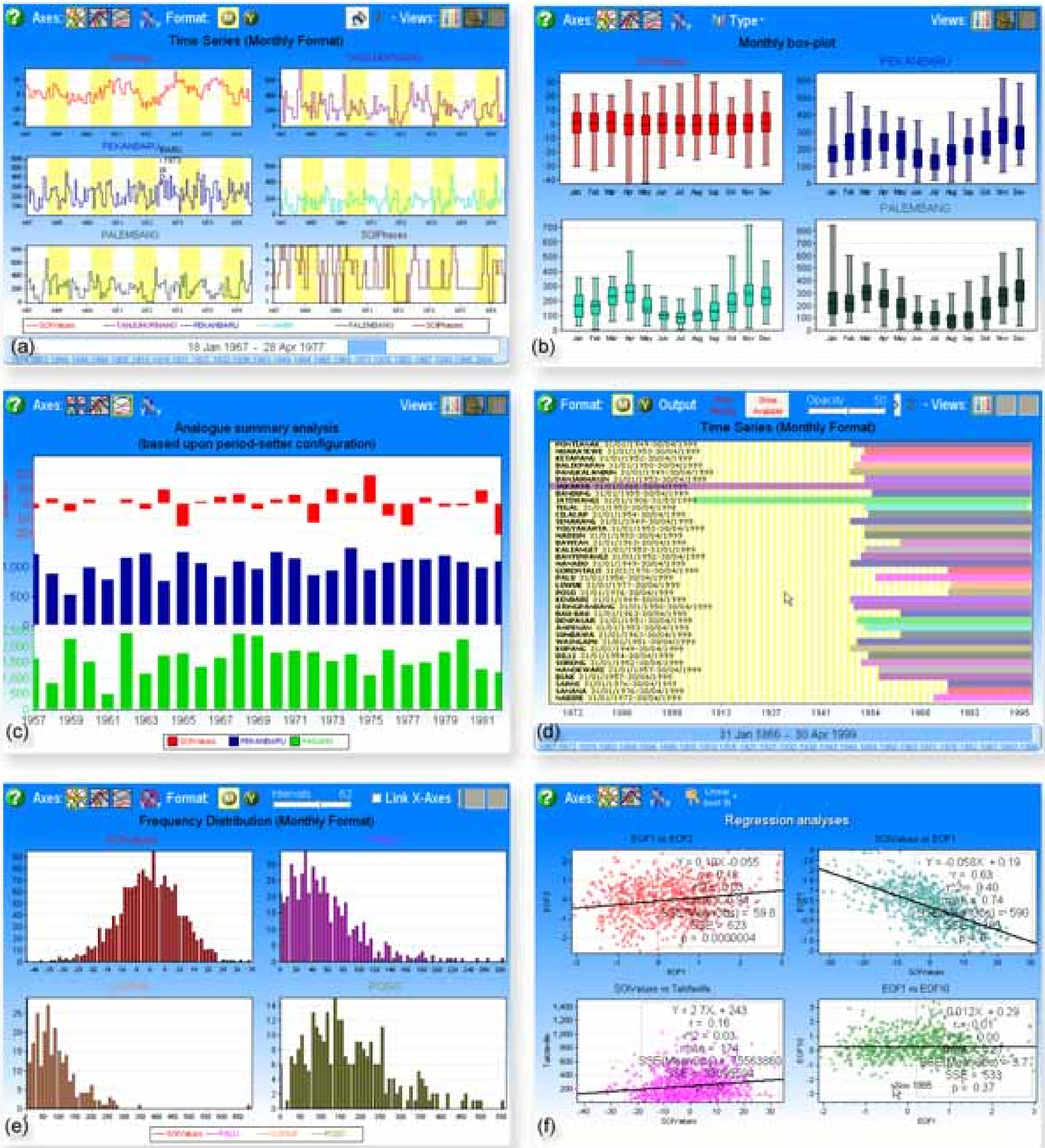


Figure A16.1 Examples of "Browser" analyses outputs include (a) timeseries explorer; (b) monthly statistics analysis; (c) analogue analysis; (d) available/missingdata analysis; (e) frequency distribution analysis; and (f) scatter plot analysis.

A timeline user control at the bottom of the window can also be used for navigation. Time series can be shown as daily (if originally in that format), monthly, or yearly formats. Passing the mouse over individual data displays their values. Missing data is represented as gaps in the time series. Box plots and bar charts can be drawn underneath each time series representing monthly statistics (max, min, mean, etc.). Annual shading can also be underlain to help distinguish alternate years.

Monthly statistics analysis: Presents monthly statistics including maximum, minimum, median, mean, and the 25th and 75th percentiles. Outputs can be displayed as box plots, bar charts or line charts.

Analogue analysis: Shows bar graphs of the predictor and predictand analogue totals (or averages) based on the periods defined in the period setter tool.

Available/missingdata analysis: Stacked Gantt bars showing either the available data periods or missing data sections in daily, monthly or yearly formats. A time–line control at the bottom of the window is also available for navigation.

Frequency distribution analysis: User–definable frequency distribution bar charts with axis synchronization options.

Scatter plot/regression analysis: Dragging and dropping time series onto each other in the input panel creates the scatter plots. Several regression options are available, and individual points are hot–tracked to display the dates. Scatter plots are switchable between daily, monthly and yearly formats.

10.16.2 Station analyses

Eight analyses have been included to generate and analyse forecasts of individual predictand data (Figure A16.2). Analyses include:

Probability distributions: Forecasts are presented in the form of probability distributions for both stratification and discriminant analysis predictive systems, accompanied by distributions of climatology. Stratification-based outputs are presented as multiple distributions representing separate stratifications with current conditions in bold. Discriminant analysis based outputs are presented as single distributions generated from averaging upper and lower envelopes from multiple two-category discriminant analysis iterations (see Chiew and Siriwardena, 2005). The user can interact with the plotted distributions to reveal interpolated values. Historical events (dates) can also be superimposed onto the curves.

Probability pie charts: Tercile and above/below median outlooks are presented here in the form of pie charts (sometimes called ‘chocolate wheels’). This represents the simplest way to disseminate forecast information to end users. Training size, LEPS skill score and percent consistent values accompany each pie chart.

Box plot analysis: Box plots representing different stratifications are presented here to help visualize and compare the variations between stratified samples. This is particularly useful when differentiating the impacts of EL Niño and La Niña climate extremes.

Sampling regression analysis: Scatter plots of predictor versus predictand analogues are presented to show their correlation. Equations are generated which can be used for regression-based forecasting. Multiple scatter plots are generated when using discriminant analysis based predictive systems containing more than one predictor element. Points can be hot-tracked to show which event they relate to.

Skill score analysis: A table or “skill map” of skill scores (LEPS, Modified LEPS, Percent consistent, or ROC) is presented for a range of inter-annual forecast periods and lead–times. The map represents forecast skill results of 108 separate “cross-validated hindcast” analyses (12 periods by 9 lead times, by default). The forecast period is represented on the x-axis, with the lead times on the y axis. The skill score results are assigned colours relative to the magnitude of each score: a blue square denotes forecasting skill greater than climatology (chance); a red square denotes forecasting skill worse than climatology; while a white square denotes skill the same as climatology. A circle within the skill map represents the current period-setter conditions. Users can click on any square within the skill map to automatically synchronise the period-setter for those conditions.

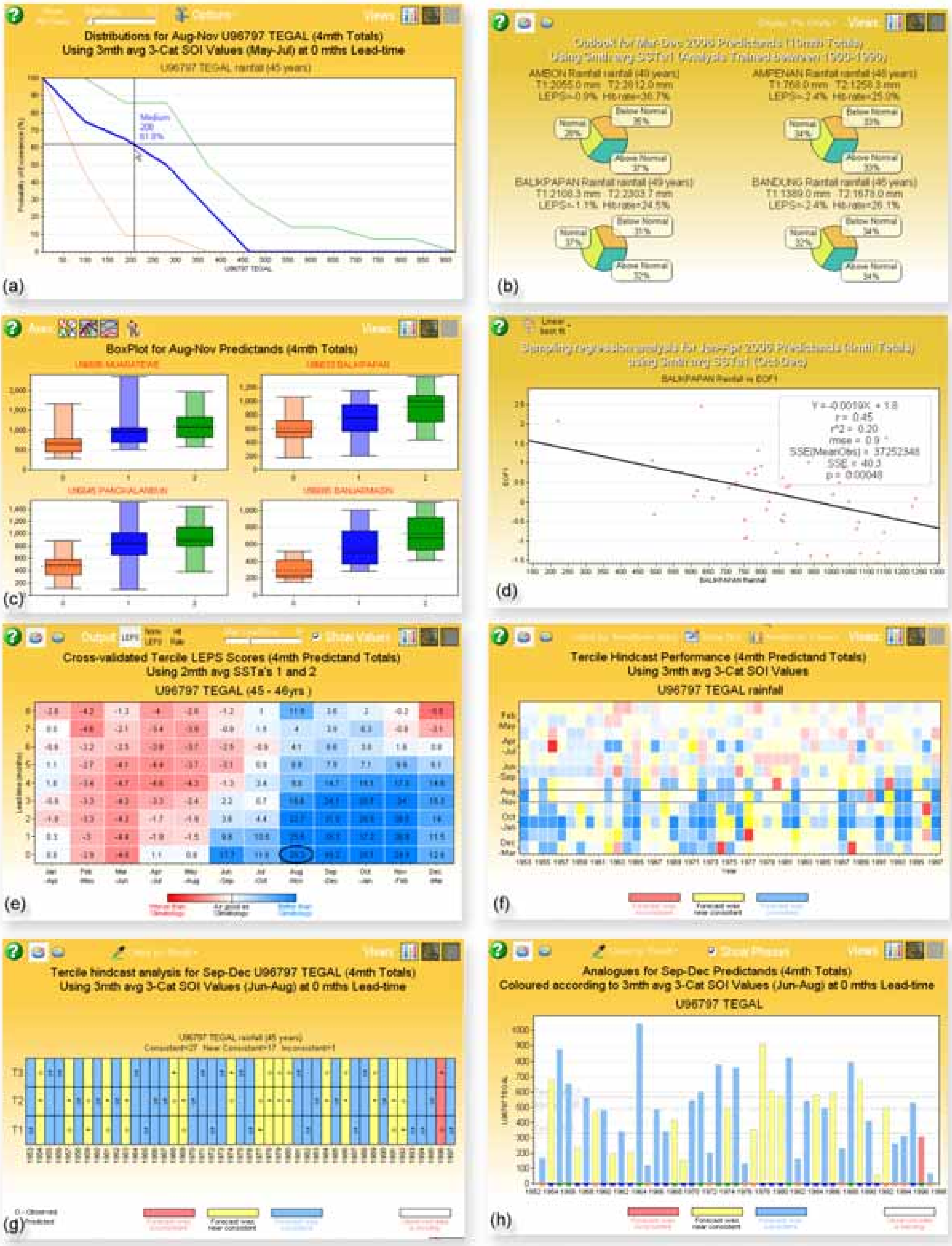


Figure A16.2 Examples of station analyses including (a) stratification probability distributions; (b) tercile probability pie charts; (c) box plots of stratifications; (d) predictor/predictand regression analysis; (e) tercile LEPS skill score map; (f) hindcast performance calendar; (g) seasonal hindcast analysis; and (h) historical analogue analysis.

Hindcast performance calendar: A table of all hindcast results over the defined testing period (same as the training period by default) for each successive month is presented here. Results are colour-coded according to a variety of user-defined schemes; discrete colours based on hindcasts being ‘consistent’, ‘near-consistent’, or ‘inconsistent’; graduated colours based on the previous scheme, but with colour weightings representing forecast strength (largest probability size); and graduated colours based on LEPS skill scores. This table is also interactive allowing the user to synchronises the period setter with individual cells. All of the graduated colour schemes provide visual information on how good a particular forecast was, with very good forecasts showing in strong blue colours, and very poor forecasts showing in strong red colours. Hindcasts similar to climatology (‘unskilled’) are represented in close-to-white colours regardless of whether they were consistent or inconsistent.

Seasonal hindcast analysis: A portion of the output from the previous analysis has been extracted and displayed here representing the hindcast performance for the current predictand period. A timeline of hindcast years is split into vertical tercile (or above/below median) groupings with observed (O) and predicted (P) categories highlighted. The colouring scheme from the previous analysis has been adopted. Also, a detailed hindcast evaluation is available in the report view with numerical outputs for validating and investigating individual hindcasts.

Historical analogue analysis: This analysis presents an alternative view of the seasonal hindcast analysis in bar chart form, with individual bars representing predictand analogues totals (or averages) colour-coded according to the previously defined hindcast colour schemes. For stratification-based predictive systems, bars can also be colour-tagged based on the corresponding stratification phase for each year.

10.16.3 Spatial analyses

The spatial analysis tools have been developed to generate and assess regional forecast distributions and skill (Figure A16.3). The tools are presented as a single interface with many options for generating and comparing a wide range of forecasting variable in multiple mapping windows. Zooming and scrolling is synchronized across multiple maps, and textual outputs are also available.

There are currently around 30 output types that can be displayed on the charts, and more are planned in the future. Outputs include training, testing and missing data counts; and threshold values, forecasting probabilities, LEPS, modified LEPS, percent-consistent, ROC, and p-value outputs for both tercile and above/below median forecasts.

The display of these outputs can be filtered by selecting any single output as a filter control. For example, the user can display the LEPS scores for stations that have a LEPS p–value of greater than 0.95, providing a crude way of determining the LEPS value for climatology (which will vary depending on training size, phase count, calculation methodology) for the current predictive system. A summary of the regional average results can be displayed as an overlay in each map (Figure A16.3b,d,f).

To analyse temporal forecast characteristics, the user can choose to generate outputs for the 12 starting months of the year (Figure A16.3b). Individual station results are displayed as coloured bubbles that are sized according to either a user-defined metric, or scaled according to the training data size. Colour schemes vary according to the output type. The user can select metadata to display above each station, including station name, training data size, and the numerical value of the plotted data (Figure A16.3a,d).

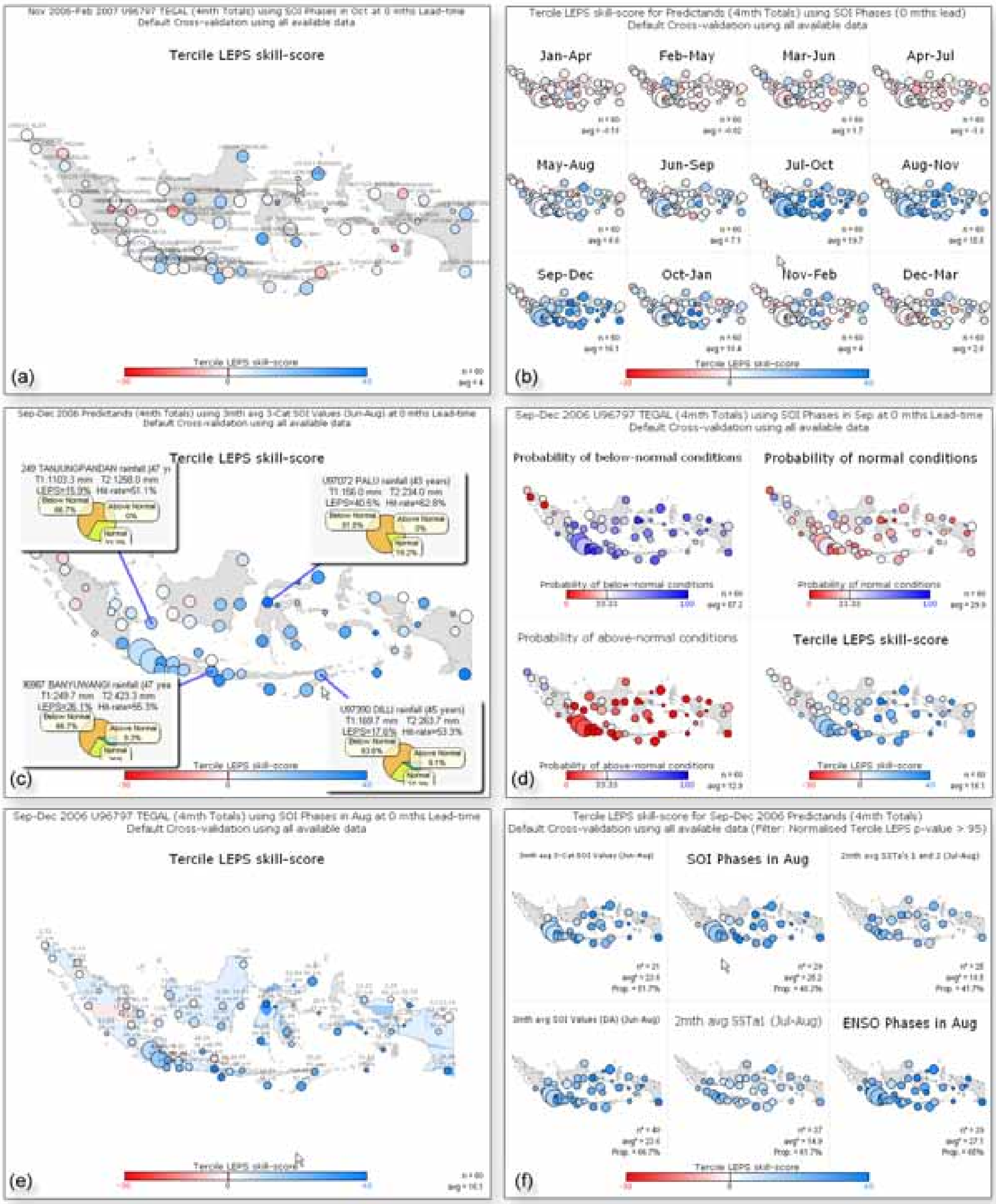


Figure A16.3 Examples of spatial analysis outputs including (a) simple station output with station name and ‘countsized’ points; (b) 12month output; (c) simple output with probability overlays; (d) multiple output types; (e) point-based outputs with contoured underlay and printed result; and (f) multiple predictor analysis with result filtered on LEPS pvalues.

10.17 Appendix 17: Groundwater analysis results

Table A17.1 Percolation rate, working head, yield and transmissivity as obtained from pumping tests carried out in October 2005.

Well code	Percolation rate (l/sec)	Working depression head (m)	Yield (l/sec)				Transmissivity (m3/day/m)
			Max	Min	Average	Std. deviation	
K1	0.143	0.627	0.424	0.034	0.173	0.103	42.74
K2	0.191	0.375	0.576	0.026	0.110	0.125	46.12
K3	0.026	0.468	0.026	0.016	0.025	0.003	na
K4	0.005	0.261	0.017	0.000	0.006	0.007	na
K5	0.099	0.347	0.131	0.079	0.103	0.011	na
T1	0.064	0.226	0.157	0.026	0.072	0.031	na
T2	0.021	0.631	0.052	0.010	0.023	0.008	na
T3	0.032	0.562	0.052	0.000	0.031	0.016	na
T4	0.064	0.226	0.157	0.026	0.072	0.031	na
T5	na	na	na	na	na	na	na
T6	na	na	na	na	na	na	na

Table A17.2 Percolation rate, working head, yield and transmissivity as obtained from pumping tests carried out in Jan–Feb 2006.

Well code	Percolation rate (l/sec)	Working depression head (m)	Yield (l/sec)				Transmissivity (m3/day/m)
			Max	Min	Average	Std. deviation	
K1	0.195	0.704	0.678	0.078	0.232	0.147	46.5
K2	0.061	0.568	0.209	0.000	0.073	0.050	20.08
K3							
K4	na	na	na	na	na	na	na
K5	0.074	0.162	0.314	0.013	0.100	0.090	na
T1	na	na	na	na	na	na	na
T2	0.0168	1.26	0.026	0.000	0.018	0.007	na
T3	0.0497	1.39	0.079	0.026	0.046	0.011	na
T4	0.185	0.394	0.314	0.011	0.115	0.108	34.2
T5	0.027	0.79	0.052	0.016	0.030	0.011	na
T6	na	na	na	na	na	na	na

Table A17.3 Percolation rate, working head, yield and transmissivity as obtained from pumping tests carried out in May 2006.

Well code	Percolation rate (l/sec)	Working depression head (m)	Yield (l/sec)				Transmissivity (m3/day/m)
			Max	Min	Average	Std. deviation	
K1	na	na	na	na	na	na	na
K2	0.075	0.24	0.616	0.025	0.097	0.092	na
K3	0.023	0.986	0.052	0.000	0.025	0.011	97.52
K4	0.019	1.047	0.027	0.000	0.014	0.009	na
K5	0.078	0.29	0.262	0.000	0.100	0.077	22.14
T1	0.011	0.74	0.026	0.000	0.012	0.006	94.88
T2	0.12	1.03	0.052	0.000	0.013	0.009	na
T3	na	na	na	na	na	na	na
T4	0.064	0.75	0.026	0.000	0.013	0.008	na
T5	0.188	0.48	0.052	0.005	0.020	0.010	na
T6	0.129	0.843	0.026	0.000	0.013	0.007	53.76

10.18 Appendix 18: HowLeaky parameterisations

10.18.1 Lombok HowLeaky soil parameterisation

Lombok Black Vertisol $(HOWLEAKY)Data - Soils\Lombok Black Vertisol.soil

	Lay1	Lay2	Lay3	Lay4	Lay5
Number of Horizons	4				
Layer Depth (Cumulative)	100	300	600	1200	mm
Air dry moisture	11	10	10	10	%Vol
Wilting point	14	18	21	24	%Vol
Field capacity	35	34	33	32	%Vol
Sat. water content	51	46	38	35	%Vol
Maximum drainage from layer	50	12	8	5	mm/day
Stage 2 evap., Cona	4				
Stage 1 evap. limit, U	8	mm			
Runoff curve no.(bare soil)	75				
CN Reduction 100% cover	20				
CN Reduction - Tillage	10				
Rainfall to 0 roughness	400	mm			
USLE K factor	0.4	metric			
USLE P factor	1				
Field slope	0.2	%			
Slope length	100	m			
Rill/interrill ratio	1	(0-1)			
Bulk density (layer 1)	1.2				
Soil cracking	No				
Sediment Delivery Ratio	-	(0-1)			

Lombok Sodic Brown Vertisol $(HOWLEAKY)Data - Soils\Lombok Sodic Brown Vertiso

	Lay1	Lay2	Lay3	Lay4	Lay5
Number of Horizons	4				
Layer Depth (Cumulative)	100	300	600	1200	mm
Air dry moisture	8	10	10	10	%Vol
Wilting point	16	14	20	24	%Vol
Field capacity	33	31	30	29	%Vol
Sat. water content	47	41	35	32	%Vol
Maximum drainage from layer	25	10	6	3	mm/day
Stage 2 evap., Cona	4				
Stage 1 evap. limit, U	8	mm			
Runoff curve no.(bare soil)	78				
CN Reduction 100% cover	20				
CN Reduction - Tillage	10				
Rainfall to 0 roughness	400	mm			
USLE K factor	0.4	metric			
USLE P factor	1				
Field slope	0.2	%			
Slope length	100	m			
Rill/interrill ratio	1	(0-1)			
Bulk density (layer 1)	1.2				
Soil cracking	No				
Sediment Delivery Ratio	-	(0-1)			

(Ksat1) Lombok Black Vertisol $(HOWLEAKY)Data - Soils\(Ksat1) Lombok Black Vertis

	Lay1	Lay2	Lay3	Lay4	Lay5
Number of Horizons	4				
Layer Depth (Cumulative)	100	300	600	1200	mm
Air dry moisture	11	10	10	10	%Vol
Wilting point	14	18	21	24	%Vol
Field capacity	35	34	33	32	%Vol
Sat. water content	51	46	38	35	%Vol
Maximum drainage from layer	50	12	8	1	mm/day
Stage 2 evap., Cona	4				
Stage 1 evap. limit, U	8	mm			
Runoff curve no.(bare soil)	75				
CN Reduction 100% cover	20				
CN Reduction - Tillage	10				
Rainfall to 0 roughness	400	mm			
USLE K factor	0.4	metric			
USLE P factor	1				
Field slope	0.2	%			
Slope length	100	m			
Rill/interrill ratio	1	(0-1)			
Bulk density (layer 1)	1.2				
Soil cracking	No				
Sediment Delivery Ratio	0	(0-1)			

(Ksat0.6) Lombok Sodic Brown Vertisol $(HOWLEAKY)Data - Soils\(Ksat 0.6) Lombok

	Lay1	Lay2	Lay3	Lay4	Lay5
Number of Horizons	4				
Layer Depth (Cumulative)	100	300	600	1200	mm
Air dry moisture	8	10	10	10	%Vol
Wilting point	16	14	20	24	%Vol
Field capacity	33	31	30	29	%Vol
Sat. water content	47	41	35	32	%Vol
Maximum drainage from layer	25	10	6	0.6	mm/day
Stage 2 evap., Cona	4				
Stage 1 evap. limit, U	8	mm			
Runoff curve no.(bare soil)	78				
CN Reduction 100% cover	20				
CN Reduction - Tillage	10				
Rainfall to 0 roughness	400	mm			
USLE K factor	0.4	metric			
USLE P factor	1				
Field slope	0.2	%			
Slope length	100	m			
Rill/interrill ratio	1	(0-1)			
Bulk density (layer 1)	1.2				
Soil cracking	No				
Sediment Delivery Ratio	0	(0-1)			

(Ksat1) Lombok Black Vertisol (Ponded) $(HOWLEAKY)Data - Soils\(Ksat 1) Lombok B

	Lay1	Lay2	Lay3	Lay4	Lay5
Number of Horizons	4				
Layer Depth (Cumulative)	100	300	600	1200	mm
Air dry moisture	11	10	10	10	%Vol
Wilting point	14	18	21	24	%Vol
Field capacity	35	34	33	32	%Vol
Sat. water content	51	46	38	35	%Vol
Maximum drainage from layer	50	12	8	1	mm/day
Stage 2 evap., Cona	100				
Stage 1 evap. limit, U	100	mm			
Runoff curve no.(bare soil)	75				
CN Reduction 100% cover	20				
CN Reduction - Tillage	10				
Rainfall to 0 roughness	400	mm			
USLE K factor	0.4	metric			
USLE P factor	1				
Field slope	0.2	%			
Slope length	100	m			
Rill/interrill ratio	1	(0-1)			
Bulk density (layer 1)	1.2				
Soil cracking	No				
Sediment Delivery Ratio	0	(0-1)			

(Ksat0.6) Lombok Sodic Brown Vertisol (Ponded) $(HOWLEAKY)Data - Soils\(Ksat 0.

	Lay1	Lay2	Lay3	Lay4	Lay5
Number of Horizons	4				
Layer Depth (Cumulative)	100	300	600	1200	mm
Air dry moisture	8	10	10	10	%Vol
Wilting point	16	14	20	24	%Vol
Field capacity	33	31	30	29	%Vol
Sat. water content	47	41	35	32	%Vol
Maximum drainage from layer	25	10	6	0.6	mm/day
Stage 2 evap., Cona	100				
Stage 1 evap. limit, U	100	mm			
Runoff curve no.(bare soil)	78				
CN Reduction 100% cover	20				
CN Reduction - Tillage	10				
Rainfall to 0 roughness	400	mm			
USLE K factor	0.4	metric			
USLE P factor	1				
Field slope	0.2	%			
Slope length	100	m			
Rill/interrill ratio	1	(0-1)			
Bulk density (layer 1)	1.2				
Soil cracking	No				
Sediment Delivery Ratio	0	(0-1)			

(DUL+5%) Lombok Black Vertisol $(HOWLEAKY)Data - Soils\(DUL+5%) Lombok B.

Number of Horizons	4				
	Lay1	Lay2	Lay3	Lay4	Lay5
Layer Depth (Cumulative)	100	300	600	1200	mm
Air dry moisture	11	10	10	10	%Vol
Wilting point	14	18	21	24	%Vol
Field capacity	40	39	38	37	%Vol
Sat. water content	51	46	38	35	%Vol
Maximum drainage from layer	50	12	8	5	mm/day
Stage 2 evap., Cona	4				
Stage 1 evap. limit, U	8	mm			
Runoff curve no.(bare soil)	75				
CN Reduction 100% cover	20				
CN Reduction - Tillage	10				
Rainfall to 0 roughness	400	mm			
USLE K factor	0.4	metric			
USLE P factor	1				
Field slope	0.2	%			
Slope length	100	m			
Rill/interrill ratio	1	(0-1)			
Bulk density (layer 1)	1.2				
Soil cracking	No				
Sediment Delivery Ratio	0	(0-1)			

10.18.2 Lombok HowLeaky vegetation parameterisation

Phase 1_Chillies LAI (LAI) $(HOWLEAKY)Data - Vegetation\Phase 1 Chillies.vege

Potential max LAI	2.5	cm^2/cm^2
Prop. season for max LAI	0.8	fraction
Prop. max LAI (1st)	5	%
Prop. grow-season (1st)	15	%
Prop. max LAI (2nd)	75	%
Prop. grow-season (2nd)	60	%
Degree days plant-harvest	2200	oC
Senesence coefficient	0.1	
Radiation use efficiency	1	g/m^2/MJ
Harvest index	0.55	
Base temperature	0	oC
Optimal temperature	30	oC
Maximum root depth	600	mm
Daily root growth	20	mm
Water stress threshold	0.2	(0-1)
Stress days to death	21	days
Residue decomposition rate	5	%/day
Residue at full cover	10000	kg/ha
Planting scheduling	Automatic	
Start of planting window	14	Nov
End of planting window	14	Dec
Min continuous plantings	1	
Max continuous plantings	999	
Minimum fallow length	1	
Planting rain	25	mm
Days to summate rain	7	
Min soil water ratio (layer 1)	-	*(0-1)*
Max soil water ratio (layer 1)	1	(0-1)
Minimum available soil water at planting	5	mm
Soil depth to sum planting soil water	300	mm
Ratoon crop	No	
Force planting in window	Yes	

Phase 1_Melons LAI (LAI) $(HOWLEAKY)Data - Vegetation\Phase 1 Melons.vege

Potential max LAI	2	cm^2/cm^2
Prop. season for max LAI	0.65	fraction
Prop. max LAI (1st)	15	%
Prop. grow-season (1st)	15	%
Prop. max LAI (2nd)	85	%
Prop. grow-season (2nd)	60	%
Degree days plant-harvest	2000	oC
Senesence coefficient	0.1	
Radiation use efficiency	1	g/m^2/MJ
Harvest index	0.6	
Base temperature	0	oC
Optimal temperature	30	oC
Maximum root depth	900	mm
Daily root growth	20	mm
Water stress threshold	0.2	(0-1)
Stress days to death	21	days
Residue decomposition rate	5	%/day
Residue at full cover	5000	kg/ha
Planting scheduling	Automatic	
Start of planting window	14	Nov
End of planting window	14	Dec
Min continuous plantings	1	
Max continuous plantings	999	
Minimum fallow length	1	
Planting rain	60	mm
Days to summate rain	7	
Min soil water ratio (layer 1)	0	(0-1)
Max soil water ratio (layer 1)	1	(0-1)
Minimum available soil water at planting	5	mm
Soil depth to sum planting soil water	300	mm
Ratoon crop	No	
Force planting in window	Yes	

Phase 1_Rice LAI_conference pro (LAI) $(HOWLEAKY)Data - Vegetation\Phase 1 Rice.vege

Potential max LAI	6	cm^2/cm^2
Prop. season for max LAI	0.8	fraction
Prop. max LAI (1st)	5	%
Prop. grow-season (1st)	15	%
Prop. max LAI (2nd)	75	%
Prop. grow-season (2nd)	50	%
Degree days plant-harvest	2400	oC
Senesence coefficient	0.1	
Radiation use efficiency	2.5	g/m^2/MJ
Harvest index	0.5	
Base temperature	0	oC
Optimal temperature	30	oC
Maximum root depth	600	mm
Daily root growth	20	mm
Water stress threshold	0.2	(0-1)
Stress days to death	21	days
Residue decomposition rate	5	%/day
Residue at full cover	10000	kg/ha
Planting scheduling	Automatic	
Start of planting window	14	Nov
End of planting window	14	Dec
Min continuous plantings	1	
Max continuous plantings	999	
Minimum fallow length	1	
Planting rain	60	mm
Days to summate rain	7	
Min soil water ratio (layer 1)	0	(0-1)
Max soil water ratio (layer 1)	1	(0-1)
Minimum available soil water at planting	5	mm
Soil depth to sum planting soil water	300	mm
Ratoon crop	No	
Force planting in window	Yes	

Phase 1_Soybeans (LAI) H:\SimonWhite_Files\ACIAR\SW_lombok\2007 howleaky replication of..

Potential max LAI	4	cm^2/cm^2
Prop. season for max LAI	0.8	fraction
Prop. max LAI (1st)	5	%
Prop. grow-season (1st)	15	%
Prop. max LAI (2nd)	75	%
Prop. grow-season (2nd)	60	%
Degree days plant-harvest	2200	oC
Senesence coefficient	0.3	
Radiation use efficiency	1.5	g/m^2/MJ
Harvest index	0.45	
Base temperature	0	oC
Optimal temperature	30	oC
Maximum root depth	900	mm
Daily root growth	20	mm
Water stress threshold	0.2	(0-1)
Stress days to death	21	days
Residue decomposition rate	5	%/day
Residue at full cover	10000	kg/ha
Planting scheduling	Automatic	
Start of planting window	14	Nov
End of planting window	14	Dec
Min continuous plantings	1	
Max continuous plantings	999	
Minimum fallow length	1	
Planting rain	60	mm
Days to summate rain	7	
Min soil water ratio (layer 1)	0	(0-1)
Max soil water ratio (layer 1)	1	(0-1)
Minimum available soil water at planting	5	mm
Soil depth to sum planting soil water	600	mm
Ratoon crop	No	
Force planting in window	Yes	

8 Phase 2_Chillies LAI (LAI) $(HOWLEAKY)Data - Vegetation\Phase 2 Chillies.vege

Potential max LAI	2.5	cm^2/cm^2
Prop. season for max LAI	0.8	fraction
Prop. max LAI (1st)	5	%
Prop. grow-season (1st)	15	%
Prop. max LAI (2nd)	75	%
Prop. grow-season (2nd)	60	%
Degree days plant-harvest	2200	oC
Senesence coefficient	0.1	
Radiation use efficiency	1	g/m^2/MJ
Harvest index	0.55	
Base temperature	0	oC
Optimal temperature	30	oC
Maximum root depth	600	mm
Daily root growth	20	mm
Water stress threshold	0.2	(0-1)
Stress days to death	21	days
Residue decomposition rate	5	%/day
Residue at full cover	10000	kg/ha
Planting scheduling	Automatic	
Start of planting window	7	Mar
End of planting window	21	Mar
Min continuous plantings	1	
Max continuous plantings	999	
Minimum fallow length	1	
Planting rain	25	mm
Days to summate rain	3	
Min soil water ratio (layer 1)	0	(0-1)
Max soil water ratio (layer 1)	1	(0-1)
Minimum available soil water at planting	5	mm
Soil depth to sum planting soil water	300	mm
Ratoon crop	No	
Force planting in window	Yes	

17 Phase 2_Rice LAI_conference pro (LAI) $(HOWLEAKY)Data - Vegetation\Phase 2 Rice.vege

Potential max LAI	6	cm^2/cm^2
Prop. season for max LAI	0.8	fraction
Prop. max LAI (1st)	5	%
Prop. grow-season (1st)	15	%
Prop. max LAI (2nd)	75	%
Prop. grow-season (2nd)	50	%
Degree days plant-harvest	2400	oC
Senesence coefficient	0.1	
Radiation use efficiency	2.5	g/m^2/MJ
Harvest index	0.5	
Base temperature	0	oC
Optimal temperature	30	oC
Maximum root depth	600	mm
Daily root growth	20	mm
Water stress threshold	0.2	(0-1)
Stress days to death	21	days
Residue decomposition rate	0	%/day
Residue at full cover	10000	kg/ha
Planting scheduling	Automatic	
Start of planting window	7	Mar
End of planting window	21	Mar
Min continuous plantings	1	
Max continuous plantings	1	
Minimum fallow length	1	
Planting rain	25	mm
Days to summate rain	3	
Min soil water ratio (layer 1)	0	(0-1)
Max soil water ratio (layer 1)	1	(0-1)
Minimum available soil water at planting	5	mm
Soil depth to sum planting soil water	300	mm
Ratoon crop	No	
Force planting in window	Yes	

8 Phase 2_Soybeans (LAI) $(HOWLEAKY)Data - Vegetation\Phase 2 Soybeans.vege

Potential max LAI	4	cm^2/cm^2
Prop. season for max LAI	0.8	fraction
Prop. max LAI (1st)	5	%
Prop. grow-season (1st)	15	%
Prop. max LAI (2nd)	75	%
Prop. grow-season (2nd)	60	%
Degree days plant-harvest	2200	oC
Senesence coefficient	0.3	
Radiation use efficiency	1.5	g/m^2/MJ
Harvest index	0.45	
Base temperature	0	oC
Optimal temperature	30	oC
Maximum root depth	900	mm
Daily root growth	20	mm
Water stress threshold	0.2	(0-1)
Stress days to death	21	days
Residue decomposition rate	5	%/day
Residue at full cover	10000	kg/ha
Planting scheduling	Automatic	
Start of planting window	7	Mar
End of planting window	21	Mar
Min continuous plantings	1	
Max continuous plantings	999	
Minimum fallow length	1	
Planting rain	25	mm
Days to summate rain	3	
Min soil water ratio (layer 1)	0	(0-1)
Max soil water ratio (layer 1)	1	(0-1)
Minimum available soil water at planting	5	mm
Soil depth to sum planting soil water	600	mm
Ratoon crop	No	
Force planting in window	Yes	

10 Phase 2_Tomato (LAI) $(HOWLEAKY)Data - Vegetation\Phase 2 Tomato.vege

Potential max LAI	4	cm^2/cm^2
Prop. season for max LAI	0.8	fraction
Prop. max LAI (1st)	5	%
Prop. grow-season (1st)	15	%
Prop. max LAI (2nd)	75	%
Prop. grow-season (2nd)	60	%
Degree days plant-harvest	2200	oC
Senesence coefficient	0.1	
Radiation use efficiency	1	g/m^2/MJ
Harvest index	0.55	
Base temperature	0	oC
Optimal temperature	30	oC
Maximum root depth	600	mm
Daily root growth	20	mm
Water stress threshold	0.2	(0-1)
Stress days to death	21	days
Residue decomposition rate	5	%/day
Residue at full cover	10000	kg/ha
Planting scheduling	Automatic	
Start of planting window	7	Mar
End of planting window	21	Mar
Min continuous plantings	1	
Max continuous plantings	1	
Minimum fallow length	1	
Planting rain	25	mm
Days to summate rain	3	
Min soil water ratio (layer 1)	0	(0-1)
Max soil water ratio (layer 1)	1	(0-1)
Minimum available soil water at planting	5	mm
Soil depth to sum planting soil water	300	mm
Ratoon crop	No	
Force planting in window	Yes	

10.18.3 Lombok HowLeaky tillage parameterisation

Burn residues H:\SimonWhite_Files\ACIAR\SW_lombok\2007 howleaky replication of brett's work\Data T

None $(HOWLEAKY)Data - Tillage\No Tillage.till

06 PRB prep (Phase 1) $(HOWLEAKY)Data - Tillage\PRB Prep.till

Tillage format	Fixed Date (annual)	
Primary tillage type	Disc	
Crop-residue multiplier	0.6	ratio
Roughness ratio	1	ratio
Secondary tillage type	none- ZeroTill	
Crop-residue multiplier	1	ratio
Roughness ratio	0	ratio
Primary tillage date	1	Nov
Secondary tillage date 1	1	Jan
Secondary tillage date 2	1	Jan
Secondary tillage date 3	1	Jan

Stubble Burn (Winter Crop) H:\SimonWhite_Files\ACIAR\SW_lombok\2007 howleaky replication of br

Stubble Mulch (Winter Crop) H:\SimonWhite_Files\ACIAR\SW_lombok\2007 howleaky replication of b

Zero Till H:\SimonWhite_Files\ACIAR\SW_lombok\2007 howleaky replication of brett's work\Data Templ

24 PRB prep (Phase 2) H:\SimonWhite_Files\ACIAR\SW_lombok\2007 howleaky replication of brett's w

Tillage format	Fixed Date (annual)	
Primary tillage type	Disc	
Crop-residue multiplier	0.6	ratio
Roughness ratio	1	ratio
Secondary tillage type	none- ZeroTill	
Crop-residue multiplier	1	ratio
Roughness ratio	0	ratio
Primary tillage date	23	Feb
Secondary tillage date 1	1	Jan
Secondary tillage date 2	1	Jan
Secondary tillage date 3	1	Jan

17 Ponding 20mm 90% $(HOWLEAKY)Data - Irrigation\Ponding 20mm 90%.irri

Irrigation Scheduling	Soil-Water Req. (only .	
SWD to trigger Irrigation	20	mm
Prop. GGD to end	90	%
Target Amount	Field Capacity	
Use Ponding	Yes	
Use Ring-Tank	No	

88 PRB SWD 40mm 90% $(HOWLEAKY)Data - Irrigation\PRB SWD 40mm 90%.irri

Irrigation Scheduling	Soil-Water Req. (only .	
SWD to trigger Irrigation	40	mm
Prop. GGD to end	90	%
Target Amount	Field Capacity	
Use Ponding	No	
Use Ring-Tank	No	

PRB SWD 40mm RINGTANK USED $(HOWLEAKY)Data - Irrigation\PRB SWD 40mm Ringtank Usec

PRB SWD 75mm $(HOWLEAKY)Data - Irrigation\PRB SWD 75mm.irri

22 PRB SWD 40mm 50% $(HOWLEAKY)Data - Irrigation\PRB SWD 40mm 50%.irri

Irrigation Scheduling	Soil-Water Req. (only .	
SWD to trigger Irrigation	40	mm
Prop. GGD to end	50	%
Target Amount	Field Capacity	
Use Ponding	No	
Use Ring-Tank	No	

4 Ponding 20mm 50% $(HOWLEAKY)Data - Irrigation\Ponding 20mm 50%.irri

Irrigation Scheduling	Soil-Water Req. (only .	
SWD to trigger Irrigation	20	mm
Prop. GGD to end	50	%
Target Amount	Field Capacity	
Use Ponding	Yes	
Use Ring-Tank	No	

10.18.4 Lombok HowLeaky “model options” parameterisation

53 Phase 1_0kg residue reset Nov1_20% SM reset Nov 1	$(HOWLEAKY)Data - Model Options\Pha	
Reset residue mass at defined date	Yes	
Date to reset residue	1	Nov
Crop residue reset value (kg/ha)	0	
Reset soil water at defined date	Yes	
Date to reset soil water	1	Nov
Percentage PAWC at defined date	20	%
Reset soil water at planting	No	
Calculate Lateral Flow	No	
Ignore Crop Death	No	
Use PERFECT dry matter fn	No	
Use PERFECT ground-cover fn	No	
Use PERFECT soil evap fn	No	
Use PERFECT leaf area fn	No	
Use PERFECT residue fn	No	
PAWC factor at start of simulation (fraction)	0.5	

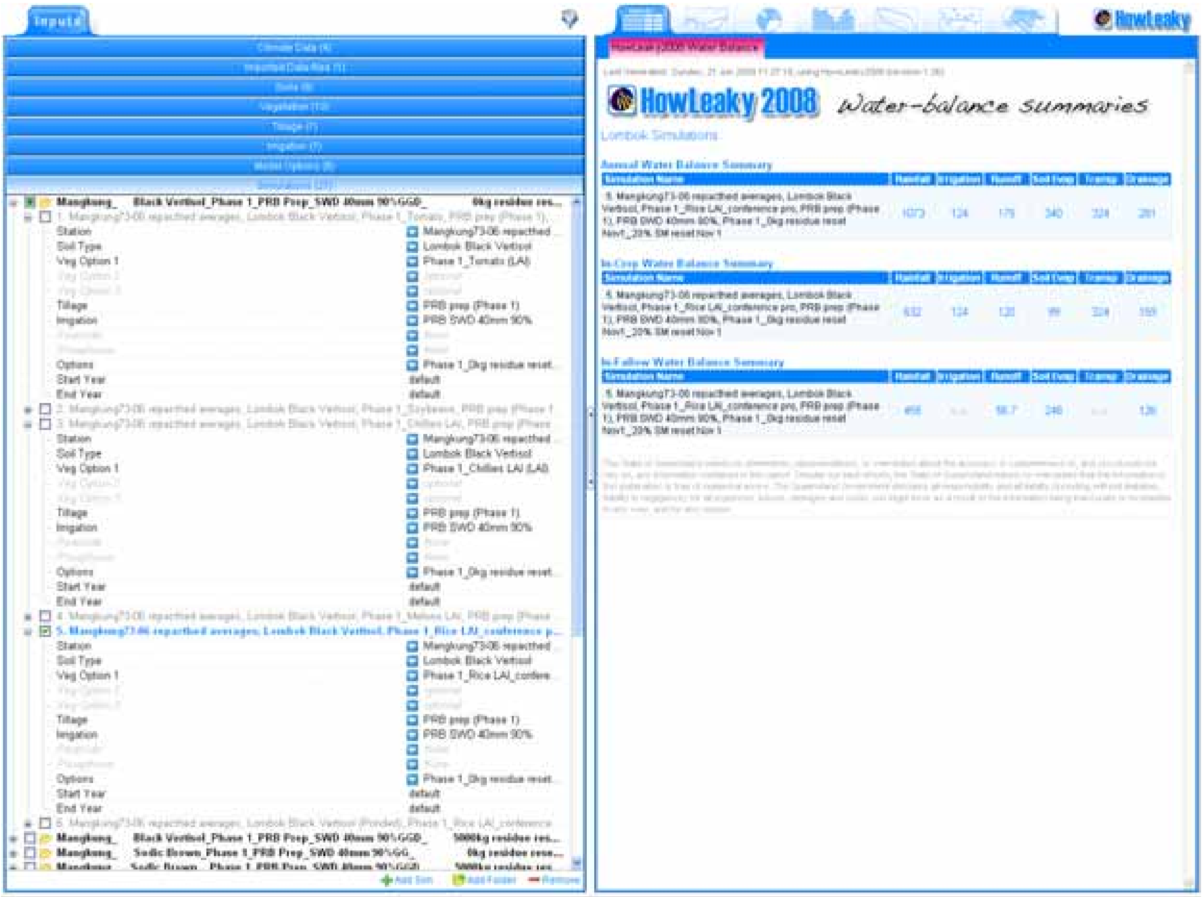
26 Phase 1_5000kg residue reset Nov1_20% SM reset Nov 1	$(HOWLEAKY)Data - Model Options\	
Reset residue mass at defined date	Yes	
Date to reset residue	2	Nov
Crop residue reset value (kg/ha)	5000	
Reset soil water at defined date	Yes	
Date to reset soil water	1	Nov
Percentage PAWC at defined date	20	%
Reset soil water at planting	No	
Calculate Lateral Flow	No	
Ignore Crop Death	No	
Use PERFECT dry matter fn	No	
Use PERFECT ground-cover fn	No	
Use PERFECT soil evap fn	No	
Use PERFECT leaf area fn	No	
Use PERFECT residue fn	No	
PAWC factor at start of simulation (fraction)	0.5	

4 Phase 1_2500kg residue reset Nov1(Melons)_20% SM reset Nov 1	$(HOWLEAKY)Data - Mode
Reset residue mass at defined date	Yes
Reset soil water at defined date	Yes
Reset soil water at planting	No
Calculate Lateral Flow	No
Ignore Crop Death	No
Use PERFECT dry matter fn	No
Use PERFECT ground-cover fn	No
Use PERFECT soil evap fn	No
Use PERFECT leaf area fn	No
Use PERFECT residue fn	No
PAWC factor at start of simulation (fraction)	0.5

42 Phase 2_5000kg residue reset Mar7_100% SM reset Mar7	$(HOWLEAKY)Data - Model Options\
Reset residue mass at defined date	Yes
Reset soil water at defined date	Yes
Reset soil water at planting	No
Calculate Lateral Flow	No
Ignore Crop Death	No
Use PERFECT dry matter fn	No
Use PERFECT ground-cover fn	No
Use PERFECT soil evap fn	No
Use PERFECT leaf area fn	No
Use PERFECT residue fn	No
PAWC factor at start of simulation (fraction)	0.5

7 Phase 2_2500kg residue reset Mar7(Melons)_100% SM reset Mar7	$(HOWLEAKY)Data - Mode
Reset residue mass at defined date	Yes
Reset soil water at defined date	Yes
Reset soil water at planting	No
Calculate Lateral Flow	No
Ignore Crop Death	No
Use PERFECT dry matter fn	No
Use PERFECT ground-cover fn	No
Use PERFECT soil evap fn	No
Use PERFECT leaf area fn	No
Use PERFECT residue fn	No
PAWC factor at start of simulation (fraction)	0.5

10.18.5 Lombok HowLeaky simulation setup example



10.19 Appendix 19: Current state of institutions and policy on extension and dissemination in Indonesia and Lombok

10.19.1 Local planning and governance

The current state of Indonesian governance under threir autonomy era is highly decentralized both in planning and implementation of policies and programs. The notion of decentralization in Indonesia is not something new but it was already initiated in 1974 with the introduction of Act No. 5 on “Basic Principles of Government at the Regional Level”. (Smoke and Lewis, 1996). To ensure better resource allocation and equity in sharing the ‘national cake”, the decentralization law was followed by the introduction of Act No.19/1999 on Regional Government and later on slightly improved to be Act No. 32/2004 in which the central government has given regional autonomy to district governments rather than provincial governments. This leads to serious concerns on efficient resource allocation and development planning in the various districts within a province, since the authority of the provincial head in development planning is being degraded. To anticipate this, central government enacted Act No.25 in 1999 which later on improved to be Act No.33/2004 on balancing of funds between the central and regional Governments. These provisions will allow regional governments to secure a considerable portion of the revenues produced in their regions (Yakin and Otsman, 2004).

Under the new decentralization system, local governments have been given considerable authority from the central government to manage their own affairs at the local level. A flowchart showing how developmental planning is designed can be seen in Figure A19.1.

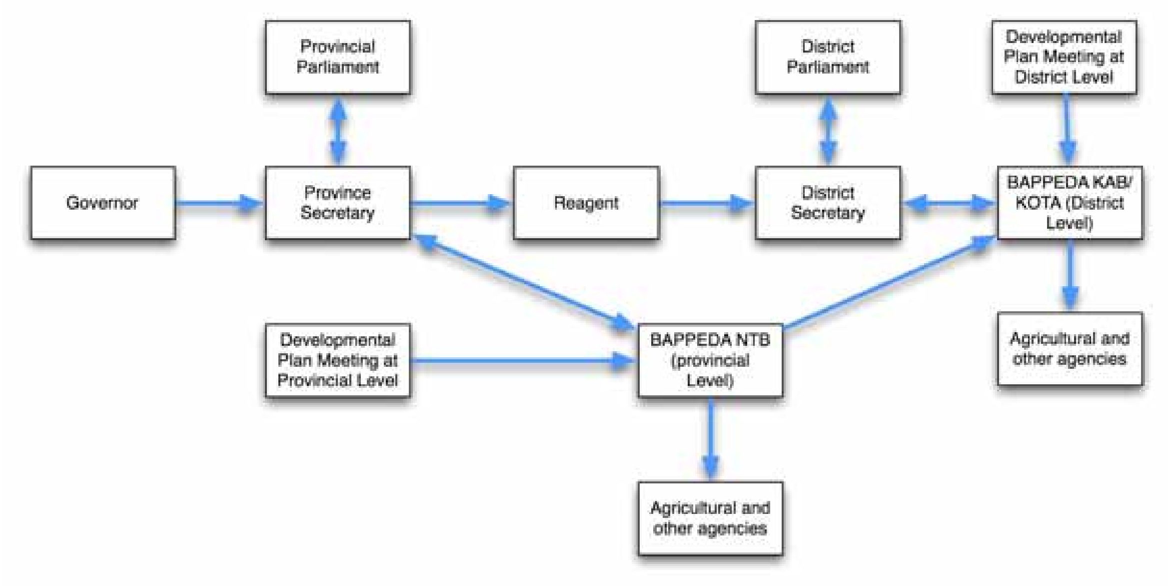


Figure A19.1 Flowchart of how developmental planning is designed, related to agricultural services.

10.19.2 Indonesian agricultural extension services

Indonesia's agricultural research and extension systems are large and complex. The Agency for Mass Guidance (Badan Pengendali Bimbingan Massal, BP Bimas) coordinates intensification programs in rice and other commodities. The provincial level Bimas unit is headed by the provincial governor. Day-to-day operations are handled by the head of the provincial office of the ministry (Kanwil). At the district level, the district head (bupati) and the head of one of the district agricultural service offices (usually that of food crops, Dinas Pertanian Tanaman Pangan) perform these roles. At the sub-district and village levels, the Bimas program is overseen by the sub-district head (camat) and village head respectively. The existence of these local units and the participation in them of local government leaders at all levels contribute to the effectiveness of Bimas activities. However, the extension function has never been fully unified under one body. Based on Joint Decree (SK Bersama) 1991, responsibility for extension has never been brought into a single organization despite several changes in the allocation of extension duties within the Ministry. The Agency for Agricultural Education and Training (AAET) is currently responsible for the education and training of extension personnel and for developing extension methods. Technical guidance of the personnel is the responsibility of the relevant directorates-general.

The Ministry of Agriculture operates or coordinates an array of provincial and district technical units to oversee and implement different aspects of its work. There are 108 provincial-level Agricultural Service (Dinas) offices: one for each of the four major commodity groupings (food crops, estate crops, livestock, and fisheries) in most of Indonesia's 33 provinces. These offices are responsible administratively to the provincial governor but are technically accountable to the relevant directorate-general at the national level. Dinas offices are divided into divisions corresponding to directorates at the national level. The Division of Agricultural Extension directs, monitors, and evaluates provincial extension programs. In each provincial and district Dinas office are placed extension subject–matter specialists (SMS, Penyuluh Pertanian Spesialis, PPS). District offices represent the Mass Guidance (Bimas) program. These offices are frequently combined with the district's Food Crops Agricultural Service office (Dinas Pertanian Tanaman Pangan, Diperta). Below the district level, there are Rural Extension Centers (Balai Penyuluhan Pertanian, BPP) where field extension agents work. However, since decentralization, changes in government agencies including the Department of Agriculture have proven difficult to coordinate.

Coordination at the national level is performed by the National Agricultural Extension Commission (Komisi Penyuluhan Pertanian Nasional, KPPN), chaired by the ministry's Secretary-General (SK Mentan 1991). At the provincial and district levels, equivalent bodies are Agricultural Extension Coordination Forums (Forum Koordinasi Penyuluhan Pertanian, FKPP–I [at the provincial level] and FKPP–II [at the district level]). The organisational structure of the extension program in Indonesia is shown in Figure A19.2.

With World Bank sponsorship, Indonesia introduced the "training and visit" system for extension in the late 1970s. Under this system, graduate extension subject-matter specialists (SMSs, penyuluh pertanian spesialis, PPS) train field extension agents in seasonally relevant material at regular fortnightly training sessions. Each field extension worker (FEA, penyuluh pertanian lapangan, PPL) is assigned to a number of villages, and visits each village once every two weeks. The field extensionist works with groups of contact farmers (kontak tani) in each village, discussing relevant topics for the time of year. These contact farmers in turn are expected to disseminate their knowledge to "follower farmers" in their village.

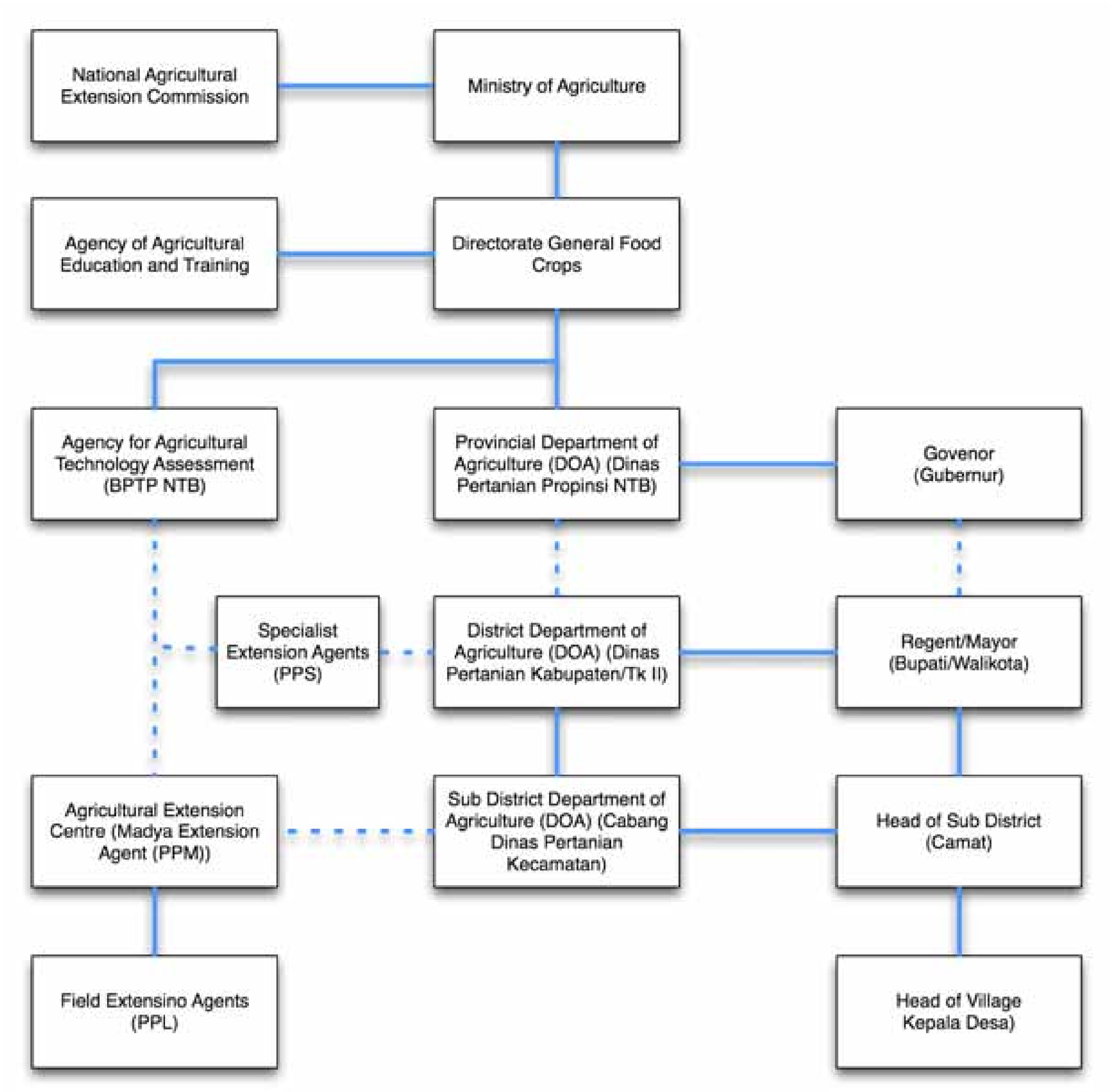


Figure A19.2 Organization structure of extension program from national level tovillage level in Indonesia.

A number of village institutions are key to the success of this extension effort. These include the village cooperative (Kooperasi Unit Desa, KUD), which markets output to the national Food Logistics Board (Bulog); kiosks selling agricultural inputs; and the Village Unit Bank, a branch of the national Bank Rakyat Indonesia, which provides credit. All are coordinated through the Bimas program. This scheme is hoped to allow a relatively rapid transfer of technology from research institutes to the farmers. It is also expected to allow for feedback, since field extension agents can refer field problems back to the relevant subject–matter specialist, who can if necessary refer them back to researchers.

Agricultural subject–matter specialists (penyuluh pertanian spesialis, PPS) are a key component of the extension system. They hold at least a sarjana (four years plus thesis) degree in an agricultural or social science. They are employed at provincial Dinas and Bimas offices (and some at Kanwils); district Dinas and Bimas offices; Agricultural Information Centers. Their tasks are (1) obtaining information on new technologies and translating it into a form usable by field agents and farmers, (2) testing technologies for local applicability, (3) training field agents, (4) solving field problems, and (5) liaising with other actors in the extension and administration systems.

In 1994 the Ministry of Agriculture established a new set of institutional arrangements for extension and dissemination of research, under decree No. 798/KPTS/OT/201/94. These were made up of a number of Agricultural Technology Assessment Institutes (BPTPs), Institutes of Rural Technology Development (LPTPs), and Installations for Agricultural Technological Assessment and Research (IP2TPs) across Indonesia. The main responsibility of these bodies is to conduct commodity research activities, and assessment and assembly of location–specific technology. Their activities include:

- conducting research on locally based/specific agricultural commodities
- verifying and developing locally based/specifically appropriate technologies
- accommodating feedback for developing the country's agricultural research program
- disseminating technology packages for use as extension documents
- facilitating technical activities on agricultural technology assessments
- handling administrative matters.

As an example of local district arrangements, in the province of West Nusa Tenggara, there are currently 6888 farmers' groups. These are made up of: 1861 beginner groups, 3365 pre-intermediate groups, 1486 intermediate groups, and 176 advanced groups. Several of those groups have formed a farmers' association (Gapoktan), where 78 of the 400 member groups have legal rights. The province also has 109 agricultural extension offices (BPPs), 65 with their own secretariat and the rest operating as working units within offices of the Department of Agriculture. The province currently has 1086 agricultural extension workers: 810 public service officers (PNSs), 29 candidate public service officers (CPNSs), 54 part-time workers, and 193 daily casual workers.

The Government of Indonesia recently enacted a new law, Act No. 16/2006, on an extension system for agriculture, fishery and forestry. Extension institutions may be of three types: government-based, private or non-government. Therefore extension practitioners could be state employees, privately-employed or voluntary. The Act also laid down some important aspects of successful extension programs, such as provision of sufficient funding, facilities and infrastructure, and effective institutional arrangements.

Indonesia is experimenting with a new approach to decentralized adaptive research through its Agricultural Technology Assessment Institutes (BPTPs), integrating researchers and extension specialists under one roof. Their brief is to assess new technology under farmer conditions and develop solutions to farmers' problems. This aims to break the tradition of a top-down, linear research-extension-farmer relationship. It has the potential, once the decentralization reform is completed and the BPTPs become financially autonomous, to develop a cooperative working pattern across the three groups, with common objectives that are designed to be farm-centric.